



# Visual C#® 2012

## HOW TO PROGRAM

FIFTH EDITION

PAUL DEITEL  
HARVEY DEITEL

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“I really love the way you guys write—it’s interesting and informative! This is, without a doubt, one of the best technical books I’ve ever read. What makes this book stand out from the crowd is its practical approach—you will not just read about C#, you will see it in action and try it yourself through the large amount of exercises. If you’re a .NET beginner, this is a gold mine for you. If you’re an experienced developer, you’ll find the book helpful as a reference book and a good way to practice and polish your .NET skills.”

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“I appreciate the variety of exercises from short answer, to identify errors, to hands-on projects; the ‘What Does This Program Do?’ exercises are really useful. The figure with C#’s single-entry/single-exit sequence, selection and repetition statements is great for reference; it’s things like this that I look for in adopting a textbook. The explanation of abstract vs. concrete classes and why one would create an abstract class in the hierarchy was excellent. I would use GUIs with Windows Forms: Part 1 as my third chapter. Typing Tutor is a cool project! Using LINQ to search directories is very cool! Good explanation of Big O and linear vs. binary searching. The diagrams really help to understand how linked lists work.” — Stephen Hustedde, South Mountain College

“Introduction to Computers, the Internet and Visual C# sets a level playing field for readers of different backgrounds. I like the focus on thinking through then writing an algorithm. Good introduction to the most popular controls and working with events. I use the techniques of the Strings chapter in the line of business apps that I build. I liked the Files and Streams chapter and the real-world example.”

— Shawn Weisfeld, Microsoft MVP and President and Founder of UserGroup.tv

“The ultimate book on how to program using Microsoft technologies. Excellent explanations, examples, necessary theoretical background and the latest technologies for desktop, web and databases.” — Kirill Osenkov, Visual Studio Languages Team, Microsoft

“Excellent intro to visual app development, classes and objects. The Control Statements chapters are perfect. The Telephone-Number Word Generator exercise is fun and challenging. Excellent Arrays chapter; the collection of exercises is really impressive. Outstanding presentations of Windows Forms apps and the I/O facilities in .NET. In the Searching and Sorting chapter, I especially enjoyed the graphics that allow the students to see the algorithms in action. Data Structures has intuitive examples and great explanations. The presentation of LINQ to XML is fabulous. Amazingly clear and intuitive presentation of generics; this chapter represents why I like this book so much—it really shines at presenting advanced topics in a way that can be easily understood by novices. I love the way the exercises are interwoven with the materials of the chapter, reinforcing and complementing the concepts.” — Octavio Hernandez, Microsoft Certified Solutions Developer (MCSD)

“Updating an already excellent book with the latest .NET features (Visual Studio 2012, LINQ to Entities, ASP.NET 4.5, Windows 8 UI, Windows Phone development, Cloud Computing with Windows Azure, etc.) can only result in a superb product. I like the explanation of properties and the discussion of value vs. reference types. The Control Statements chapters are easy to read, and their exercises are amazing. Coverage of ASP.NET is exceptional. I like your explanation of pass by value vs. pass by reference. Arrays is one of my favorite chapters. Great job explaining inheritance, polymorphism, interfaces and operator overloading. The Searching and Sorting chapter is excellent; the explanations make algorithms like quicksort easy to understand for novices.” — José Antonio González Seco, Parliament of Andalusia, Spain

“An excellent, true objects-first book. Excellent introduction to data structures and collections. Demystifies Big O notation. The generics material is a real asset.” — Gavin Osborne, Saskatchewan Institute of Applied Science and Technology

“The Arrays exercises are quite enjoyable—finishing with the implementation of a virtual machine is really something. Great chapter on polymorphism.” — Eric Lippert, Formerly of Microsoft

“Excellent chapter on exceptions.” — Vinay Ahuja, Architect, Microsoft Corporation

“An excellent introduction to XML, LINQ to XML and related technologies.” — Helena Kotas, Microsoft

“Good overview of relational databases. It hits on the right LINQ idioms.” — Alex Turner, Microsoft

“I’m pleased to see the inclusion of a diverse set of more advanced materials through online chapters, including WPF, Azure and Win8 Store apps.” — Shawn Weisfeld, Microsoft MVP and President and Founder of UserGroup.tv

“A solid introduction to Visual Studio. I loved the ‘Formulating Algorithms’ sections. Very good arrays introduction; the examples and the “Building Your Own Computer” exercise are great!” — Shay Friedman, Microsoft Visual C# MVP, CodeValue

“The text is suitable for use in my beginning and advanced C# classes. End-of-chapter exercises are challenging and reflect real-world scenarios. Introduction to LINQ and the List Collection is a great chapter; you do such a good and consistent job of explaining your code in the narrative. The focus on using LINQ to manage data is unique and cutting edge.” — Stephen Hustedde, South Mountain College

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**Paul Deitel**

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**PEARSON**

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*Shay Friedman*

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*We are grateful for your guidance and expertise.*

*Paul and Harvey Deitel*

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# Contents

Chapters 24–35 and Appendices D–G are PDF documents posted online at the book's Companion Website (located at [www.pearsonhighered.com/deitel/](http://www.pearsonhighered.com/deitel/)).

## Preface xix

## Before You Begin xxxv

<b>I</b>	<b>Introduction to Computers, the Internet and Visual C#</b>	<b>I</b>
1.1	Introduction	2
1.2	Hardware and Moore's Law	2
1.3	Data Hierarchy	3
1.4	Computer Organization	6
1.5	Machine Languages, Assembly Languages and High-Level Languages	7
1.6	Object Technology	8
1.7	Internet and World Wide Web	10
1.8	C#	12
1.8.1	Object-Oriented Programming	12
1.8.2	Event-Driven Programming	12
1.8.3	Visual Programming	12
1.8.4	An International Standard; Other C# Implementations	12
1.8.5	Internet and Web Programming	13
1.8.6	Introducing <code>async/await</code>	13
1.8.7	Other Key Contemporary Programming Languages	13
1.9	Microsoft's .NET	14
1.9.1	.NET Framework	14
1.9.2	Common Language Runtime	15
1.9.3	Platform Independence	15
1.9.4	Language Interoperability	15
1.10	Microsoft's Windows® Operating System	16
1.11	Windows Phone 8 for Smartphones	17
1.11.1	Selling Your Apps in the Windows Phone Marketplace	18
1.11.2	Free vs. Paid Apps	18
1.11.3	Testing Your Windows Phone Apps	18
1.12	Windows Azure™ and Cloud Computing	19
1.13	Visual Studio Express 2012 Integrated Development Environment	19

1.14	Painter Test-Drive in Visual Studio Express 2012 for Windows Desktop	19
1.15	Painter Test-Drive in Visual Studio Express 2012 for Windows 8	23

## **2 Dive Into® Visual Studio Express 2012 for Windows Desktop**

**33**

2.1	Introduction	34
2.2	Overview of the Visual Studio Express 2012 IDE	34
2.3	Menu Bar and Toolbar	39
2.4	Navigating the Visual Studio IDE	41
2.4.1	Solution Explorer	43
2.4.2	Toolbox	44
2.4.3	Properties Window	44
2.5	Using Help	46
2.6	Using Visual App Development to Create a Simple App that Displays Text and an Image	47
2.7	Wrap-Up	57
2.8	Web Resources	58

## **3 Introduction to C# Apps**

**65**

3.1	Introduction	66
3.2	A Simple C# App: Displaying a Line of Text	66
3.3	Creating a Simple App in Visual Studio	72
3.4	Modifying Your Simple C# App	77
3.5	Formatting Text with <code>Console.WriteLine</code>	80
3.6	Another C# App: Adding Integers	81
3.7	Memory Concepts	85
3.8	Arithmetic	86
3.9	Decision Making: Equality and Relational Operators	90
3.10	Wrap-Up	94

## **4 Introduction to Classes, Objects, Methods and strings**

**106**

4.1	Introduction	107
4.2	Classes, Objects, Methods, Properties and Instance Variables	107
4.3	Declaring a Class with a Method and Instantiating an Object of a Class	108
4.4	Declaring a Method with a Parameter	113
4.5	Instance Variables and Properties	116
4.6	UML Class Diagram with a Property	121
4.7	Software Engineering with Properties and <code>set</code> and <code>get</code> Accessors	121
4.8	Auto-Implemented Properties	123
4.9	Value Types vs. Reference Types	123
4.10	Initializing Objects with Constructors	125
4.11	Floating-Point Numbers and Type <code>decimal</code>	128
4.12	Wrap-Up	134

<b>5</b>	<b>Control Statements: Part 1</b>	<b>142</b>
5.1	Introduction	143
5.2	Algorithms	143
5.3	Pseudocode	144
5.4	Control Structures	144
5.5	<code>if</code> Single-Selection Statement	146
5.6	<code>if...else</code> Double-Selection Statement	148
5.7	<code>while</code> Repetition Statement	152
5.8	Formulating Algorithms: Counter-Controlled Repetition	154
5.9	Formulating Algorithms: Sentinel-Controlled Repetition	158
5.10	Formulating Algorithms: Nested Control Statements	166
5.11	Compound Assignment Operators	171
5.12	Increment and Decrement Operators	171
5.13	Simple Types	174
5.14	Wrap-Up	175
<b>6</b>	<b>Control Statements: Part 2</b>	<b>189</b>
6.1	Introduction	190
6.2	Essentials of Counter-Controlled Repetition	190
6.3	<code>for</code> Repetition Statement	191
6.4	Examples Using the <code>for</code> Statement	195
6.5	<code>do...while</code> Repetition Statement	199
6.6	<code>switch</code> Multiple-Selection Statement	201
6.7	<code>break</code> and <code>continue</code> Statements	209
6.8	Logical Operators	211
6.9	Structured-Programming Summary	216
6.10	Wrap-Up	221
<b>7</b>	<b>Methods: A Deeper Look</b>	<b>231</b>
7.1	Introduction	232
7.2	Packaging Code in C#	232
7.3	<code>static</code> Methods, <code>static</code> Variables and Class <code>Math</code>	234
7.4	Declaring Methods with Multiple Parameters	236
7.5	Notes on Declaring and Using Methods	240
7.6	Method-Call Stack and Activation Records	241
7.7	Argument Promotion and Casting	242
7.8	The .NET Framework Class Library	243
7.9	Case Study: Random-Number Generation	245
7.9.1	Scaling and Shifting Random Numbers	249
7.9.2	Random-Number Repeatability for Testing and Debugging	250
7.10	Case Study: A Game of Chance; Introducing Enumerations	250
7.11	Scope of Declarations	255
7.12	Method Overloading	258
7.13	Optional Parameters	260

7.14	Named Parameters	262
7.15	Recursion	263
7.16	Passing Arguments: Pass-by-Value vs. Pass-by-Reference	266
7.17	Wrap-Up	269

## **8 Arrays; Introduction to Exception Handling** 285

8.1	Introduction	286
8.2	Arrays	286
8.3	Declaring and Creating Arrays	288
8.4	Examples Using Arrays	289
8.4.1	Creating and Initializing an Array	289
8.4.2	Using an Array Initializer	290
8.4.3	Calculating a Value to Store in Each Array Element	291
8.4.4	Summing the Elements of an Array	292
8.4.5	Using Bar Charts to Display Array Data Graphically	293
8.4.6	Using the Elements of an Array as Counters	295
8.4.7	Using Arrays to Analyze Survey Results; Introduction to Exception Handling	296
8.5	Case Study: Card Shuffling and Dealing Simulation	299
8.6	<code>foreach</code> Statement	303
8.7	Passing Arrays and Array Elements to Methods	305
8.8	Passing Arrays by Value and by Reference	307
8.9	Case Study: GradeBook Using an Array to Store Grades	311
8.10	Multidimensional Arrays	316
8.11	Case Study: GradeBook Using a Rectangular Array	321
8.12	Variable-Length Argument Lists	327
8.13	Using Command-Line Arguments	329
8.14	Wrap-Up	331

## **9 Introduction to LINQ and the List Collection** 351

9.1	Introduction	352
9.2	Querying an Array of <code>int</code> Values Using LINQ	353
9.3	Querying an Array of <code>Employee</code> Objects Using LINQ	357
9.4	Introduction to Collections	362
9.5	Querying a Generic Collection Using LINQ	365
9.6	Wrap-Up	367
9.7	Deitel LINQ Resource Center	367

## **10 Classes and Objects: A Deeper Look** 371

10.1	Introduction	372
10.2	<code>Time</code> Class Case Study	372
10.3	Controlling Access to Members	376
10.4	Referring to the Current Object's Members with the <code>this</code> Reference	377
10.5	<code>Time</code> Class Case Study: Overloaded Constructors	379

10.6	Default and Parameterless Constructors	385
10.7	Composition	386
10.8	Garbage Collection and Destructors	389
10.9	<code>static</code> Class Members	390
10.10	<code>readonly</code> Instance Variables	393
10.11	Data Abstraction and Encapsulation	394
10.12	<b>Class View and Object Browser</b>	396
10.13	Object Initializers	398
10.14	Wrap-Up	398

## **11 Object-Oriented Programming: Inheritance** **405**

11.1	Introduction	406
11.2	Base Classes and Derived Classes	407
11.3	<code>protected</code> Members	409
11.4	Relationship between Base Classes and Derived Classes	410
11.4.1	Creating and Using a <code>CommissionEmployee</code> Class	410
11.4.2	Creating a <code>BasePlusCommissionEmployee</code> Class without Using Inheritance	415
11.4.3	Creating a <code>CommissionEmployee</code> – <code>BasePlusCommissionEmployee</code> Inheritance Hierarchy	420
11.4.4	<code>CommissionEmployee</code> – <code>BasePlusCommissionEmployee</code> Inheritance Hierarchy Using <code>protected</code> Instance Variables	423
11.4.5	<code>CommissionEmployee</code> – <code>BasePlusCommissionEmployee</code> Inheritance Hierarchy Using <code>private</code> Instance Variables	428
11.5	Constructors in Derived Classes	433
11.6	Software Engineering with Inheritance	434
11.7	<code>Class object</code>	434
11.8	Wrap-Up	435

## **12 OOP: Polymorphism, Interfaces and Operator Overloading** **441**

12.1	Introduction	442
12.2	Polymorphism Examples	444
12.3	Demonstrating Polymorphic Behavior	445
12.4	Abstract Classes and Methods	448
12.5	Case Study: Payroll System Using Polymorphism	450
12.5.1	Creating Abstract Base Class <code>Employee</code>	451
12.5.2	Creating Concrete Derived Class <code>SalariedEmployee</code>	453
12.5.3	Creating Concrete Derived Class <code>HourlyEmployee</code>	455
12.5.4	Creating Concrete Derived Class <code>CommissionEmployee</code>	457
12.5.5	Creating Indirect Concrete Derived Class <code>BasePlusCommissionEmployee</code>	458
12.5.6	Polymorphic Processing, Operator <code>is</code> and Downcasting	460

12.5.7	Summary of the Allowed Assignments Between Base-Class and Derived-Class Variables	465
12.6	<code>sealed</code> Methods and Classes	466
12.7	Case Study: Creating and Using Interfaces	466
12.7.1	Developing an <code>IPayable</code> Hierarchy	468
12.7.2	Declaring Interface <code>IPayable</code>	469
12.7.3	Creating Class <code>Invoice</code>	469
12.7.4	Modifying Class <code>Employee</code> to Implement Interface <code>IPayable</code>	471
12.7.5	Modifying Class <code>SalariedEmployee</code> for Use with <code>IPayable</code>	473
12.7.6	Using Interface <code>IPayable</code> to Process <code>Invoices</code> and <code>Employees</code> Polymorphically	474
12.7.7	Common Interfaces of the .NET Framework Class Library	476
12.8	Operator Overloading	477
12.9	Wrap-Up	480

## **13 Exception Handling: A Deeper Look** **486**

13.1	Introduction	487
13.2	Example: Divide by Zero without Exception Handling	488
13.3	Example: Handling <code>DivideByZeroException</code> s and <code>FormatException</code> s	491
13.3.1	Enclosing Code in a <code>try</code> Block	493
13.3.2	Catching Exceptions	493
13.3.3	Uncaught Exceptions	494
13.3.4	Termination Model of Exception Handling	495
13.3.5	Flow of Control When Exceptions Occur	495
13.4	.NET Exception Hierarchy	496
13.4.1	<code>Class SystemException</code>	496
13.4.2	Determining Which Exceptions a Method Throws	497
13.5	<code>finally</code> Block	497
13.6	The <code>using</code> Statement	504
13.7	Exception Properties	505
13.8	User-Defined Exception Classes	509
13.9	Wrap-Up	513

## **14 Graphical User Interfaces with Windows Forms: Part I** **518**

14.1	Introduction	519
14.2	Windows Forms	520
14.3	Event Handling	522
14.3.1	A Simple Event-Driven GUI	522
14.3.2	Auto-Generated GUI Code	524
14.3.3	Delegates and the Event-Handling Mechanism	526
14.3.4	Another Way to Create Event Handlers	527
14.3.5	Locating Event Information	528
14.4	Control Properties and Layout	529

14.5	Labels, TextBoxes and Buttons	533
14.6	GroupBoxes and Panels	536
14.7	CheckBoxes and RadioButtons	539
14.8	PictureBoxes	547
14.9	ToolTips	549
14.10	NumericUpDown Control	551
14.11	Mouse-Event Handling	553
14.12	Keyboard-Event Handling	556
14.13	Wrap-Up	559

## **15 Graphical User Interfaces with Windows Forms: Part 2**

**569**

15.1	Introduction	570
15.2	Menus	570
15.3	MonthCalendar Control	579
15.4	DateTimePicker Control	580
15.5	LinkLabel Control	583
15.6	ListBox Control	587
15.7	CheckedListBox Control	591
15.8	ComboBox Control	594
15.9	TreeView Control	598
15.10	ListView Control	603
15.11	TabControl Control	609
15.12	Multiple Document Interface (MDI) Windows	614
15.13	Visual Inheritance	621
15.14	User-Defined Controls	626
15.15	Wrap-Up	630

## **16 Strings and Characters: A Deeper Look**

**638**

16.1	Introduction	639
16.2	Fundamentals of Characters and Strings	640
16.3	<code>string</code> Constructors	641
16.4	<code>string</code> Indexer, Length Property and CopyTo Method	642
16.5	Comparing <code>strings</code>	643
16.6	Locating Characters and Substrings in <code>strings</code>	646
16.7	Extracting Substrings from <code>strings</code>	649
16.8	Concatenating <code>strings</code>	650
16.9	Miscellaneous <code>string</code> Methods	651
16.10	Class <code>StringBuilder</code>	652
16.11	Length and Capacity Properties, EnsureCapacity Method and Indexer of Class <code>StringBuilder</code>	653
16.12	Append and AppendFormat Methods of Class <code>StringBuilder</code>	655
16.13	Insert, Remove and Replace Methods of Class <code>StringBuilder</code>	657
16.14	Char Methods	660

16.15 (Online) Introduction to Regular Expressions	662
16.16 Wrap-Up	663

## **17 Files and Streams** **669**

17.1 Introduction	670
17.2 Data Hierarchy	670
17.3 Files and Streams	672
17.4 Classes <code>File</code> and <code>Directory</code>	673
17.5 Creating a Sequential-Access Text File	682
17.6 Reading Data from a Sequential-Access Text File	691
17.7 Case Study: Credit Inquiry Program	695
17.8 Serialization	701
17.9 Creating a Sequential-Access File Using Object Serialization	702
17.10 Reading and Deserializing Data from a Binary File	706
17.11 Wrap-Up	708

## **18 Searching and Sorting** **715**

18.1 Introduction	716
18.2 Searching Algorithms	717
18.2.1 Linear Search	717
18.2.2 Binary Search	721
18.3 Sorting Algorithms	726
18.3.1 Selection Sort	726
18.3.2 Insertion Sort	730
18.3.3 Merge Sort	734
18.4 Summary of the Efficiency of Searching and Sorting Algorithms	740
18.5 Wrap-Up	741

## **19 Data Structures** **746**

19.1 Introduction	747
19.2 Simple-Type <code>structs</code> , Boxing and Unboxing	747
19.3 Self-Referential Classes	748
19.4 Linked Lists	749
19.5 Stacks	762
19.6 Queues	766
19.7 Trees	769
19.7.1 Binary Search Tree of Integer Values	770
19.7.2 Binary Search Tree of <code>IComparable</code> Objects	777
19.8 Wrap-Up	782

## **20 Generics** **789**

20.1 Introduction	790
20.2 Motivation for Generic Methods	791
20.3 Generic-Method Implementation	793

20.4	Type Constraints	796
20.5	Overloading Generic Methods	798
20.6	Generic Classes	799
20.7	Wrap-Up	808

## **21 Collections** **814**

21.1	Introduction	815
21.2	Collections Overview	815
21.3	Class Array and Enumerators	818
21.4	Nongeneric Collections	821
21.4.1	Class ArrayList	821
21.4.2	Class Stack	826
21.4.3	Class Hashtable	828
21.5	Generic Collections	833
21.5.1	Generic Class SortedDictionary	834
21.5.2	Generic Class LinkedList	836
21.6	Covariance and Contravariance for Generic Types	840
21.7	Wrap-Up	843

## **22 Databases and LINQ** **849**

22.1	Introduction	850
22.2	Relational Databases	851
22.3	A Books Database	852
22.4	LINQ to Entities and the ADO.NET Entity Framework	856
22.5	Querying a Database with LINQ	857
22.5.1	Creating the ADO.NET Entity Data Model Class Library	858
22.5.2	Creating a Windows Forms Project and Configuring It to Use the Entity Data Model	862
22.5.3	Data Bindings Between Controls and the Entity Data Model	864
22.6	Dynamically Binding Query Results	869
22.6.1	Creating the <b>Display Query Results</b> GUI	870
22.6.2	Coding the <b>Display Query Results</b> App	871
22.7	Retrieving Data from Multiple Tables with LINQ	874
22.8	Creating a Master/Detail View App	879
22.8.1	Creating the Master/Detail GUI	880
22.8.2	Coding the Master/Detail App	881
22.9	Address Book Case Study	883
22.9.1	Creating the <b>Address Book</b> App's GUI	884
22.9.2	Coding the <b>Address Book</b> App	885
22.10	Tools and Web Resources	889
22.11	Wrap-Up	889

## **23 Web App Development with ASP.NET** **897**

23.1	Introduction	898
------	--------------	-----

23.2	Web Basics	899
23.3	Multitier App Architecture	900
23.4	Your First Web App	902
23.4.1	Building the <code>WebTime</code> App	904
23.4.2	Examining <code>WebTime.aspx</code> 's Code-Behind File	913
23.5	Standard Web Controls: Designing a Form	914
23.6	Validation Controls	918
23.7	Session Tracking	925
23.7.1	Cookies	926
23.7.2	Session Tracking with <code>HttpSessionState</code>	927
23.7.3	<code>Options.aspx</code> : Selecting a Programming Language	928
23.7.4	<code>Recommendations.aspx</code> : Displaying Recommendations Based on Session Values	932
23.8	Case Study: Database-Driven ASP.NET Guestbook	933
23.8.1	Building a Web Form that Displays Data from a Database	935
23.8.2	Modifying the Code-Behind File for the Guestbook App	940
23.9	Online Case Study: ASP.NET AJAX	941
23.10	Online Case Study: Password-Protected Books Database App	942
23.11	Wrap-Up	942

<b>Chapters on the Web</b>	<b>949</b>
----------------------------	------------

<b>A Operator Precedence Chart</b>	<b>950</b>
------------------------------------	------------

<b>B Simple Types</b>	<b>952</b>
-----------------------	------------

<b>C ASCII Character Set</b>	<b>954</b>
------------------------------	------------

<b>Appendices on the Web</b>	<b>955</b>
------------------------------	------------

<b>Index</b>	<b>957</b>
--------------	------------

Chapters 24–35 and Appendices D–G are PDF documents posted online at the book's Companion Website (located at [www.pearsonhighered.com/deitel/](http://www.pearsonhighered.com/deitel/)).

## **24 XML and LINQ to XML**

## **25 Windows 8 UI and XAML**

## **26 Windows 8 Graphics and Multimedia**

- 27 Building a Windows Phone 8 App**
- 28 Asynchronous Programming with `async` and `await`**
- 29 Web App Development with ASP.NET: A Deeper Look**
- 30 Web Services**
- 31 Building a Windows Azure™ Cloud Computing App**
- 32 GUI with Windows Presentation Foundation**
- 33 WPF Graphics and Multimedia**
- 34 ATM Case Study, Part 1: Object-Oriented Design with the UML**
- 35 ATM Case Study, Part 2: Implementing an Object-Oriented Design**
- D Number Systems**
- E UML 2: Additional Diagram Types**
- F Unicode®**
- G Using the Visual C# 2012 Debugger**

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# Preface

Welcome to the Visual C#® 2012 computer programming language and the world of Microsoft® Windows® and Internet and web programming with Microsoft’s .NET platform. Please read the book’s back cover and inside back cover—these concisely capture the book’s essence. In this Preface we provide more details.

This book is appropriate for introductory course sequences based on the curriculum recommendations of two key professional organizations—the ACM and the IEEE. The examples are accessible to computer science, information technology, software engineering and business students in novice-level and intermediate-level C# courses. The book can also be used by professional programmers.

At the heart of the book is the Deitel signature *live-code approach*—rather than using code snippets, we present concepts in the context of complete working programs followed by sample executions. Read the Before You Begin section after this Preface for instructions on setting up your computer to run the hundreds of code examples. The source code is available at [www.deitel.com/books/vcsharp2012htp](http://www.deitel.com/books/vcsharp2012htp) and [www.pearsonhighered.com/deitel](http://www.pearsonhighered.com/deitel). Use the source code we provide to *compile and run each program* as you study it—this will help you master Visual C# and related Microsoft technologies faster and at a deeper level.

We believe that this book and its supplements for students and instructors will give you an informative, engaging, challenging and entertaining introduction to Visual C#. If you have questions, we’re easy to reach at [deitel@deitel.com](mailto:deitel@deitel.com)—we’ll respond promptly. For book updates, visit [www.deitel.com/books/vcsharp2012htp](http://www.deitel.com/books/vcsharp2012htp), join our social media communities on Facebook ([www.deitel.com/DeitelFan](http://www.deitel.com/DeitelFan)), Twitter (@deitel), Google+ ([gplus.to/deitel](http://gplus.to/deitel)) and LinkedIn ([bit.ly/DeitelLinkedIn](http://bit.ly/DeitelLinkedIn)), and subscribe to the *Deitel® Buzz Online* newsletter ([www.deitel.com/newsletter/subscribe.html](http://www.deitel.com/newsletter/subscribe.html)).

## Visual C#® 2012, the Visual Studio® 2012 IDE, .NET 4.5, Windows® 7 and Windows® 8

The new Visual C# 2012 and its associated technologies motivated us to write *Visual C# 2012 How to Program*, 5/e. These are some of the key features of this new edition:

- **Use with Windows 7, Windows 8 or both.** The book is designed so that you can continue to use Windows 7 now and begin to evolve to Windows 8, if you like, or you can move right to Windows 8. All of the code examples in Chapters 1–24 and 28–35 were tested on *both* Windows 7 and Windows 8. The code examples for the Windows-8-specific chapters—Chapter 25 (Windows 8 UI and XAML), Chapter 26 (Windows 8 Graphics and Multimedia) and Chapter 27 (Building a Windows Phone 8 App)—were tested *only* on Windows 8.
- **C# and Visual C#.** The C# language has been standardized internationally by ECMA and ISO (the standards document is available free of charge at [bit.ly/ECMA334](http://bit.ly/ECMA334)). Visual C# 2012 is Microsoft’s implementation of this standard.

- ***Modular multi-GUI treatment with Windows Forms, Windows 8 UI and WPF.*** The printed book features Windows Forms GUI; optional online chapters contain treatments of Windows 8 UI (user interface) and WPF GUI. Windows 8 UI apps are called *Windows Store apps*. In Chapter 25, you'll learn how to create and test Windows Store apps and upload them to Microsoft's Windows Store.
- ***Modular treatment of graphics and multimedia with Windows 8 and WPF.*** The book features optional online chapters on both Windows 8 Graphics and Multimedia (Chapter 26) and WPF Graphics and Multimedia (Chapter 33).
- ***Database with LINQ to Entities.*** In the previous edition of this book, we discussed LINQ (Language Integrated Query) to SQL (Microsoft's SQL Server database system). Microsoft stopped further development on LINQ to SQL in 2008 in favor of the newer and more robust LINQ to Entities and the ADO.NET Entity Framework, which we've switched to in this edition, keeping the discussion friendly for novices.
- ***SQL Server database.*** We use Microsoft's free SQL Server Express 2012 (which installs with the free Visual Studio Express 2012 for Windows Desktop) to present the fundamentals of database programming. Chapters 22–23 and 29–30 use database and LINQ capabilities to build an address-book desktop app, a web-based guestbook app, a bookstore app and an airline reservation system app.
- ***ASP.NET 4.5.*** Microsoft's .NET server-side technology, ASP.NET, enables you to create robust, scalable web-based apps. In Chapter 23, you'll build several apps, including a web-based guestbook that uses ASP.NET and the ADO .NET Entity Framework to store data in a database and display data in a web page. The chapter also discusses the IIS Express web server for testing your web apps on your local computer.
- ***Building a Windows Phone 8 App.*** Windows Phone 8 is Microsoft's latest operating system for smartphones. It features multi-touch support for touchpads and touchscreen devices, enhanced security features and more. In Chapter 27, you'll build a complete working Windows Phone 8 app and test it on the Windows Phone simulator; we'll discuss how to upload apps to the Windows Phone Store.
- ***Building a Windows Azure™ Cloud Computing App.*** Windows Azure is a cloud computing platform that allows you to develop, manage and distribute your apps in the cloud. Chapter 31 shows you how to build a Windows Azure app that can store data in the cloud.
- ***Asynchronous programming with `async` and `await`.*** Asynchronous programming is simplified in Visual C# 2012 with the new `async` and `await` capabilities. We introduce asynchronous programming with `async` and `await` in Chapter 28.

## Object-Oriented Programming

- ***Early-objects approach.*** The book introduces the basic concepts and terminology of object technology in Chapter 1. In Chapter 2, Dive Into Visual Studio 2012 Express for Windows Desktop, you'll *visually* manipulate objects, such as labels and images. In Chapter 3, Introduction to C# Apps, you'll write Visual C# *program code*.

that manipulates preexisting objects. You'll develop your first customized classes and objects in Chapter 4. Presenting objects and classes early gets you "thinking about objects" immediately and mastering these concepts more thoroughly.

- *Rich coverage of programming fundamentals.* Chapters 5 and 6 present a friendly treatment of control statements and problem solving.
- *A clear, example-driven presentation of classes, objects, inheritance, polymorphism and interfaces.*
- *Optional case study: Using the UML to develop an object-oriented design and Visual C# implementation of an Automated Teller Machine (ATM).* The UML™ (Unified Modeling Language™) is the industry-standard graphical language for modeling object-oriented systems. We introduce the UML in the early chapters. Online Chapters 34 and 35 include an *optional* case study on object-oriented design using the UML. We design and implement the software for a simple automated teller machine. We analyze a typical *requirements document* that specifies the system to be built. We determine the *classes* needed to implement that system, the *attributes* the classes need to have, the *behaviors* the classes need to exhibit and we specify how the classes must *interact* with one another to meet the system requirements. From the design we produce a complete working Visual C# implementation. Students often report a "light bulb moment"—the case study helps them "tie it all together" and truly understand object orientation.
- *Three programming paradigms.* We discuss *structured programming, object-oriented programming* and *generic programming*.

## Complete Code Examples

We include a broad range of example programs selected from computer science, business, simulation, game playing, graphics, multimedia and many other areas (Fig. 1).

Examples		
Account class	Card shuffling and dealing	Credit-inquiry program
Address book case study	CheckedListBox control	Data binding
Airline reservation web-service	ComboBox control	Date class
Animating the width and height of a video	CommissionEmployee class	DateTimePicker control
Applying transforms to a polygon	Common Windows 8 UI controls	Defining gradients in XAML
ArrayList class	Common WPF controls	Dice rolling
BasePlusCommissionEmployee class	Compound interest calculations	Directory class
Binary search	Counter-controlled repetition	Document navigation using XNode
Blackjack game web-service	Craps dice game simulation	Drawing basic shapes
Books database	Creating and using a text file	Drawing polylines and polygons
	Creating custom windows and using timers	Employee class
		File class

**Fig. 1** | A small sample of the book's hundreds of examples. (Part 1 of 2.)

Examples		
Formatting fonts	NegativeNumberException	StringBuilder class
Generic class Stack	NumericUpDown control	TabControl
Generic class List	Object serialization	Text-to-speech and speech-to-text
GradeBook class	Overloaded constructors	Time class
Guestbook app	PictureBox displaying images	Toolbars
HourlyEmployee class	Reading sequential-access files	TreeView control
Session tracking in ASP.NET	Recursive Factorial method	TV GUI showing GUI customization
Invoice class	REST Web services with JSON and XML	Poll analysis
IPayable interface	SalariedEmployee class	Polymorphism demonstration
Keyboard events	Searching directories with LINQ	Querying a database with LINQ to Entities
LinkLabel control	Sequential search	Queue class
LINQ to Objects with arrays	Sorting an array	RadioButton control
ListBox control	Stack unwinding	
Math tutor using web services		
Menus		

**Fig. 1** | A small sample of the book's hundreds of examples. (Part 2 of 2.)

## Interesting, Entertaining and Challenging Exercises

- Extensive self-review exercises *and* answers are included for self-study.
- Each chapter concludes with a substantial set of exercises, which generally includes simple recall of important terminology and concepts, identifying the errors in code samples, writing individual program statements, writing small portions of Visual C# classes, writing complete programs and implementing major projects. Figure 2 lists a small sampling of the book's hundreds of exercises, including selections from our *Making a Difference* exercises set, which encourage you to use computers and the Internet to research and solve significant social problems—we hope you'll approach these exercises with *your own* values, politics and beliefs.

Exercises		
Airline Reservations System	Card Shuffling and Dealing	Ecofont
All Possible Three-Letter Words from a Five-Letter Word	Car-Pool Savings Calculator	Eight Queens
Baseball Database App	Coin Tossing	Employee Class
Binary Tree Traversals	Complex Numbers	Enforcing Privacy with Cryptography
Blackjack	Computer-Assisted Instruction	Enhanced Painter
Body Mass Index Calculator	Computerization of Health Records	Factorials
Bucket Sort	Cooking with Healthier Ingredients	Fuzzy Dice Order Form
Building Your Own Computer	Credit Limit Calculator	Game of Craps
Calendar and Appointments	Dice Rolling	Gas Mileage
Carbon Footprint Calculator		Generic Method Overloading

**Fig. 2** | A sampling of the book's exercises. (Part 1 of 2.)

**Exercises**

Guess the Number Game	Quicksort	Student Poll
Invoice Class	Quiz App	Target-Heart-Rate Calculator
Knight's Tour	Rational Numbers	Tax Plan Alternatives: The “FairTax”
MDI Text Editor	Restaurant Bill Calculator	Telephone-Number Word Generator
Nutrition Information	Salary Calculator	Tic-Tac-Toe
Palindromes	Sales Commissions	Towers of Hanoi
Phishing Scanner	Savings-Account Class	Turtle Graphics
Phone-Book Web Service	Sieve of Eratosthenes	Typing Tutor
Pig Latin	Tortoise and Hare Simulation	Web-based Address Book
Polymorphic Banking Program Using Account Hierarchy	SMS Language	World Population Growth
Pythagorean Triples	Spam Scanner	
	Story Writer	

**Fig. 2** | A sampling of the book’s exercises. (Part 2 of 2.)**Illustrations and Figures**

Abundant tables, line drawings, UML diagrams, programs and program outputs are included. A sampling of these is shown in Figs. 3 and 4.

**Main text tables, drawings and diagrams**

Anchoring demonstration	Escape sequences	LINQ to XML class hierarchy
Ajax-enabled web app	GroupBox properties	Master/Detail app
Binary tree graphical representation	HttpSessionState properties	Math class methods
Circular, doubly linked list	Implicit conversions between simple types	Mouse events and event arguments
Circular, singly linked list	Increment and decrement operators	.NET Framework Class Library namespaces
Client receiving a response from a web server	insertAtBack operation represented graphically	Number of comparisons for common Big O notations
Client requesting a response from a web server	insertAtFront operation represented graphically	Object methods inherited by all classes
Creating a web service	Interaction between a web-service client and a SOAP web service	Polymorphic interface for the Employee hierarchy classes
Collection classes of the .NET Framework	Interfaces of the .NET Framework Class Library	Precedence of arithmetic operators
Common built-in commands from the WPF command library	Keyboard events and event arguments	removeFromBack operation represented graphically
Components and controls	Keywords and contextual keywords	removeFromFront operation represented graphically
Custom-control creation	Linked list graphical representation	Rules of forming structured apps
DatePicker properties/event		SDI and MDI forms
Doubly linked list		
Entity-relationship diagram for the Books database		

**Fig. 3** | A sampling of the book’s tables, drawings and diagrams. (Part 1 of 2.)

Main text tables, drawings and diagrams		
Searching and sorting algorithms with Big O values Single-entry/single-exit sequence, selection and repetition statements	<code>string</code> format specifiers Three-tier architecture Traditional web app reloading the page for every user interaction	Tree structure for the document <code>article.xml</code> Validation app enhanced by ASP.NET Ajax XSL style-sheet elements

**Fig. 3** | A sampling of the book's tables, drawings and diagrams. (Part 2 of 2.)

Object-oriented design case study drawings and diagrams	
Use case diagram for the ATM system from the user's perspective Class diagram with an association among classes Class diagram showing composition relationships Class diagram for the ATM system model Classes with attributes State diagram for the ATM Activity diagram for a <code>BalanceInquiry</code> transaction Activity diagram for a <code>Withdrawal</code> transaction Classes in the ATM system with attributes and operations Communication diagram of the ATM executing a balance inquiry	Communication diagram for executing a balance inquiry Sequence diagram that models a <code>Withdrawal</code> executing Use case diagram for a modified version of our ATM system that also allows users to transfer money between accounts Class diagram showing composition relationships of a class <code>Car</code> Class diagram for the ATM system model including class <code>Deposit</code> Activity diagram for a <code>Deposit</code> transaction Sequence diagram that models a <code>Deposit</code> executing

**Fig. 4** | A sampling of the object-oriented design case study drawings and diagrams.

## Other Features

- *We use LINQ to query files, databases, XML and collections.* The introductory LINQ to Objects chapter (Chapter 9), is intentionally simple and brief to encourage instructors to begin covering LINQ technology early. Later in the book, we take a deeper look, using LINQ to Entities (Chapters 22–23 and 29–30) and LINQ to XML (Chapters 24, 30 and 31).
- *Local type inference.* When you initialize a local variable in its declaration, you can omit the variable's type—the compiler *infers* it from the initializer value.
- *Object initializers.* For new objects, you can use object initializer syntax (similar to array initializer syntax) to assign values to the new object's `public` properties and `public` instance variables.
- *We emphasize the IDE's IntelliSense feature* that helps you write code faster and with fewer errors.
- *Files and strings.*
- *Data structures chapter sequence, including searching and sorting, data structures, generics and collections.*

- **Integrated exception handling.** We introduce exception handling early (Chapter 8, Arrays; Introduction to Exception Handling) to ensure that we do not access an array element outside the array's bounds. Chapter 10, Classes and Objects: A Deeper Look, shows how to indicate an exception when a member function receives an invalid argument. We cover the complete details of exception handling in Chapter 13, Exception Handling: A Deeper Look.
- **Visual C# XML capabilities.** Extensible Markup Language (XML) is pervasive in the software-development industry, e-business and throughout the .NET platform. In optional online Chapter 24, we introduce XML syntax and programmatically manipulate the elements of an XML document using LINQ to XML. XAML is an XML vocabulary that's used to describe graphical user interfaces, graphics and multimedia. We discuss XAML in optional online Chapters 25–26 and 32–33.
- **Web app development with ASP.NET 4.5 and ASP.NET AJAX.** Optional online Chapter 29 extends Chapter 23's ASP.NET discussion with a case study on building a password-protected, web-based bookstore app. Also, we introduce in Chapter 29 ASP.NET AJAX controls and use them to add AJAX functionality to web apps to give them a look and feel similar to that of desktop apps.
- **WCF (Windows Communication Foundation) web services.** Web services enable you to package app functionality in a manner that turns the web into a library of reusable services. Optional online Chapter 30 includes case studies on building an airline reservation web service, a blackjack web service and a math question generator web service that's called by a math tutor app.
- **WPF (Windows Presentation Foundation) GUI, graphics and multimedia.** We extend the core book's GUI coverage in optional online Chapters 32–33 with an introduction to Windows Presentation Foundation (WPF)—a XAML-based Microsoft framework that preceded Windows 8 UI and integrates GUI, graphics and multimedia capabilities. We implement a painting app, a text editor, a color chooser, a book-cover viewer, a television video player, various animations, and speech synthesis and recognition apps.

## Companion Website

The printed book contains the core content (Chapters 1–23) for introductory course sequences. Several optional online chapters are available for advanced courses and professionals. Figure 5 lists the chapters and appendices that are available in searchable PDF format on the book's password-protected Companion Website at:

[www.pearsonhighered.com/deitel](http://www.pearsonhighered.com/deitel)

See the inside front cover of the book for an access code.

### Online chapters

Chapter 24, XML and LINQ to XML

Chapter 25, Windows 8 UI and XAML

**Fig. 5** | Online chapters and appendices in *Visual C# 2012 How to Program, 5/e.* (Part I of 2.)

Online chapters
Chapter 26, Windows 8 Graphics and Multimedia
Chapter 27, Building a Windows Phone 8 App
Chapter 28, Introduction to Concurrency: <code>async</code> and <code>await</code>
Chapter 29, Web App Development with ASP.NET: A Deeper Look
Chapter 30, Web Services
Chapter 31, Building a Windows Azure™ Cloud Computing App
Chapter 32, GUI with Windows Presentation Foundation
Chapter 33, WPF Graphics and Multimedia
Chapter 34, ATM Case Study, Part 1: Object-Oriented Design with the UML
Chapter 35, ATM Case Study, Part 2: Implementing an Object-Oriented Design
Appendix D, Number Systems
Appendix E, UML 2: Additional Diagram Types
Appendix F, Unicode®
Appendix G, Using the Visual Studio 2012 Debugger
Index (The online index includes the content from the printed book and the online content. The printed book index covers only the printed material.)

**Fig. 5** | Online chapters and appendices in *Visual C# 2012 How to Program, 5/e.* (Part 2 of 2.)

## VideoNotes

The Companion Website also includes extensive *VideoNotes*—watch and listen as co-author Paul Deitel discusses key code examples in the core chapters of the book. *VideoNotes* allow for self-paced instruction with easy navigation, including the ability to select, play, rewind, fast-forward and stop within each video.

We've created a jump table that maps each *VideoNote* to the corresponding figures in the book ([www.deitel.com/books/vcsharphtp5/jump\\_table.pdf](http://www.deitel.com/books/vcsharphtp5/jump_table.pdf)). *VideoNotes* are free with the purchase of a *new* textbook. If you have a *used* book you can purchase access to the *VideoNotes* for this book as follows:

1. Go to [www.pearsonhighered.com/deitel/](http://www.pearsonhighered.com/deitel/).
2. Scroll to *Visual C# 2012 How to Program, 5/e* and click **Companion Website**.
3. Click the **Register** button.
4. On the registration page, enter your student access code found beneath the scratch-off panel on the inside front cover of this book. Do not type the dashes. You can use lower- or uppercase. The access code can be used *only once*. This subscription is valid for twelve months upon activation and is *not transferable*. If this access code on your book has already been revealed, it may no longer be valid. If this is the case, click the **Website Purchase** link and follow the instructions.
5. Once your personal Login Name and Password are confirmed, you can begin using the *Visual C# 2012 How to Program, 5/e* Companion Website.

## Book Overview and Chapter Dependencies

This section discusses the book's modular organization to help instructors plan their syllabi.

### *Introduction to Visual C# and Visual Studio 2012 Express*

Chapter 1, Introduction to Computers, the Internet and Visual C#, introduces computing fundamentals and Microsoft's .NET platform. If you do not need to cover these fundamentals, you should still cover the **Painter** app test-drive. The vast majority of the book's examples will run on Windows 7 and Windows 8 using *Visual Studio Express 2012 for Windows Desktop*, which we test-drive in Section 1.14. Chapters 25–26 can be run *only* on Windows 8 using *Visual Studio Express 2012 for Windows 8*, which we test-drive in Section 1.15. There are other versions of *Visual Studio Express 2012* for web development and Windows Phone development—we cover these in the corresponding chapters.

Chapter 2, Dive Into® Visual Studio Express 2012 for Windows Desktop, shows how to develop a simple GUI app that displays text and an image. We'll look at Visual Studio Express 2012 for Windows 8 in more depth in Chapter 25.

### *Introduction to Visual C# Fundamentals and Object-Oriented Programming*

The chapters in this module of the book:

- Chapter 3, Introduction to C# Apps
- Chapter 4, Introduction to Classes, Objects, Methods and **strings**
- Chapter 5, Control Statements: Part 1
- Chapter 6, Control Statements: Part 2
- Chapter 7, Methods: A Deeper Look
- Chapter 8, Arrays; Introduction to Exception Handling

present C# programming fundamentals (data types, operators, control statements, methods and arrays) and introduce object-oriented programming. These chapters should be covered in order. Chapter 8 introduces exception handling with an example that demonstrates accessing an element outside an array's bounds.

### *Object-Oriented Programming: A Deeper Look*

The chapters in this module of the book:

- Chapter 9, Introduction to LINQ and the **List** Collection
- Chapter 10, Classes and Objects: A Deeper Look
- Chapter 11, Object-Oriented Programming: Inheritance
- Chapter 12, OOP: Polymorphism, Interfaces and Operator Overloading
- Chapter 13, Exception Handling: A Deeper Look
- Chapter 34, ATM Case Study, Part 1: Object-Oriented Design with the UML
- Chapter 35, ATM Case Study, Part 2: Implementing an Object-Oriented Design

provide a deeper look at object-oriented programming, including classes, objects, inheritance, polymorphism, interfaces and exception handling. Chapter 9, Introduction to LINQ and the **List** Collection, introduces Microsoft's Language Integrated Query (LINQ) technology, which provides a uniform syntax for manipulating data from various data sources,

such as arrays, collections and, as you'll see in later chapters, XML and databases. This chapter can be deferred, but it's required for one example in Chapter 17 (Fig. 17.6) and many of the later chapters starting with Chapter 22, Databases and LINQ. Online Chapters 34–35 present an *optional* object-oriented design and implementation case study that requires the C# and object-oriented programming concepts presented in Chapters 3–8 and 10–13.

### ***Windows Forms Graphical User Interfaces (GUIs)***

There are now three GUI technologies in Windows—Windows Forms (which is a legacy technology), Windows 8 UI (available *only* on Windows 8) and Windows Presentation Foundation (WPF). We surveyed instructors teaching Visual C# and they still prefer Windows Forms for their classes, so we provide a two-chapter introduction to Windows Forms:

- Chapter 14, Graphical User Interfaces with Windows Forms: Part 1
- Chapter 15, Graphical User Interfaces with Windows Forms: Part 2

in the print book, then use Windows Forms GUIs in several other print and online chapters. Most examples in Chapters 14–15 can be presented after Chapter 4. For those who wish to present or study Microsoft's more recent GUI, graphics and multimedia technologies, we provide two-chapter online introductions to Windows 8 UI, graphics and multimedia (Chapters 25–26) and WPF GUI, graphics and multimedia (Chapters 32–33).

### ***Strings and Files***

We introduce strings beginning in Chapter 4 and use them throughout the book. Chapter 16, Strings and Characters: A Deeper Look, investigates strings in more depth. Chapter 17, Files and Streams, introduces text-file processing and object-serialization for input/output of entire objects. Chapter 16 can be presented at any point after Chapter 4. Chapter 17 requires C#, object-oriented programming and Windows Forms concepts presented in Chapters 3–14.

### ***Searching, Sorting and Data Structures***

The chapters in this module of the book:

- Chapter 18, Searching and Sorting
- Chapter 19, Data Structures
- Chapter 20, Generics
- Chapter 21, Collections

introduce searching, sorting and data structures. Most C# programmers should use .NET's *built-in* searching, sorting and collections (prepackaged data structures) capabilities, which are discussed in Chapter 21. For instructors who wish to present how to implement customized searching, sorting and data structures capabilities, we provide Chapters 18–20, which require the concepts presented in Chapters 3–8 and 10–13.

### ***Databases and an Introduction to Web App Development***

Chapter 22, Databases and LINQ, introduces database app development using the ADO.NET Entity Framework and LINQ to Entities. The chapter's examples require C#, object-oriented programming and Windows Forms concepts presented in Chapters 3–14. Chapter 23, Web App Development with ASP.NET, introduces web app development.

The last example in this chapter requires the LINQ and database techniques presented in Chapter 22.

### *Extensible Markup Language (XML)*

Chapter 24, XML and LINQ to XML, introduces XML, which is used in several later chapters. The first few sections of this chapter are required to understand the XAML markup that's used to build Windows 8 GUI, graphics and multimedia apps (Chapters 25–26), Windows Phone 8 apps (Chapter 27) and WPF GUI, graphics and multimedia apps (Chapters 32–33). The remainder of the chapter discusses LINQ to XML, which allows you to manipulate XML using LINQ syntax. These capabilities are used in Chapters 30 and 31.

### *Windows 8 UI, Graphics and Multimedia; Windows Phone*

The chapters in this module of the book:

- Chapter 25, Windows 8 UI and XAML
- Chapter 26, Windows 8 Graphics and Multimedia
- Chapter 27, Building a Windows Phone 8 App

present Windows 8 UI, graphics and multimedia, and Windows Phone 8 app development. These chapters can be used only on computers running Windows 8 and depend on event-handling concepts that are presented in Chapter 14, and the introduction to XML at the beginning of Chapter 24 (see Section 24.1 for details). Developing a Windows Phone 8 app is similar to developing a Windows 8 UI app.

### *Asynchronous Programming*

Chapter 28, Asynchronous Programming with `async` and `await`, demonstrates .NET's and Visual C#'s new simplified asynchronous programming capabilities. These are commonly used in Web app and Web service development (among many other uses).

### *Web App Development and Web Services*

The chapters in this module of the book:

- Chapter 29, Web App Development with ASP.NET: A Deeper Look
- Chapter 30, Web Services
- Chapter 31, Building a Windows Azure™ Cloud Computing App

continue our discussion of Web app development from Chapter 23 and introduce web services, including a case study on cloud computing with Windows Azure. Chapters 30 and 31 depend on the LINQ to XML discussion in Chapter 24.

### *Windows Presentation Foundation (WPF) GUI, Graphics and Multimedia*

The chapters in this module of the book

- Chapter 32, GUI with Windows Presentation Foundation
- Chapter 33, WPF Graphics and Multimedia

discuss Windows Presentation Foundation GUI, graphics and multimedia. These chapters can be used on computers running Windows 7 or Windows 8 and depend on event-handling concepts that are presented in Chapter 14 and the introduction to XML at the beginning of Chapter 24.

## Teaching Approach

*Visual C# 2012 How to Program, 5/e* contains a rich collection of examples. We concentrate on building good software and stress program clarity.

**Live-Code Approach.** The book is loaded with “live-code” examples. Most new concepts are presented in the context of complete working Visual C# apps, followed by one or more executions showing program inputs and outputs. In the few cases where we show a code snippet, to ensure correctness we first tested it in a complete working program then copied the code from the program and pasted it into the book.

**Syntax Shading.** For readability, we syntax shade the code, similar to the way most integrated-development environments and code editors syntax color the code. Our syntax-shading conventions are:

```
comments appear like this
keywords appear like this
constants and literal values appear like this
all other code appears in black
```

**Code Highlighting.** We place gray rectangles around each program’s key code segments.

**Using Fonts for Emphasis.** We place the key terms and the index’s page reference for each defining occurrence in **bold** text for easy reference. We show on-screen components in the **bold Helvetica** font (for example, the **File** menu) and Visual C# program text in the **Lucida** font (for example, **int count = 5**). We use *italics* for emphasis.

**Objectives.** The chapter objectives preview the topics covered in the chapter.

**Programming Tips.** We include programming tips to help you focus on important aspects of program development. These tips and practices represent the best we’ve gleaned from a combined seven decades of programming and teaching experience.



### Good Programming Practice

*The Good Programming Practices call attention to techniques that will help you produce programs that are clearer, more understandable and more maintainable.*



### Common Programming Error

*Pointing out these Common Programming Errors reduces the likelihood that you’ll make them.*



### Error-Prevention Tip

*These tips contain suggestions for exposing and removing bugs from your programs; many of the tips describe aspects of Visual C# that prevent bugs from getting into programs.*



### Performance Tip

*These tips highlight opportunities for making your programs run faster or minimizing the amount of memory that they occupy.*



### Portability Tip

*The Portability Tips help you write code that will run on a variety of platforms.*



### Software Engineering Observation

The Software Engineering Observations highlight architectural and design issues that affect the construction of software systems, especially large-scale systems.



### Look-and-Feel Observation

These observations help you design attractive, user-friendly graphical user interfaces that conform to industry norms.

**Summary Bullets.** We present a detailed bullet-list summary of each chapter.

**Terminology.** We include a list of the important terms defined in each chapter.

**Index.** We've included an extensive index for reference. Defining occurrences of key terms in the index are highlighted with a **bold** page number.

## Obtaining the Software Used in Visual C# How to Program, 5/e

We wrote the code examples in *Visual C# 2012 How to Program, 5/e* using Microsoft's *free* Visual Studio Express 2012 products, including:

- Visual Studio Express 2012 for Windows Desktop (Chapters 1–24, 28 and 32–35), which includes Visual C# and other Microsoft development tools. This runs on Windows 7 and 8.
- Visual Studio Express 2012 for Web (Chapters 23 and 29–31)
- Visual Studio Express 2012 for Windows 8 (Chapters 25–26)
- Visual Studio Express 2012 for Windows Phone (Chapter 27)

Each of these is available for download at

[www.microsoft.com/visualstudio/eng/products/  
visual-studio-express-products](http://www.microsoft.com/visualstudio/eng/products/visual-studio-express-products)

## Instructor Supplements

The following supplements are available to *qualified instructors only* through Pearson Education's Instructor Resource Center ([www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc)):

- *Solutions Manual* contains solutions to *most* of the end-of-chapter exercises. We've added many *Making a Difference* exercises, most with solutions. Please do not write to us requesting access to the Pearson Instructor's Resource Center. Access is restricted to college instructors teaching from the book. Instructors may obtain access only through their Pearson representatives. If you're not a registered faculty member, contact your Pearson representative or visit [www.pearsonhighered.com/educator/relocator/](http://www.pearsonhighered.com/educator/relocator/). Exercise Solutions are *not* provided for "project" exercises. Check out our Programming Projects Resource Center for lots of additional exercise and project possibilities:

[www.deitel.com/ProgrammingProjects](http://www.deitel.com/ProgrammingProjects)

- *Test Item File* of multiple-choice questions (approximately two per book section)
- *Customizable PowerPoint® slides* containing all the code and figures in the text, plus bulleted items that summarize the key points in the text.

## Microsoft DreamSpark™

### *Professional Developer and Designer Tools for Students*

Microsoft provides many of its professional developer tools to students for free via a program called DreamSpark ([www.dreamspark.com](http://www.dreamspark.com)). See the website for details on verifying your student status so you take advantage of this program.

## Acknowledgments

We'd like to thank Abbey Deitel and Barbara Deitel of Deitel & Associates, Inc. for long hours devoted to this project. Abbey co-authored this Preface and Chapter 1 and she and Barbara painstakingly researched the new capabilities of Visual C# 2012, .NET 4.5, Windows 8, Windows Phone 8, Windows Azure and other key topics.

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### *Reviewers*

We wish to acknowledge the efforts of our reviewers. The book was scrutinized by academics teaching C# courses and industry experts. They provided countless suggestions for improving the presentation. Any remaining flaws in the book are our own.

*Fifth Edition Reviewers:* Shay Friedman (Microsoft Visual C# MVP), Octavio Hernandez (Microsoft Certified Solutions Developer), Stephen Hustedde (South Mountain College), José Antonio González Seco (Parliament of Andalusia, Spain) and Shawn Weisfeld (Microsoft MVP and President and Founder of UserGroup.tv).

*Other recent edition reviewers:* Huanhui Hu (Microsoft Corporation), Narges Kasiri (Oklahoma State University), Charles Liu (University of Texas at San Antonio), Dr. Hamid R. Nemati (The University of North Carolina at Greensboro), Jeffrey P. Scott (Blackhawk Technical College), Douglas B. Bock (MCSD.NET, Southern Illinois University Edwardsville), Dan Crevier (Microsoft), Amit K. Ghosh (University of Texas at El Paso), Marcelo Guerra Hahn (Microsoft), Kim Hamilton (Software Design Engineer at Microsoft and co-author of *Learning UML 2.0*), James Edward Keysor (Florida Institute of Technology), Helena Kotas (Microsoft), Chris Lovett (Software Architect at Microsoft), Bashar Lulu (INETA Country Leader, Arabian Gulf), John McIlhinney (Spatial Intelligence; Microsoft MVP 2008 Visual Developer, Visual Basic), Ged Mead (Microsoft Visual Basic MVP, DevCity.net), Anand Mukundan (Architect, Polaris Software Lab Ltd.), Timothy Ng (Microsoft), Akira Onishi (Microsoft), Joe Stagner (Senior Program Manager, Developer Tools & Platforms), Erick Thompson (Microsoft), Jesús Ubaldo Quevedo-Torrero (University of Wisconsin–Parkside, Department of Computer Science) and Zijiang Yang (Western Michigan University).

As you read the book, we'd sincerely appreciate your comments, criticisms and suggestions for improving the text. Please address all correspondence to:

[deitel@deitel.com](mailto:deitel@deitel.com)

We'll respond promptly. We really enjoyed writing this book—we hope you enjoy reading it!

*Paul Deitel  
Harvey Deitel*

## About the Authors

Paul Deitel, CEO and Chief Technical Officer of Deitel & Associates, Inc., is a graduate of MIT, where he studied Information Technology. Through Deitel & Associates, Inc., he has delivered hundreds of programming courses to industry clients, including Cisco, IBM, Siemens, Sun Microsystems, Dell, Fidelity, NASA at the Kennedy Space Center, the National Severe Storm Laboratory, White Sands Missile Range, Rogue Wave Software, Boeing, SunGard Higher Education, Nortel Networks, Puma, iRobot, Invensys and many more. He and his co-author, Dr. Harvey M. Deitel, are the world's best-selling programming-language textbook/professional book/video authors.

Paul was named as a Microsoft® Most Valuable Professional (MVP) for C# in 2012. According to Microsoft, "the Microsoft MVP Award is an annual award that recognizes exceptional technology community leaders worldwide who actively share their high quality, real world expertise with users and Microsoft."



2012 C# MVP

Dr. Harvey Deitel, Chairman and Chief Strategy Officer of Deitel & Associates, Inc., has 50 years of experience in the computer field. Dr. Deitel earned B.S. and M.S. degrees in Electrical Engineering from MIT and a Ph.D. in Mathematics from Boston University. He has extensive college teaching experience, including earning tenure and serving as the Chairman of the Computer Science Department at Boston College before founding Deitel & Associates, Inc., in 1991 with his son, Paul Deitel. The Deitels' publications have earned international recognition, with translations published in Chinese, Korean, Japanese, German, Russian, Spanish, French, Polish, Italian, Portuguese, Greek, Urdu and Turkish. Dr. Deitel has delivered hundreds of programming courses to corporate, academic, government and military clients.

## Deitel® Dive-Into® Series Programming Languages Training

Deitel & Associates, Inc., founded by Paul Deitel and Harvey Deitel, is an internationally recognized authoring and corporate training organization, specializing in computer programming languages, object technology, mobile app development and Internet and web software technology. The company's training clients include many of the world's largest companies, government agencies, branches of the military, and academic institutions. The company offers instructor-led training courses delivered at client sites worldwide on major programming languages and platforms, including Visual C#®, Visual Basic®, Visual C++®, C++, C, Java™, XML®, Python®, object technology, Internet and web programming, Android app development, Objective-C and iPhone app development and a growing list of additional programming and software development courses.

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# Before You Begin

This section contains information you should review before using this book and instructions to ensure that your computer is set up properly for use with this book.

### ***Font and Naming Conventions***

We use fonts to distinguish between features, such as menu names, menu items, and other elements that appear in the program-development environment. Our convention is to emphasize IDE features in a sans-serif bold **Helvetica** font (for example, **Properties** window) and to emphasize program text in a sans-serif **Lucida** font (for example, `bool x = true`).

### ***Software***

This textbook uses the following software:

- Microsoft Visual Studio Express 2012 for Windows Desktop
- Microsoft Visual Studio Express 2012 for Web (Chapters 23 and 29–31)
- Microsoft Visual Studio Express 2012 for Windows 8 (Chapters 25–26)
- Microsoft Visual Studio Express 2012 for Windows Phone (Chapter 27)

Each is available free for download at [www.microsoft.com/express](http://www.microsoft.com/express). The Express Editions are fully functional, and there's no time limit for using the software.

### ***Hardware and Software Requirements for the Visual Studio 2012 Express Editions***

To install and run the Visual Studio 2012 Express Editions, ensure that your system meets the minimum requirements specified at:

[www.microsoft.com/visualstudio/eng/products/compatibility](http://www.microsoft.com/visualstudio/eng/products/compatibility)

Microsoft Visual Studio Express 2012 for Windows 8 works *only* on Windows 8.

### ***Viewing File Extensions***

Several screenshots in *Visual C# 2012 How to Program, 5/e* display file names with file-name extensions (e.g., `.txt`, `.cs` or `.png`). Your system's settings may need to be adjusted to display file-name extensions. Follow these steps to configure your Windows 7 computer:

1. In the **Start** menu, select **All Programs**, then **Accessories**, then **Windows Explorer**.
2. Press **Alt** to display the menu bar, then select **Folder Options...** from **Windows Explorer**'s **Tools** menu.
3. In the dialog that appears, select the **View** tab.
4. In the **Advanced settings:** pane, uncheck the box to the left of the text **Hide extensions for known file types**. [*Note:* If this item is already unchecked, no action needs to be taken.]
5. Click **OK** to apply the setting and close the dialog.

Follow these steps to configure your Windows 8 computer:

1. On the **Start** screen, click the **Desktop** tile to switch to the desktop.
2. On the task bar, click the **File Explorer** icon to open the **File Explorer**.
3. Click the **View** tab, then ensure that the **File name extensions** checkbox is checked.

### *Obtaining the Code Examples*

The examples for *Visual C# 2012 How to Program, 5/e* are available for download at

[www.deitel.com/books/vcsharp2012http/](http://www.deitel.com/books/vcsharp2012http/)

If you're not already registered at our website, go to [www.deitel.com](http://www.deitel.com) and click the **Register** link below our logo in the upper-left corner of the page. Fill in your information. There's no charge to register, and we do not share your information with anyone. We send you only account-management e-mails unless you register separately for our free e-mail newsletter at [www.deitel.com/newsletter/subscribe.html](http://www.deitel.com/newsletter/subscribe.html). *You must enter a valid e-mail address.* After registering, you'll receive a confirmation e-mail with your verification code. Click the link in the confirmation email to go to [www.deitel.com](http://www.deitel.com) and sign in.

Next, go to [www.deitel.com/books/vcsharp2012http/](http://www.deitel.com/books/vcsharp2012http/). Click the **Examples** link to download the ZIP archive file to your computer. Write down the location where you save the file—most browsers will save the file into your **Downloads** folder.

Throughout the book, steps that require you to access our example code on your computer assume that you've extracted the examples from the ZIP file and placed them at **C:\Examples**. You can extract them anywhere you like, but if you choose a different location, you'll need to update our steps accordingly. You can extract the ZIP archive file's contents using tools such as WinZip ([www.winzip.com](http://www.winzip.com)), 7-zip ([www.7-zip.org](http://www.7-zip.org)) or the built-in capabilities of **Windows Explorer** on Window 7 or **File Explorer** on Windows 8.

### *Visual Studio Theme*

Visual Studio 2012 has a **Dark** theme (the default) and a **Light** theme. The screen captures shown in this book use the **Light** theme, which is more readable in print. If you'd like to switch to the **Light** theme, in the **TOOLS** menu, select **Options...** to display the **Options** dialog. In the left column, select **Environment**, then select **Light** under **Color theme**. Keep the **Options** dialog open for the next step.

### *Displaying Line Numbers and Configuring Tabs*

Next, you'll change the settings so that your code matches that of this book. To have the IDE display line numbers, expand the **Text Editor** node in the left pane then select **All Languages**. On the right, check the **Line numbers** checkbox. Next, expand the **C#** node in the left pane and select **Tabs**. Make sure that the option **Insert spaces** is selected. Enter **3** for both the **Tab size** and **Indent size** fields. Any new code you add will now use three spaces for each level of indentation. Click **OK** to save your settings.

### *Miscellaneous Notes*

- Some people like to change the workspace layout in the development tools. You can return the tools to their default layouts by selecting **Window > Reset Window Layout**.

- Many of the menu items we use in the book have corresponding icons shown with each menu item in the menus. Many of the icons also appear on one of the toolbars at the top of the development environment. As you become familiar with these icons, you can use the toolbars to help speed up your development time. Similarly, many of the menu items have keyboard shortcuts (also shown with each menu item in the menus) for accessing commands quickly.

You are now ready to begin your Visual C# studies with *Visual C# 2012 How to Program, 5/e*. We hope you enjoy the book!

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# Introduction to Computers, the Internet and Visual C#

I



*The chief merit of language is clearness.*

—Galen

*Our life is frittered away with detail. . . . Simplify, simplify.*

—Henry David Thoreau

*Man is still the most extraordinary computer of all.*

—John F. Kennedy

## Objectives

In this chapter you'll learn:

- Basic hardware, software and data concepts.
- The different types of programming languages.
- The history of the Visual C# programming language and the Windows operating system.
- What cloud computing with Windows Azure is.
- Basics of object technology.
- The history of the Internet and the World Wide Web.
- The parts that Windows 8, .NET 4.5, Visual Studio 2012 and Visual C# 2012 play in the Visual C# ecosystem.
- To test-drive a Visual C# 2012 drawing app.

# Outline

<b>1.1</b>	Introduction	I.9.3	Platform Independence
<b>1.2</b>	Hardware and Moore's Law	I.9.4	Language Interoperability
<b>1.3</b>	Data Hierarchy	<b>1.10</b>	Microsoft's Windows® Operating System
<b>1.4</b>	Computer Organization	<b>1.11</b>	Windows Phone 8 for Smartphones
<b>1.5</b>	Machine Languages, Assembly Languages and High-Level Languages	I.11.1	Selling Your Apps in the Windows Phone Marketplace
<b>1.6</b>	Object Technology	I.11.2	Free vs. Paid Apps
<b>1.7</b>	Internet and World Wide Web	I.11.3	Testing Your Windows Phone Apps
<b>1.8</b>	C#	<b>1.12</b>	Windows Azure™ and Cloud Computing
1.8.1	Object-Oriented Programming	<b>1.13</b>	Visual Studio Express 2012 Integrated Development Environment
1.8.2	Event-Driven Programming	<b>1.14</b>	Painter Test-Drive in Visual Studio Express 2012 for Windows Desktop
1.8.3	Visual Programming	<b>1.15</b>	Painter Test-Drive in Visual Studio Express 2012 for Windows 8
1.8.4	An International Standard; Other C# Implementations		
1.8.5	Internet and Web Programming		
1.8.6	Introducing <code>async/await</code>		
1.8.7	Other Key Contemporary Programming Languages		
<b>1.9</b>	Microsoft's .NET		
1.9.1	.NET Framework		
1.9.2	Common Language Runtime		

*Self-Review Exercises | Answers to Self-Review Exercises | Exercises | Making a Difference Exercises*

## 1.1 Introduction

Welcome to Visual C# 2012 which, from this point forward, we'll refer to simply as C#.<sup>1</sup> C# is a powerful computer programming language that's appropriate for building substantial information systems.

You're already familiar with the powerful tasks computers perform. Using this textbook, you'll write instructions commanding computers to perform those kinds of tasks and you'll prepare yourself to address new challenges.

Computers process *data* under the control of sequences of instructions called **computer programs**. These programs guide the computer through *actions* specified by people called **computer programmers**. The programs that run on a computer are referred to as **software**. In this book, you'll learn *object-oriented programming*—today's key programming methodology that's enhancing programmer productivity, and reducing software development costs. You'll create many *software objects* that model both abstract and real-world *things*. And you'll build C# apps for a variety of environments including the *desktop*—and new to this edition of the book—mobile devices like *smartphones* and *tablets*, and even “the *cloud*.”

## 1.2 Hardware and Moore's Law

A computer consists of various devices referred to as **hardware**, such as the keyboard, screen, mouse, hard disks, memory, DVD drives and processing units. Every year or two,

1. The name C#, pronounced “C-sharp,” is based on the musical # notation for “sharp” notes.

the capacities of computer hardware have approximately *doubled* inexpensively. This remarkable trend often is called **Moore’s Law**, named for the person who identified it, Gordon Moore, co-founder of Intel—the leading manufacturer of the processors in today’s computers and **embedded systems**, such as smartphones, appliances, game controllers, cable set-top boxes and automobiles.

Moore’s Law and *related* observations apply especially to

- the amount of *memory* that computers have for running programs and processing data
- the amount of *secondary storage* (such as hard disk storage) they have to hold programs and data over longer periods of time
- their *processor speeds*—the speeds at which computers **execute** their programs (i.e., do their work)

Similar growth has occurred in the communications field, in which costs have plummeted as enormous demand for communications *bandwidth* (i.e., information-carrying capacity) has attracted intense competition. We know of no other fields in which technology improves so quickly and costs fall so rapidly. Such phenomenal improvement is truly fostering the *Information Revolution* and creating significant career opportunities.

As a result of this continuing stream of technological advances, computers already can perform calculations and make logical decisions phenomenally faster than human beings can. Many of today’s personal computers can perform *billions* of calculations in one second—more than a human can perform in a lifetime. *Supercomputers* are already performing *thousands of trillions (quadrillions)* of instructions per second! The world’s fastest supercomputer—the Cray Titan—can perform over 17 quadrillion calculations per second—(17.59 *petaflops*)<sup>2</sup>—that’s *more than 2 million calculations per second for every person on the planet!* And—these “upper limits” are expanding quickly!

## 1.3 Data Hierarchy

Data items processed by computers form a **data hierarchy** that becomes larger and more complex in structure as we progress from the simplest data items (called “bits”) to richer data items, such as characters, fields, and so on. Figure 1.1 illustrates a portion of the data hierarchy.

### *Bits*

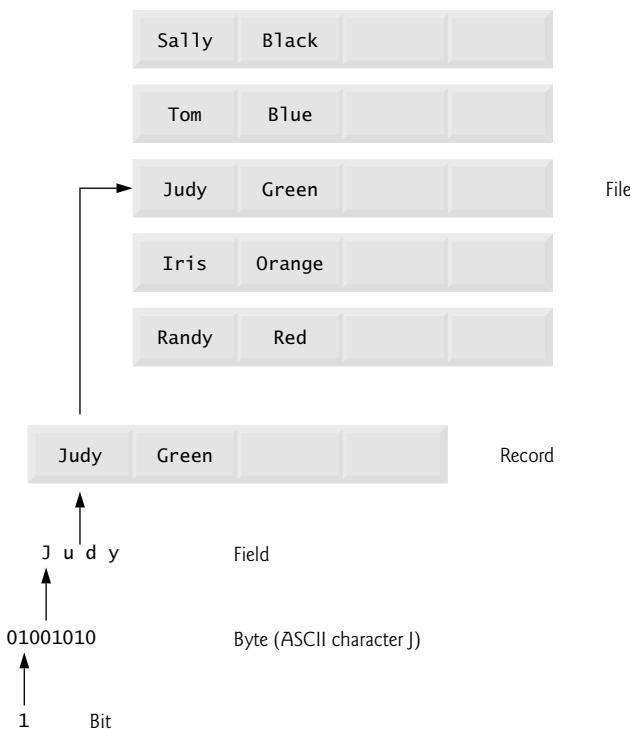
The smallest data item in a computer can assume the value 0 or the value 1. Such a data item is called a **bit** (short for “binary digit”—a digit that can assume either of *two* values). It’s remarkable that the impressive functions performed by computers involve only the simplest manipulations of 0s and 1s—*examining a bit’s value, setting a bit’s value and reversing a bit’s value* (from 1 to 0 or from 0 to 1). We discuss binary numbers (and closely related octal and hexadecimal numbers) in more detail in Appendix D, Number Systems.

### *Characters*

It’s tedious for people to work with data in the low-level form of bits. Instead, we prefer to work with *decimal digits* (0–9), *letters* (A–Z and a–z), and *special symbols* (e.g., \$, @, %,

---

2. [top500.org/lists/2012/11/](http://top500.org/lists/2012/11/).



**Fig. 1.1** | Data hierarchy.

&, \*, (,), -, +, ", :, ? and / ). Digits, letters and special symbols are known as **characters**. The computer's **character set** is the set of all the characters used to write programs and represent data items on that device. Computers process only 1s and 0s, so every character is represented as a pattern of 1s and 0s. The **Unicode** character set contains characters for many of the world's languages. C# supports several character sets, including 16-bit Unicode® characters that are composed of two **bytes**—each byte is composed of eight bits. See Appendix B for more information on the **ASCII (American Standard Code for Information Interchange)** character set—the popular *subset* of Unicode that represents uppercase and lowercase letters in the English alphabet, digits and some common *special characters*.

### **Fields**

Just as characters are composed of bits, **fields** are composed of characters or bytes. A field is a group of characters or bytes that conveys meaning. For example, a field consisting of uppercase and lowercase letters could be used to represent a person's name, and a field consisting of decimal digits could represent a person's age.

### **Records**

Several related fields can be used to compose a **record**. In a payroll system, for example, the record for an employee might consist of the following fields (possible types for these fields are shown in parentheses):

- Employee identification number (a whole number)
- Name (a string of characters)
- Address (a string of characters)
- Hourly pay rate (a number with a decimal point)
- Year-to-date earnings (a number with a decimal point)
- Amount of taxes withheld (a number with a decimal point)

Thus, a record is a group of related fields. In the preceding example, all the fields belong to the *same* employee. A company might have many employees and a payroll record for each.

### *Files*

A **file** is a group of related records. [Note: More generally, a file contains arbitrary data in arbitrary formats. In some operating systems, a file is viewed simply as a *sequence of bytes*—any organization of the bytes in a file, such as organizing the data into records, is a view created by the programmer.] It's not unusual for an organization to have thousands or even millions of files, some containing billions or even trillions of characters of information. You'll work with files in Chapter 17.

### *Database*

A **database** is a collection of data that's organized for easy access and manipulation. The most popular database model is the *relational database* in which data is stored in simple *tables*. A table includes *records* and *fields*. For example, a table of students might include first name, last name, major, year, student ID number and grade point average fields. The data for each student is a record, and the individual pieces of information in each record are the fields. You can *search*, *sort* and otherwise manipulate the data based on its relationship to multiple tables or databases. For example, a university might use data from the student database in combination with data from databases of courses, on-campus housing, meal plans, etc. We discuss databases in Chapter 22.

### *Big Data*

The amount of data being produced worldwide is enormous and growing quickly. According to IBM, approximately 2.5 quintillion bytes (2.5 *exabytes*) of data are created daily and 90% of the world's data was created in just the past two years.<sup>3</sup> According to an IDC study, approximately 1.8 *zettabytes* (equal to 1.8 trillion gigabytes) of data was used worldwide in 2011.<sup>4</sup> Figure 1.2 shows relationships between byte measurements.

Unit	Bytes	Which is approximately
1 kilobyte (KB)	1024 bytes	$10^3$ (1024 bytes exactly)
1 megabyte (MB)	1024 kilobytes	$10^6$ (1,000,000 bytes)
1 gigabyte (GB)	1024 megabytes	$10^9$ (1,000,000,000 bytes)

**Fig. 1.2** | Byte measurements. (Part 1 of 2.)

3. [www-01.ibm.com/software/data/bigdata/](http://www-01.ibm.com/software/data/bigdata/).

4. [www.emc.com/collateral/about/news/idc-emc-digital-universe-2011-infographic.pdf](http://www.emc.com/collateral/about/news/idc-emc-digital-universe-2011-infographic.pdf).

Unit	Bytes	Which is approximately
1 terabyte (TB)	1024 gigabytes	$10^{12}$ (1,000,000,000,000 bytes)
1 petabyte (PB)	1024 terabytes	$10^{15}$ (1,000,000,000,000,000 bytes)
1 exabyte (EB)	1024 petabytes	$10^{18}$ (1,000,000,000,000,000,000 bytes)
1 zettabyte (ZB)	1024 exabytes	$10^{21}$ (1,000,000,000,000,000,000,000 bytes)

**Fig. 1.2** | Byte measurements. (Part 2 of 2.)

## 1.4 Computer Organization

Regardless of differences in *physical* appearance, computers can be envisioned as divided into various **logical units** or sections.

### *Input Unit*

This “receiving” section obtains information (data and computer programs) from **input devices** and places it at the disposal of the other units for processing. Most information is entered into computers through keyboards, touch screens and mouse devices. Other forms of input include receiving voice commands, scanning images and barcodes, reading from secondary storage devices (such as hard drives, DVD drives, Blu-ray Disc™ drives and USB flash drives—also called “thumb drives” or “memory sticks”), receiving video from a webcam or smartphone and having your computer receive information from the Internet (such as when you download videos from YouTube or e-books from Amazon). Newer forms of input include position data from GPS devices, and motion and orientation information from accelerometers in smartphones or game controllers (such as Microsoft® Kinect™, Nintendo’s Wii™ Remote and Sony’s PlayStation® Move).

### *Output Unit*

This “shipping” section takes information that the computer has processed and places it on various **output devices** to make it available for use outside the computer. Most information that’s output from computers today is displayed on screens; printed on paper (“going green” discourages this); played as audio or video on PCs and media players (such as Apple® iPod®) and giant screens in sports stadiums; transmitted over the Internet or used to control other devices, such as robots, 3D printers and “intelligent” appliances.

### *Memory Unit*

This rapid-access, relatively low-capacity “warehouse” section retains information that’s entered through the input unit, making it immediately available for processing when needed. The memory unit also retains processed information until it can be placed on output devices by the output unit. Information in the memory unit is *volatile*—it’s typically *lost* when the computer’s power is turned off. The memory unit is often called either **memory** or **primary memory**—on desktop and notebook computers it commonly contains as much as 16 GB (GB stands for gigabytes; a gigabyte is approximately one billion bytes).

### *Arithmetic and Logic Unit (ALU)*

This “manufacturing” section performs *calculations*, such as addition, subtraction, multiplication and division. It also contains the *decision* mechanisms that allow the computer,

for example, to *compare* two items from the memory unit to determine whether they’re equal. In today’s systems, the ALU is usually implemented as part of the next logical unit, the CPU.

### ***Central Processing Unit (CPU)***

This “administrative” section coordinates and supervises the operation of the other sections. The CPU tells the input unit when information should be read into the memory unit, tells the ALU when information from the memory unit should be used in calculations and tells the output unit when to send information from the memory unit to certain output devices. Many of today’s computers have multiple CPUs and, hence, can perform many operations simultaneously. A **multi-core processor** implements multiple processors on a single “microchip”—a *dual-core processor* has two CPUs and a *quad-core processor* has four CPUs. Many of today’s desktop computers have quad-core processors that can execute billions of instructions per second. In this book you’ll learn how to write programs that can keep all these processors running in parallel to get your computing tasks done faster.

### ***Secondary Storage Unit***

This is the long-term, high-capacity “warehousing” section. Programs or data not actively being used by the other units normally are placed on secondary storage devices (such as your *hard drive*) until they’re again needed, possibly hours, days, months or even years later. Information on secondary storage devices is *persistent*—it’s *preserved* even when the computer’s power is turned off. Secondary storage data takes much longer to access than information in primary memory, but the cost per unit of secondary storage is much less than that of primary memory. Examples of secondary storage devices include CD drives, DVD drives and flash drives, some of which can hold up to 768 GB. Typical hard drives on desktop and notebook computers can hold up to 2 TB (TB stands for *terabytes*; a terabyte is approximately one trillion bytes). New to this edition, you’ll see that storage in “the cloud” can be viewed as additional secondary storage accessible by your C# apps.

## **1.5 Machine Languages, Assembly Languages and High-Level Languages**

Programmers write instructions in various programming languages (such as C#), some directly understandable by computers and others requiring intermediate *translation* steps.

### ***Machine Languages***

Any computer can *directly* understand only its own **machine language**, defined by its hardware architecture. Machine languages generally consist of numbers, ultimately reduced to 1s and 0s. Such languages are cumbersome for humans, who prefer words like “add” and “subtract” to indicate the operations to be performed, so the machine language numeric versions of these instructions were referred to as **code**. The term “code” has become more broadly used and now refers to the program instructions in *all* levels of language.

### ***Assembly Languages and Assemblers***

Machine language was simply too slow and tedious to work with. Instead, programmers began using English-like *abbreviations* to represent elementary operations. These abbreviations form the basis of **assembly languages**. *Translator programs* called **assemblers** convert assembly-language code to machine code quickly. Although assembly-language code is

clearer to humans, it's incomprehensible to computers until translated to machine language code.

### *High-Level Languages, Compilers and Interpreters*

To speed the programming process even further, **high-level languages** were developed in which single statements could be written to accomplish substantial tasks. High-level languages, such as C#, Visual Basic, C++, C, Objective-C and Java, allow you to write instructions that look almost like everyday English and contain commonly used mathematical expressions. Translator programs called **compilers** convert high-level language code into machine language code.

The process of compiling a large high-level language program into machine language can take a considerable amount of computer time. **Interpreter** programs were developed to execute high-level language programs directly (without the need for compilation), although more slowly than compiled programs.

## **1.6 Object Technology**

C# is an object-oriented programming language. In this section we'll introduce the basics of object technology.

Building software quickly, correctly and economically remains an elusive goal at a time when demands for new and more powerful software are soaring. **Objects**, or more precisely the *classes* objects come from, are essentially *reusable* software components. There are date objects, time objects, audio objects, video objects, automobile objects, people objects, etc. Almost any *noun* can be reasonably represented as a software object in terms of *attributes* (e.g., name, color and size) and *behaviors* (e.g., calculating, moving and communicating). Software developers have discovered that using a modular, object-oriented design and implementation approach can make software-development groups much more productive than was possible with earlier techniques—object-oriented programs are often easier to understand, correct and modify.

### *The Automobile as an Object*

Let's begin with a simple analogy. Suppose you want to *drive a car and make it go faster by pressing its accelerator pedal*. What must happen before you can do this? Well, before you can drive a car, someone has to *design* it. A car typically begins as engineering drawings, similar to the *blueprints* that describe the design of a house. These drawings include the design for an accelerator pedal. The pedal *hides* from the driver the complex mechanisms that actually make the car go faster, just as the brake pedal hides the mechanisms that slow the car, and the steering wheel hides the mechanisms that turn the car. This enables people with little or no knowledge of how engines, braking and steering mechanisms work to drive a car easily.

Before you can drive a car, it must be *built* from the engineering drawings that describe it. A completed car has an *actual* accelerator pedal to make the car go faster, but even that's not enough—the car won't accelerate on its own (we hope), so the driver must *press* the pedal to accelerate the car.

### *Methods and Classes*

Let's use our car example to introduce some key object-oriented programming concepts. Performing a task in a program requires a **method**. The method houses the program state-

ments that actually perform the task. It *hides* these statements from its user, just as a car's accelerator pedal hides from the driver the mechanisms of making the car go faster. In object-oriented programming languages, we create a program unit called a **class** to house the set of methods that perform the class's tasks. For example, a class that represents a bank account might contain one method to *deposit* money to an account, another to *withdraw* money from an account and a third to *inquire* what the account's current balance is. A class that represents a car might contain methods for accelerating, braking and turning. A class is similar in concept to a car's engineering drawings, which house the design of an accelerator pedal, steering wheel, and so on.

### **Making Objects from Classes**

Just as someone has to *build a car* from its engineering drawings before you can actually drive a car, you must *build an object* from a class before a program can perform the tasks that the class's methods define. The process of doing this is called *instantiation*. An object is then referred to as an **instance** of its class.

### **Reuse**

Just as a car's engineering drawings can be *reused* many times to build many cars, you can *reuse* a class many times to build many objects. Reuse of existing classes when building new classes and programs saves time and effort. Reuse also helps you build more reliable and effective systems, because existing classes and components often have gone through extensive *testing* (to locate problems), *debugging* (to correct those problems) and *performance tuning*. Just as the notion of *interchangeable parts* was crucial to the Industrial Revolution, reusable classes are crucial to the software revolution that's been spurred by object technology.



### **Software Engineering Observation 1.1**

*Use a building-block approach to creating your programs. Avoid reinventing the wheel—use existing pieces wherever possible. This software reuse is a key benefit of object-oriented programming.*

### **Messages and Method Calls**

When you drive a car, pressing its gas pedal sends a *message* to the car to perform a task—that is, to go faster. Similarly, you *send messages to an object*. Each message is implemented as a **method call** that tells a method of the object to perform its task. For example, a program might call a particular bank-account object's *deposit* method to increase the account's balance.

### **Attributes and Instance Variables**

A car, besides having capabilities to accomplish tasks, also has *attributes*, such as its color, its number of doors, the amount of gas in its tank, its current speed and its record of total miles driven (i.e., its odometer reading). Like its capabilities, the car's attributes are represented as part of its design in its engineering diagrams (which, for example, include an odometer and a fuel gauge). As you drive an actual car, these attributes are carried along with the car. Every car maintains its *own* attributes. For example, each car knows how much gas is in its own gas tank, but *not* how much is in the tanks of *other* cars.

An object, similarly, has attributes that it carries along as it's used in a program. These attributes are specified as part of the object's class. For example, a bank-account object has a *balance attribute* that represents the amount of money in the account. Each bank-

account object knows the balance in the account it represents, but *not* the balances of the *other* accounts in the bank. Attributes are specified by the class's **instance variables**.

### ***Encapsulation***

Classes **encapsulate** (i.e., wrap) attributes and methods into objects—an object's attributes and operations are intimately related. Objects may communicate with one another, but they're normally not allowed to know how other objects are implemented—implementation details are *hidden* within the objects themselves. This **information hiding**, as we'll see, is crucial to good software engineering.

### ***Inheritance***

A new class of objects can be created quickly and conveniently by **inheritance**—the new class absorbs the characteristics of an existing class, possibly customizing them and adding unique characteristics of its own. In our car analogy, an object of class “convertible” certainly *is an* object of the more *general* class “automobile,” but more *specifically*, the roof can be raised or lowered.

### ***Object-Oriented Analysis and Design (OOAD)***

Soon you'll be writing programs in C#. Perhaps, like many programmers, you'll simply turn on your computer and start typing. This approach may work for small programs (like the ones we present in the early chapters of this book), but what if you were asked to create a software system to control thousands of automated teller machines for a major bank? Or suppose you were assigned to work on a team of thousands of software developers building the next U.S. air traffic control system? For projects so large and complex, you should not simply sit down and start writing programs.

To create the best solutions, you should follow a detailed **analysis** process for determining your project's **requirements** (i.e., defining *what* the system is supposed to do) and developing a **design** that satisfies them (i.e., deciding *how* the system should do it). Ideally, you'd go through this process and carefully review the design (and have your design reviewed by other software professionals) before writing any code. If this process involves analyzing and designing your system from an object-oriented point of view, it's called an **object-oriented analysis and design (OOAD)** process. Languages like C# are object oriented. Programming in such a language, called **object-oriented programming (OOP)**, allows you to implement an object-oriented design as a working system.

### ***The UML (Unified Modeling Language)***

Though many different OOAD processes exist, a single graphical language for communicating the results of *any* OOAD process—known as the *Unified Modeling Language (UML)*—is now the most widely used graphical scheme for modeling object-oriented systems. We present our first simple UML diagrams in Chapters 4 and 5, then use them in our deeper treatment of object-oriented programming through Chapter 12. In our optional ATM Software Engineering Case Study in Chapters 34–35 we present a simple subset of the UML's features as we guide you through a simple object-oriented design experience.

## **1.7 Internet and World Wide Web**

In the late 1960s, ARPA—the Advanced Research Projects Agency of the United States Department of Defense—rolled out plans to network the main computer systems of approxi-

mately a dozen ARPA-funded universities and research institutions. The computers were to be connected with communications lines operating at a then-stunning 56 Kbps (1 Kbps is equal to 1,024 bits per second), at a time when most people (of the few who even had networking access) were connecting over telephone lines to computers at a rate of 110 bits per second. Academic research was about to take a giant leap forward. ARPA proceeded to implement what quickly became known as the ARPAnet, the precursor to today's **Internet**.

Things worked out differently from the original plan. Although the ARPAnet enabled researchers to network their computers, its main benefit proved to be the capability for quick and easy communication via what came to be known as electronic mail (e-mail). This is true even on today's Internet, with e-mail, instant messaging, file transfer and social media such as Facebook and Twitter, enabling billions of people worldwide to communicate quickly and easily.

The protocol (set of rules) for communicating over the ARPAnet became known as the **Transmission Control Protocol** (TCP). TCP ensured that messages, consisting of sequentially numbered pieces called *packets*, were properly routed from sender to receiver, arrived intact and were assembled in the correct order.

### *The Internet: A Network of Networks*

In parallel with the early evolution of the Internet, organizations worldwide were implementing their own networks for both intraorganization (that is, within an organization) and interorganization (that is, between organizations) communication. A huge variety of networking hardware and software appeared. One challenge was to enable these different networks to communicate with each other. ARPA accomplished this by developing the Internet Protocol (IP), which created a true "network of networks," the current architecture of the Internet. The combined set of protocols is now called **TCP/IP**.

Businesses rapidly realized that by using the Internet, they could improve their operations and offer new and better services to their clients. Companies started spending large amounts of money to develop and enhance their Internet presence. This generated fierce competition among communications carriers and hardware and software suppliers to meet the increased infrastructure demand. As a result, **bandwidth**—the information-carrying capacity of communications lines—on the Internet has increased tremendously, while hardware costs have plummeted.

### *The World Wide Web: Making the Internet User-Friendly*

The **World Wide Web** (simply called "the web") is a collection of hardware and software associated with the Internet that allows computer users to locate and view multimedia-based documents (documents with various combinations of text, graphics, animations, audios and videos) on almost any subject. The introduction of the web was a relatively recent event. In 1989, Tim Berners-Lee of CERN (the European Organization for Nuclear Research) began to develop a technology for sharing information via "hyperlinked" text documents. Berners-Lee called his invention the **HyperText Markup Language** (HTML). He also wrote communication protocols such as **HyperText Transfer Protocol** (HTTP) to form the backbone of his new hypertext information system, which he referred to as the **World Wide Web**.

In 1994, Berners-Lee founded an organization, called the **World Wide Web Consortium** (W3C, [www.w3.org](http://www.w3.org)), devoted to developing web technologies. One of the W3C's

primary goal is to make the web universally accessible to everyone regardless of disabilities, language or culture. In this book, you'll use C# and other Microsoft technologies to build web-based apps.

## 1.8 C#

In 2000, Microsoft announced the C# programming language. C# has roots in the C, C++ and Java programming languages. It has similar capabilities to Java and is appropriate for the most demanding app-development tasks, especially for building today's large-scale enterprise apps, and web-based, mobile and "cloud"-based apps.

### 1.8.1 Object-Oriented Programming

C# is *object oriented*—we've discussed the basics of object technology and will present a rich treatment of object-oriented programming throughout the book. C# has access to the powerful **.NET Framework Class Library**—a vast collection of prebuilt classes that enable you to develop apps quickly (Fig. 1.3). We'll say more about .NET in Section 1.9.

Some key capabilities in the .NET Framework Class Library	
Database	Debugging
Building web apps	Multithreading
Graphics	File processing
Input/output	Security
Computer networking	Web communication
Permissions	Graphical user interface
Mobile	Data structures
String processing	

**Fig. 1.3** | Some key capabilities in the .NET Framework Class Library.

### 1.8.2 Event-Driven Programming

C# is **event driven**. You'll write programs that respond to user-initiated **events** such as mouse clicks, keystrokes, timer expirations and—new in Visual C# 2012—*touches* and *finger swipes*—gestures that are widely used on smartphones and tablets.

### 1.8.3 Visual Programming

Microsoft's Visual C# is a *visual programming language*—in addition to writing program statements to build portions of your apps, you'll also use Visual Studio's graphical user interface (GUI) to conveniently drag and drop predefined objects like *buttons* and *textboxes* into place on your screen, and label and resize them. Visual Studio will write much of the GUI code for you.

### 1.8.4 An International Standard; Other C# Implementations

C# has been standardized internationally. This enables other implementations of the language besides Microsoft's Visual C#, such as Mono ([www.mono-project.com](http://www.mono-project.com)) that runs on

Linux systems, iOS (for Apple's iPhone, iPad and iPod touch), Google's Android and Windows. You can find the C# standard document at:

[www.ecma-international.org/publications/standards/Ecma-334.htm](http://www.ecma-international.org/publications/standards/Ecma-334.htm)

### 1.8.5 Internet and Web Programming

Today's apps can be written with the aim of communicating among the world's computers. As you'll see, this is the focus of Microsoft's .NET strategy. In Chapters 23, 29 and 30, you'll build web-based apps with C# and Microsoft's ASP.NET technology.

### 1.8.6 Introducing `async/await`

In most programming today, each task in a program must finish executing before the next task can begin. This is called *synchronous programming* and is the style we use for most of this book. C# also allows *asynchronous programming* in which multiple tasks can be performed at the *same* time. Asynchronous programming can help you make your apps more responsive to user interactions, such as mouse clicks and keystrokes, among many other uses.

Asynchronous programming in previous versions of Visual C# was difficult and error prone. Visual C# 2012's new `async` and `await` capabilities simplify asynchronous programming, because the compiler hides much of the associated complexity from the developer. In Chapter 28, we'll provide a brief introduction to asynchronous programming with `async` and `await`.

### 1.8.7 Other Key Contemporary Programming Languages

Figure 1.4 summarizes some popular programming languages with features comparable to those of C#.

Programming language	Description
C	C was implemented in 1972 by Dennis Ritchie at Bell Laboratories. It initially became widely known as the UNIX operating system's development language. Today, most of the code for general-purpose operating systems is written in C or C++.
C++	C++, an extension of C, was developed by Bjarne Stroustrup in the early 1980s at Bell Laboratories. C++ provides several features that "spruce up" the C language, but more important, it provides capabilities for <i>object-oriented programming</i> . It's often used in apps with stringent performance requirements such as operating systems, real-time systems, embedded systems and communications systems. Visual C++ is Microsoft's version of the language.

**Fig. 1.4** | Other programming languages. (Part 1 of 2.)

Programming language	Description
Java	In the 1990s, Sun Microsystems (now part of Oracle) developed the C++-based object-oriented programming language called Java. A key goal of Java is to be able to write programs that will run on a great variety of computer systems and computer-control devices—this is sometimes called <i>write once, run anywhere</i> . Java is used to develop large-scale enterprise apps, to enhance the functionality of web servers (the computers that provide the content we see in our web browsers), to provide apps for consumer devices (e.g., smartphones, tablets, television set-top boxes, appliances, automobiles and more) and for many other purposes. Microsoft developed C# as a competitive language to Java.
Visual Basic	Visual Basic evolved from BASIC, developed in the 1960s at Dartmouth College for introducing novices to fundamental programming techniques. When Bill Gates founded Microsoft in the 1970s, he implemented BASIC on several early personal computers. In the late 1980s and the early 1990s, Microsoft developed the Microsoft Windows <b>graphical user interface (GUI)</b> —the <i>visual</i> part of the operating system with which users interact. With the creation of the Windows GUI, the natural evolution of BASIC was to <b>Visual Basic</b> , introduced by Microsoft in 1991 to make programming Windows apps easier. The latest versions of Visual Basic have capabilities comparable to those of C#.
Objective-C	Objective-C is another object-oriented language based on C. It was developed at Stepstone in the early 1980s and later acquired by NeXT, which in turn was acquired by Apple. It has become the key programming language for the Mac OS X desktop operating system and all iOS-based devices, such as iPods, iPhones and iPads.

**Fig. 1.4** | Other programming languages. (Part 2 of 2.)

## 1.9 Microsoft's .NET

In 2000, Microsoft announced its **.NET initiative** ([www.microsoft.com/net](http://www.microsoft.com/net)), a broad vision for using the Internet and the web in the development, engineering, distribution and use of software. Rather than forcing you to use a single programming language, .NET permits you to create apps in *any* .NET-compatible language (such as C#, Visual Basic, Visual C++ and many others). Part of the initiative includes Microsoft's ASP.NET technology.

### 1.9.1 .NET Framework

The **.NET Framework** executes apps and contains the **.NET Framework Class Library**, which provides many capabilities that you'll use to build substantial C# apps quickly and easily. The .NET Framework Class Library has *thousands* of valuable *prebuilt* classes that have been tested and tuned to maximize performance. You'll learn how to create your own

classes, but you should *re-use* the .NET Framework classes whenever possible to speed up the software development process, while enhancing the quality and performance of the software you develop.

### 1.9.2 Common Language Runtime

The **Common Language Runtime** (CLR), another key part of the .NET Framework, executes .NET programs and provides functionality to make them easier to develop and debug. The CLR is a **virtual machine** (VM)—software that manages the execution of programs and hides from them the underlying operating system and hardware. The source code for programs that are executed and managed by the CLR is called *managed code*. The CLR provides various services to managed code, such as integrating software components written in different .NET languages, error handling between such components, enhanced security, automatic memory management and more. Unmanaged-code programs do not have access to the CLR’s services, which makes unmanaged code more difficult to write.<sup>5</sup> Managed code is compiled into machine-specific instructions in the following steps:

1. First, the code is compiled into **Microsoft Intermediate Language** (MSIL). Code converted into MSIL from other languages and sources can be woven together by the CLR—this allows programmers to work in their preferred .NET programming language. The MSIL for an app’s components is placed into the app’s *executable file*—the file that causes the computer to perform the app’s tasks.
2. When the app executes, another compiler (known as the **just-in-time compiler** or **JIT compiler**) in the CLR translates the MSIL in the executable file into machine-language code (for a particular platform).
3. The machine-language code executes on that platform.

### 1.9.3 Platform Independence

If the .NET Framework exists and is installed for a platform, that platform can run *any* .NET program. The ability of a program to run without modification across multiple platforms is known as **platform independence**. Code written once can be used on another type of computer without modification, saving time and money. In addition, software can target a wider audience. Previously, companies had to decide whether converting their programs to different platforms—a process called **porting**—was worth the cost. With .NET, porting programs is no longer an issue, at least once .NET itself has been made available on the platforms.

### 1.9.4 Language Interoperability

The .NET Framework provides a high level of **language interoperability**. Because software components written in different .NET languages (such as C# and Visual Basic) are all compiled into MSIL, the components can be combined to create a single unified program. Thus, MSIL allows the .NET Framework to be **language independent**.

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5. [msdn.microsoft.com/en-us/library/8bs2ecf4.aspx](http://msdn.microsoft.com/en-us/library/8bs2ecf4.aspx).

The .NET Framework Class Library can be used by any .NET language. .NET 4.5, which was released in 2012, includes several improvements and new features to make your apps faster and more responsive. It also features .NET for Windows Store Apps—a subset of .NET that's used to create Windows 8 UI (user interface) style apps.

## 1.10 Microsoft's Windows® Operating System

Microsoft's Windows is the most widely used desktop operating system worldwide. **Operating systems** are software systems that make using computers more convenient for users, developers and system administrators. They provide *services* that allow each app to execute safely, efficiently and *concurrently* (i.e., in parallel) with other apps. Other popular desktop operating systems include Linux and Mac OS X. Popular *mobile operating systems* used in smartphones and tablets include Microsoft's Windows Phone, Google's Android, Apple's iOS (for iPhone, iPad and iPod Touch devices) and BlackBerry OS. Figure 1.5 presents the evolution of the Windows operating system.

Version	Description
Windows in the 1990s	In the mid-1980s, Microsoft developed the <b>Windows operating system</b> based on a graphical user interface with buttons, textboxes, menus and other graphical elements. The various versions released throughout the 1990s were intended for personal computing. Microsoft entered the corporate operating systems market with the 1993 release of <i>Windows NT</i> .
Windows XP and Windows Vista	<i>Windows XP</i> was released in 2001 and combined Microsoft's corporate and consumer operating system lines. It remains popular today—according to a 2012 Netmarketshare study, it's used on more than 40% of Windows computers ( <a href="http://netmarketshare.com/operating-system-market-share.aspx?qprid=10&amp;qpcustomd=0">netmarketshare.com/operating-system-market-share.aspx?qprid=10&amp;qpcustomd=0</a> ). <i>Windows Vista</i> , released in 2007, offered the attractive new Aero user interface, many powerful enhancements and new apps and enhanced security. But Vista never caught on—today, it has “only” six percent of the total desktop operating systems market share (that's still a pretty significant number; <a href="http://netmarketshare.com/operating-system-market-share.aspx?qprid=10&amp;qpcustomd=0">netmarketshare.com/operating-system-market-share.aspx?qprid=10&amp;qpcustomd=0</a> ).
Windows 7	<i>Windows 7</i> , now the most widely used version of Windows, includes enhancements to the Aero user interface, faster startup times, further refinement of Vista's security features, touch-screen with multi-touch support, and more. Windows 7 had a 44% market share, and overall, Windows (including Windows 7, Windows XP and Windows Vista) had over 90% of the desktop operating system market share worldwide ( <a href="http://netmarketshare.com/operating-system-market-share.aspx?qprid=10&amp;qpcustomd=0">netmarketshare.com/operating-system-market-share.aspx?qprid=10&amp;qpcustomd=0</a> ). The core chapters of this book use Windows 7, Visual Studio 2012 and Visual C# 2012.

**Fig. 1.5** | The evolution of the Windows operating system. (Part 1 of 2.)

Version	Description
Windows 8 for Desktops and Tablets	<p><b>Windows 8</b>, released in 2012 provides a similar platform (the underlying system on which apps run) and <i>user experience</i> across a wide range of devices including personal computers, smartphones, tablets and the Xbox Live online game service. The new look-and-feel features a Start screen with <i>tiles</i> that represent each app, similar to that of <i>Windows Phone</i>—Microsoft’s operating system for smartphones. Windows 8 features <i>multi-touch</i> support for <i>touch-pads</i> and <i>touchscreen</i> devices, enhanced security features and more.</p>
Windows 8 UI (User Interface)	<p>Visual C# 2012 supports the new Windows 8 UI (previously called “Metro”) which has a clean look-and-feel with minimal distractions to the user. Windows 8 apps feature a <i>chromeless window</i>—there’s no longer a border around the window with the typical interface elements such as title bars and menus. These elements are <i>hidden</i>, allowing apps to fill the <i>entire</i> screen, which is particularly helpful on smaller screens such as tablets and smartphones. The interface elements are displayed in the <i>app bar</i> when the user <i>swipes</i> the top or bottom of the screen by holding down the mouse button, moving the mouse in the swipe direction and releasing the mouse button; this can be done with a <i>finger swipe</i> on a touchscreen device. We discuss Windows 8 and the Windows 8 UI in Chapter 25 and Windows Phone 8 in Chapter 27.</p>

**Fig. 1.5** | The evolution of the Windows operating system. (Part 2 of 2.)

### Windows Store

You can sell Windows 8 UI desktop and tablet apps or offer them for free in the Windows Store. The fee to become a registered Windows Store developer is \$49 for individuals and \$99 for companies, however the fee is waived for Microsoft DreamSpark program students (see the Preface). For Windows 8 UI apps, Microsoft retains 30% of the purchase price and distributes 70% to you, up to \$25,000. If revenues for your app exceed that amount, Microsoft will retain 20% of the purchase price and distribute 80% to you.

The Windows Store offers several business models for monetizing your app. You can charge the full price for your app before download, with prices starting at \$1.49. You can also offer a time-limited trial or feature-limited trial that allows users to try the app before purchasing the full version, sell virtual goods (such as additional app features) using in-app purchases and more. To learn more about the Windows Store and monetizing your apps, visit [msdn.microsoft.com/en-us/library/windows/apps/bb229519.aspx](http://msdn.microsoft.com/en-us/library/windows/apps/bb229519.aspx).

## 1.11 Windows Phone 8 for Smartphones

**Windows Phone 8** is a pared down version of Windows 8 designed for *smartphones*. These are *resource-constrained devices*—they have less memory and processor power than desktop computers, and limited battery life. Windows Phone 8 has the *same* core operating systems services as Windows 8, including a common file system, security, networking, media and Internet Explorer 10 (IE10) web browser technology. However, Windows Phone 8 has

only the features necessary for smartphones, allowing them to run efficiently, minimizing the burden on the device's resources.

New to this edition of the book, you'll use Visual C# 2012 to develop your own Windows Phone 8 apps. Just as the Objective-C programming language has increased in popularity due to iOS app development for iPhone, iPad and iPod touch, Visual C# 2012 is sure to become even more popular as the demand for Windows Phones increases. International Data Corporation (IDC) predicts that Windows Phone will have over 19% of the smartphone market share by 2016, second only to Android and ahead of Apple's iPhone.<sup>6</sup> You'll learn how to develop Windows Phone apps in Chapter 27.

### 1.11.1 Selling Your Apps in the Windows Phone Marketplace

You can sell your own Windows Phone apps in the Windows Phone Marketplace ([www.windowsphone.com/marketplace](http://www.windowsphone.com/marketplace)), similar to other app commerce platforms such as Apple's App Store, Google Play (formerly Android Market), Facebook's App Center and the Windows Store. You can also earn money by making your apps free for download and selling *virtual goods* (e.g., additional content, game levels, e-gifts and add-on features) using *in-app purchase*.

### 1.11.2 Free vs. Paid Apps

A recent study by Gartner found that 89% of all mobile apps are free, and that number is likely to increase to 93% by 2016, at which point in-app purchases will account for over 40% of mobile app revenues.<sup>7</sup> Paid Windows Phone 8 apps range in price from \$1.49 (which is higher than the \$0.99 starting price for apps in Google Play and Apple's App Store) to \$999.99. The average price for mobile apps is approximately \$1.50 to \$3, depending on the platform. For Windows Phone apps, Microsoft retains 30% of the purchase price and distributes 70% to you. At the time of this writing, there were over 100,000 apps in the Windows Phone Marketplace.<sup>8</sup>

### 1.11.3 Testing Your Windows Phone Apps

You can test your phone apps on the Windows Phone Emulator that Microsoft provides with the Windows Phone 8 SDK (software development kit). To test your apps on a Windows phone and to sell your apps or distribute your free apps through the Windows Phone Marketplace, you'll need to join the *Windows Phone Dev Center*. There's an annual fee of \$99; the program is *free* to DreamSpark students (for more information about DreamSpark, see the Preface) and to MSDN subscribers. The website includes development tools, sample code, tips for selling your apps, design guidelines and more. To join the Windows Phone Dev Center and submit apps, visit [dev.windowsphone.com/en-us/downloadsdk](http://dev.windowsphone.com/en-us/downloadsdk).

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6. [www.idc.com/getdoc.jsp?containerId=prUS23523812](http://www.idc.com/getdoc.jsp?containerId=prUS23523812).

7. [techcrunch.com/2012/09/11/free-apps/](http://techcrunch.com/2012/09/11/free-apps/).

8. [windowsteamblog.com/windows\\_phone/b/windowsphone/archive/2012/06/20/announcing-windows-phone-8.aspx](http://windowsteamblog.com/windows_phone/b/windowsphone/archive/2012/06/20/announcing-windows-phone-8.aspx).

## 1.12 Windows Azure™ and Cloud Computing

Cloud computing allows you to use software and data stored in the “cloud”—i.e., accessed on remote computers (or servers) via the Internet and available on demand—rather than having it stored on your desktop, notebook computer or mobile device. Cloud computing gives you the flexibility to increase or decrease computing resources to meet your resource needs at any given time, making it more cost effective than purchasing expensive hardware to ensure that you have enough storage and processing power at their occasional peak levels. Using cloud computing services also saves money by shifting the burden of *managing* these apps to the service provider. New to this edition of the book, in Chapter 31 you’ll use Microsoft’s **Windows Azure**—a cloud computing platform that allows you to develop, manage and distribute your apps in the cloud. With Windows Azure, your apps can store their data in the cloud so that the data is available at all times from any of your desktop computer and mobile devices. Verified DreamSpark students can download Visual Studio 2012 Professional which includes built-in support for Windows 8 and Windows Azure.<sup>9</sup> You can sign up for a free 90-day trial of Windows Azure at [www.windowsazure.com/en-us/pricing/free-trial/](http://www.windowsazure.com/en-us/pricing/free-trial/).

## 1.13 Visual Studio Express 2012 Integrated Development Environment

C# programs are created using Microsoft’s Visual Studio—a collection of software tools called an **Integrated Development Environment (IDE)**. The **Visual Studio 2012 Express** IDE enables you to *write, run, test and debug* C# programs quickly and conveniently. It also supports Microsoft’s Visual Basic, Visual C++ and F# programming languages. Most of this book’s examples were built using *Visual Studio Express 2012 for Windows Desktop*, which runs on both Windows 7 and Windows 8. The Windows 8 UI and Windows 8 Graphics and Multimedia chapters require *Visual Studio Express 2012 for Windows 8*.

## 1.14 Painter Test-Drive in Visual Studio Express 2012 for Windows Desktop

[*Note:* This test-drive can be performed on a computer running either Windows 7 or Windows 8. The steps shown here are for Windows 7. We discuss running an app on Windows 8 in Section 1.15.]

You’ll now use *Visual Studio Express 2012 for Windows Desktop* to “test-drive” an existing app that enables you to draw on the screen using the mouse. The **Painter** app—which you’ll build in a later chapter—allows you to choose among several brush sizes and colors. The elements and functionality you see in this app are typical of what you’ll learn to program in this text. The following steps walk you through test-driving the app.

### Step 1: Checking Your Setup

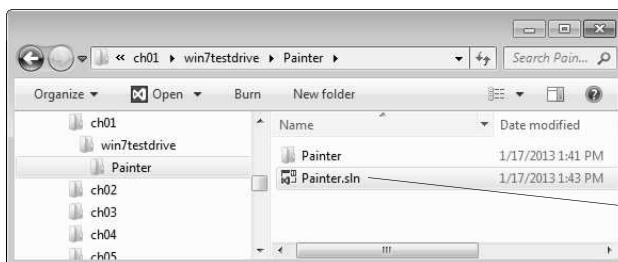
Confirm that you’ve set up your computer and the software properly by reading the book’s Before You Begin section that follows the Preface.

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9. [www.dreamspark.com/Product/Product.aspx?productid=44](http://www.dreamspark.com/Product/Product.aspx?productid=44).

### Step 2: Locating the Painter App's Directory

Open a Windows Explorer window and navigate to `C:\examples\ch01\win7testdrive`. (We assume you placed the examples in the `C:\examples` folder.) Double click the Painter folder to view its contents (Fig. 1.6), then double click the `Painter.sln` file to open the app's solution in Visual Studio. An app's *solution* contains all of the app's *code files*, *supporting files* (such as *images*, *videos*, *data files*, etc.) and configuration information. We'll discuss the contents of a solution in more detail in the next chapter.



Double click `Painter.sln` to open the project in Visual Studio

**Fig. 1.6** | Contents of `C:\examples\ch01\win7testdrive\Painter`.

Depending on your system configuration, Windows Explorer might not display file name extensions. To display them (like `.sln` in Fig. 1.6):

1. In Windows Explorer, type `Alt + t` to display the **Tools** menu, then select **Folder options....**
2. Select the **View** tab in the **Folder Options** dialog.
3. Locate the checkbox **Hide extensions for known file types** and ensure that it's un-checked.
4. Click **OK** to dismiss the **Folder Options** dialog.

### Step 3: Running the Painter App

To see the running Painter app, click the **Start** (▶) button (Fig. 1.7) or press the *F5* key. Figure 1.8 shows the executing app.

Figure 1.8 labels several of the app's graphical elements—called **controls**. These include **GroupBoxes**, **RadioButtons**, **Buttons** and a **Panel**. These controls and many others are discussed throughout the text. The app allows you to draw with a **Black**, **Red**, **Blue** or **Green** brush of **Small**, **Medium** or **Large** size. As you drag the mouse on the white **Panel**, the app draws circles of the specified color and size at the mouse pointer's current position. The slower you drag the mouse, the closer the circles will be. Thus, dragging slowly draws a continuous line (as in Fig. 1.9) and dragging quickly draws individual circles with space in between. You can also **Undo** your previous operation or **Clear** the drawing to start from scratch by pressing the **Buttons** below the **RadioButtons** in the GUI. By using existing *controls*—which are *objects*—you can create powerful apps much faster than if you had to write all the code yourself. This is a key benefit of *software reuse*.

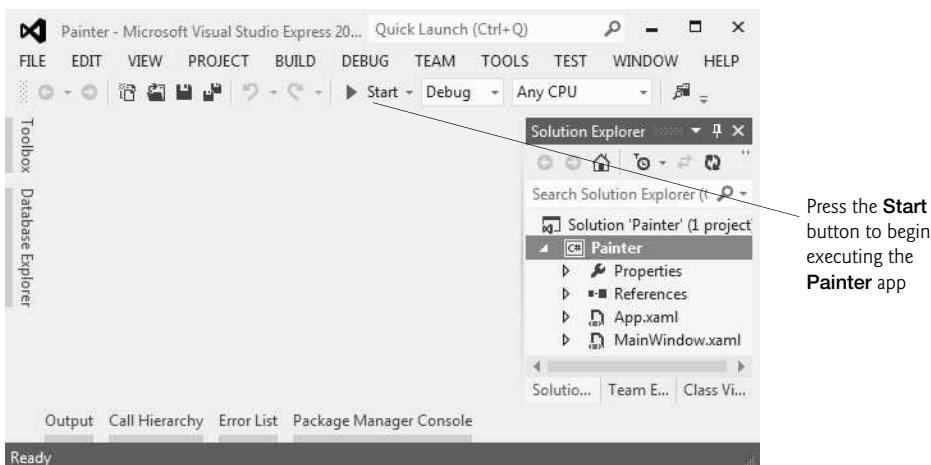


Fig. 1.7 | Running the Painter app.

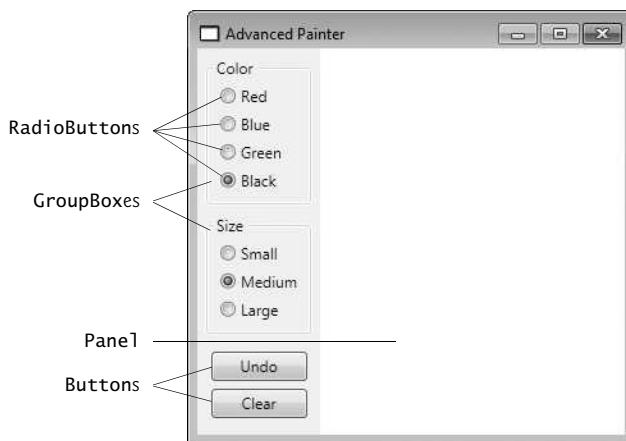
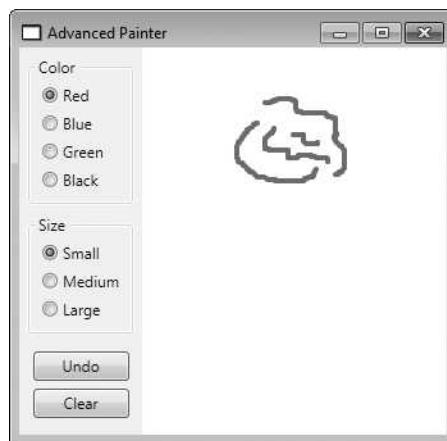


Fig. 1.8 | Painter app running in Windows 7.

The brush's properties, selected in the RadioButtons labeled **Black** and **Medium**, are *default settings*—the initial settings you see when you first run the app. Programmers include default settings to provide *reasonable* choices that the app will use if the user *does not* change the settings. Default settings also provide visual cues for users to choose their own settings. Now you'll choose your own settings as a user of this app.

#### Step 4: Changing the Brush Color

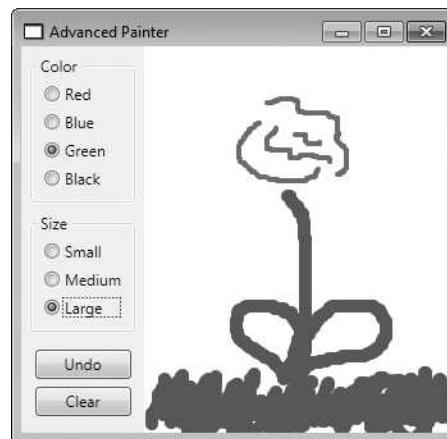
Click the RadioButton labeled **Red** to change the brush color, then click the RadioButton labeled **Small** to change the brush size. Position the mouse over the white Panel, then drag the mouse to draw with the brush. Draw flower petals, as shown in Fig. 1.9.



**Fig. 1.9** | Drawing flower petals with a small red brush.

#### *Step 5: Changing the Brush Color and Size*

Click the **Green** RadioButton to change the brush color. Then, click the **Large** RadioButton to change the brush size. Draw grass and a flower stem, as shown in Fig. 1.10.



**Fig. 1.10** | Drawing the flower stem and grass with a large green brush.

#### *Step 6: Finishing the Drawing*

Click the **Blue** and **Medium** RadioButtons. Draw raindrops, as shown in Fig. 1.11, to complete the drawing.

#### *Step 7: Stopping the App*

When you run an app from Visual Studio, you can terminate it by clicking the stop button (■) on the Visual Studio toolbar or by clicking the close box (☒) on the running app's window.



**Fig. 1.11** | Drawing rain drops with a medium blue brush.

Now that you've completed the test-drive, you're ready to begin developing C# apps. In Chapter 2, Dive Into® Visual Studio, you'll use Visual Studio to create your first C# program using *visual programming* techniques. As you'll see, Visual Studio will generate for you the code that builds the app's GUI. In Chapter 3, Introduction to C# Apps, you'll begin writing C# programs containing conventional program code that you write.

## 1.15 Painter Test-Drive in Visual Studio Express 2012 for Windows 8

[*Note:* This test-drive can be performed *only* on a computer running Windows 8.] You'll now use Visual Studio to "test-drive" an existing Windows 8 UI app that enables you to draw on the screen using the mouse. The **Painter** app—which you'll build in a later chapter—allows you to choose among several brush sizes and colors. The elements and functionality you see in this app are typical of what you'll learn to program in this text. The following steps walk you through test-driving the app.

### *Step 1: Checking Your Setup*

Confirm that you've set up your computer and the software properly by reading the book's Before You Begin section that follows the Preface.

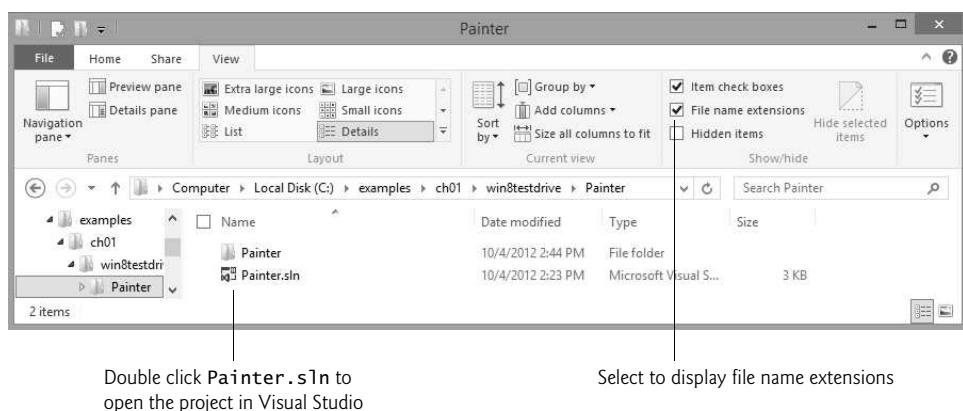
### *Step 2: Switching to the Windows 8 Desktop*

Click the **Desktop** tile in the Windows 8 Start screen to switch to the desktop.

### *Step 3: Locating the Painter App's Directory*

Click the **File Explorer** (Explorer icon) in the task bar to open a **File Explorer** window, then locate the `C:\examples\ch01\win8testdrive` folder. (We assume you placed the examples in the `C:\examples` folder.) Double click the **Painter** folder to view its contents (Fig. 1.12), then double click the **Painter.sln** file to open the app's solution in Visual Studio. An app's *solution* contains all of the app's *code files, supporting files* (such as *images, videos, data*

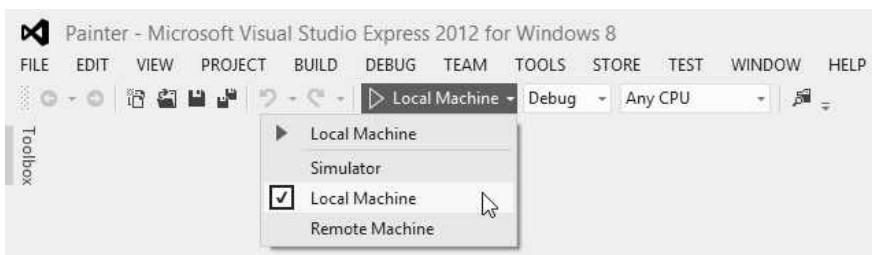
*files*, etc.) and configuration information. We'll discuss the contents of a solution in more detail in the next chapter. [Note: Depending on your system configuration, the **File Explorer** window might not display file name extensions. To display file name extensions (like `.sln` in Fig. 1.12), click the **View** tab in the **File Explorer** window, then ensure that **File name extensions** is selected.]



**Fig. 1.12** | Contents of `C:\examples\ch01\win8testdrive\Painter`.

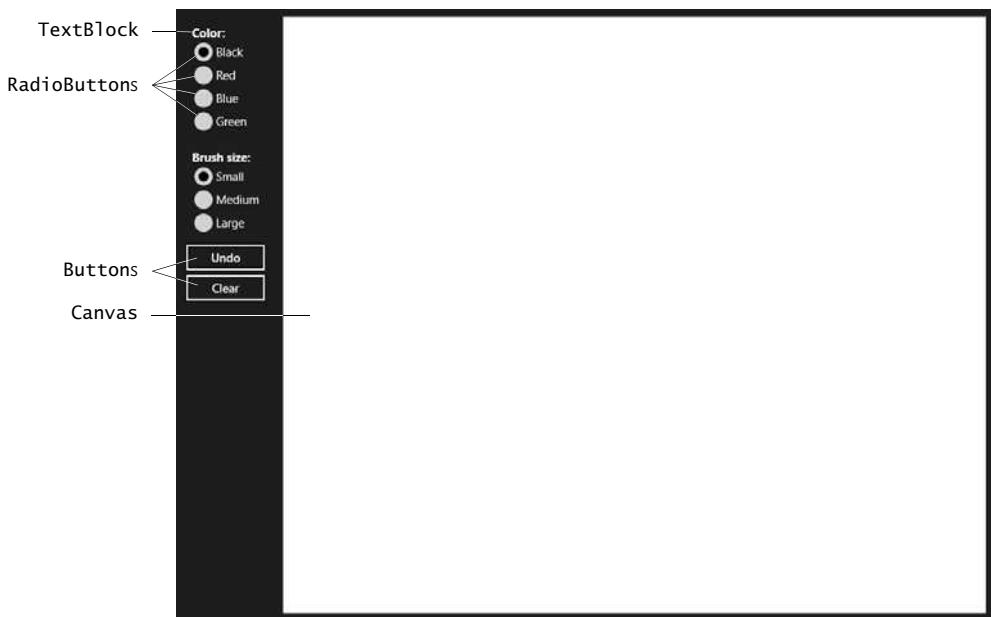
#### Step 4: Running the Painter App

Windows 8 UI apps normally occupy the *full* screen, though you can also *snap* apps to a 320-pixel-wide area at the left or right of the screen to see two apps side-by-side. To see the running Painter app, you can install it on the Windows 8 **Start** screen and execute it by selecting **Local Machine** (Fig. 1.13) then clicking the **Start Debugging** (▶) button or pressing the *F5* key. Once you install the app on the **Start** screen, you can also run it by clicking its **Start** screen tile. Figure 1.14 shows the executing app. Later chapters will discuss the **Simulator** and **Remote Machine** options shown in Fig. 1.13 for running apps.



**Fig. 1.13** | Selecting the **Local Machine** for running the Painter app.

Figure 1.14 labels several of the app's graphical elements—called **controls**. These include **TextBlocks**, **RadioButtons**, **Buttons** and a **Canvas**. These controls and many others are discussed throughout the text. The app allows you to draw with a **Black**, **Red**,



**Fig. 1.14 | Painter** app running in Windows 8.

Blue or Green brush of Small, Medium or Large size. As you drag the mouse on the white Canvas (an object used for drawing), the app draws circles of the specified color and size at the mouse pointer's current position. The slower you drag the mouse, the closer the circles will be. Thus, dragging slowly draws a continuous line (as in Fig. 1.15) and dragging quickly draws individual circles with space in between (as you can see with some of the rain drops in Fig. 1.17). You can also Undo your previous operation or Clear the drawing to start from scratch by pressing the Buttons below the RadioButtons in the GUI. By using existing *controls*—which are *objects*—you can create powerful apps much faster than if you had to write all the code yourself. This is a key benefit of *software reuse*.

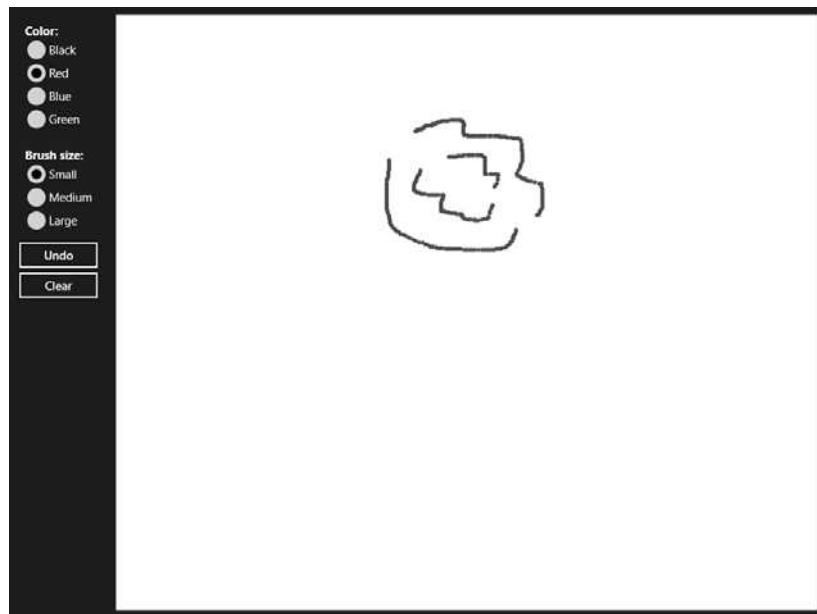
The brush's properties, selected in the RadioButtons labeled Black and Small, are *default settings*—the initial settings you see when you first run the app. Programmers include default settings to provide *reasonable* choices that the app will use if the user *does not* change the settings. Default settings also provide visual cues for users to choose their own settings. Now you'll choose your own settings as a user of this app.

#### **Step 5: Changing the Brush Color**

Click the RadioButton labeled Red to change the brush color. Position the mouse over the white Canvas, then drag the mouse to draw with the brush. Draw flower petals, as shown in Fig. 1.15.

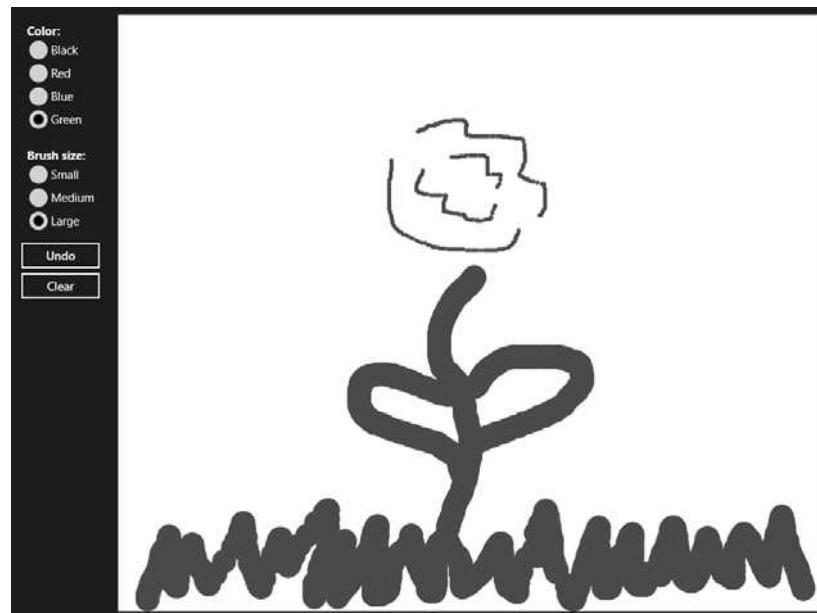
#### **Step 6: Changing the Brush Color and Size**

Click the RadioButton labeled Green to change the brush color again. Then, click the RadioButton labeled Large to change the brush size. Draw grass and a flower stem, as shown in Fig. 1.16.



**Fig. 1.15** | Drawing flower petals with a small red brush.

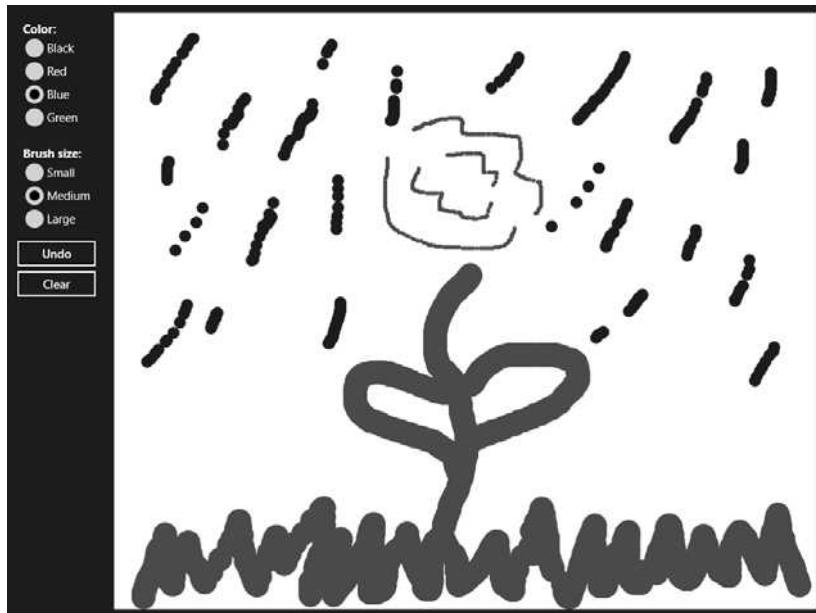
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**Fig. 1.16** | Drawing the flower stem and grass with a large green brush.

**Step 7: Finishing the Drawing**

Click the Blue and Medium RadioButtons. Draw raindrops, as shown in Fig. 1.17, to complete the drawing.



**Fig. 1.17** | Drawing rain drops with a medium blue brush.

**Step 8: Stopping the App**

When you run an app from Visual Studio, you can terminate it by clicking the stop button (■) on the Visual Studio toolbar. Typically, when you're done using a Windows 8 UI app like Painter, you don't terminate the app. Instead you simply run another app. Windows 8 suspends the execution of the previous app you were running, but keeps it in memory in case you decide to *return* to the app. Windows may decide to terminate a suspended app to free up memory for executing other apps. To explicitly shut down a Windows 8 UI app, simply drag from the top of the screen to the bottom or press *Alt + F4*.

Now that you've completed the test-drive, you're ready to begin developing C# apps. In Chapter 2, Dive Into® Visual Studio, you'll use Visual Studio to create your first C# program using *visual programming* techniques. As you'll see, Visual Studio will generate for you the code that builds the app's GUI. In Chapter 3, Introduction to C# Apps, you'll begin writing C# programs containing conventional program code that you write.

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**Self-Review Exercises**

- 1.1** Fill in the blanks in each of the following statements:
- Computers process data under the control of sequences of instructions called \_\_\_\_\_.

- b) A computer consists of various devices referred to as \_\_\_\_\_, such as the keyboard, screen, mouse, hard disks, memory, DVD drives and processing units.
- c) Data items processed by computers form a(n) \_\_\_\_\_ that becomes larger and more complex in structure as we progress from the simplest data items (called “bits”) to richer data items, such as characters, fields, and so on.
- d) Computers can directly understand only their \_\_\_\_\_ language, which is composed only of 1s and 0s.
- e) The three types of computer programming languages discussed in the chapter are machine languages, \_\_\_\_\_ and \_\_\_\_\_.
- f) Programs that translate high-level-language programs into machine language are called \_\_\_\_\_.
- g) A(n) \_\_\_\_\_ processor implements several processors on a single “microchip”—a dual-core processor has two CPUs and a quad-core processor has four CPUs.

**I.2** Fill in the blanks in each of the following statements:

- a) Objects, or more precisely the \_\_\_\_\_ that objects come from, are essentially reusable software components.
- b) You send messages to an object. Each message is implemented as a method that tells a method of the object to perform its task.
- c) A new class of objects can be created quickly and conveniently by \_\_\_\_\_; the new class absorbs the characteristics of an existing class, possibly customizing them and adding unique characteristics of its own.
- d) To create the best solutions, you should follow a detailed analysis process for determining your project’s \_\_\_\_\_ (i.e., defining what the system is supposed to do) and developing a design that satisfies them (i.e., deciding how the system should do it).
- e) Visual C# 2012 is \_\_\_\_\_ driven. You’ll write programs that respond to mouse clicks, keystrokes, timer expirations and—new in Visual C# 2012—touches and finger swipes.
- f) Microsoft’s Visual C# is a(n) \_\_\_\_\_ programming language—in addition to writing program statements to build portions of your apps, you’ll also use Visual Studio’s graphical user interface (GUI) to conveniently drag and drop predefined objects like buttons and textboxes into place on your screen, and label and resize them.
- g) C++ provides several features that “spruce up” the C language, but more important, it provides capabilities for \_\_\_\_\_-oriented programming.
- h) A key goal of Java is to be able to write programs that will run on a great variety of computer systems and computer-control devices. This is sometimes called \_\_\_\_\_ .

**I.3** Fill in the blanks in each of the following statements:

- a) The \_\_\_\_\_ executes .NET programs.
- b) The CLR provides various services to \_\_\_\_\_ code, such as integrating software components written in different .NET languages, error handling between such components, enhanced security and more.
- c) The ability of a program to run without modification across multiple platforms is known as platform \_\_\_\_\_ .
- d) Visual Studio is a(n) \_\_\_\_\_ in which C# programs are developed.
- e) The new Windows 8 look-and-feel features a Start screen with \_\_\_\_\_ that represent each app, is similar to that of *Windows Phone*—a Microsoft operating system for smartphones.
- f) Windows 8 apps feature a(n) \_\_\_\_\_ window; there’s no longer a border around the window with the typical interface elements such as title bars and menus.
- g) You can sell your own Windows Phone apps in the \_\_\_\_\_ .
- h) You can test your phone apps on the Windows Phone \_\_\_\_\_ that Microsoft provides with the Windows Phone SDK (software development kit).

**1.4**

- State whether each of the following is *true* or *false*. If *false*, explain why.
- a) Software objects model both abstract and real-world things.
  - b) The most popular database model is the *relational database* in which data is stored in simple *tables*. A table includes *records* and *fields*.
  - c) A database is a collection of data that's organized for easy access and manipulation.
  - d) Secondary storage data takes much longer to access than data in primary memory, but the cost per unit of secondary storage is much higher than that of primary memory.
  - e) High-level languages allow you to write instructions that look almost like everyday English and contain commonly used mathematical expressions.
  - f) An object has attributes that it carries along as it's used in a program.
  - g) The Transmission Control Protocol (TCP) ensures that messages, consisting of sequentially numbered pieces called bytes, were properly routed from sender to receiver, arrived intact and were assembled in the correct order.
  - h) The information-carrying capacity of communications lines on the Internet has increased tremendously, while hardware costs have increased.
  - i) You can build web-based apps with C# and Microsoft's ASP.NET technology.
  - j) Java has become the key programming language for the Mac OS X desktop operating system and all iOS-based devices, such as iPods, iPhones and iPads.
  - k) Microsoft's ASP.WEB technology is used to create web apps.
  - l) Microsoft's Windows operating system is the most widely used desktop operating system worldwide.
  - m) Windows 8 is designed for resource-constrained devices that have less memory and processor power than desktop computers, and limited battery life.
  - n) Visual C# 2012 also can be used to develop Windows Phone 8 apps. Visual C# 2012 is sure to become even more popular as the demand for Windows Phones increases.

**1.5**

Arrange these byte measurements in order from smallest to largest: terabyte, megabyte, petabyte, gigabyte and kilobyte.

**1.6**

Describe the two-step translation process for preparing your C# code to execute on your particular computer.

**1.7**

Why might Windows terminate a suspended app?

## Answers to Self-Review Exercises

**1.1**    a) computer programs. b) hardware. c) data hierarchy. d) machine. e) assembly languages, high-level languages. f) compilers. g) multi-core.

**1.2**    a) classes. b) call. c) inheritance. d) requirements. e) event. f) visual. g) object. h) write once, run anywhere.

**1.3**    a) Common Language Runtime (CLR) of the .NET Framework. b) managed. c) independence. d) IDE. e) tiles. f) chromeless. g) Windows Phone Marketplace. h) Emulator.

**1.4**    a) True. b) True. c) True. d) False: The cost per unit of secondary storage is much lower than that of primary memory. e) True. f) True. g) False. Packets—not bytes. h) False. Hardware costs have decreased. i) True. j) False. The language is Objective-C, not Java. k) False. It's ASP.NET technology. l) True. m) False. Windows Phone 8 is designed for resource-constrained devices. n) True.

**1.5**    kilobyte, megabyte, gigabyte, terabyte, petabyte.

**1.6**    C# code is first compiled into MSIL and placed in an executable file. When the app executes, another compiler called the JIT(just-in-time) compiler in the CLR translates the MSIL in the executable file into machine-language code (for a particular platform).

**1.7**    To free up memory for executing other apps.

## Exercises

- 1.8** Fill in the blanks in each of the following statements:
- The programs that run on a computer are referred to as \_\_\_\_\_.
  - Systems such as smartphones, appliances, game controllers, cable set-top boxes and automobiles that contain small computers are called \_\_\_\_\_.
  - Just as characters are composed of bits, \_\_\_\_\_ are composed of characters or bytes.
  - Information on secondary storage devices is \_\_\_\_\_; it's preserved even when the computer's power is turned off.
  - Translator programs called \_\_\_\_\_ convert high-level language code into machine language code.
  - In object-oriented programming languages, we create a program unit called a(n) \_\_\_\_\_ to house the set of methods that perform its tasks.
  - Use a building-block approach to creating your programs. Avoid reinventing the wheel—use existing pieces wherever possible. Such software \_\_\_\_\_ is a key benefit of object-oriented programming.
- 1.9** Fill in the blanks in each of the following statements:
- Although many different OOAD processes exist, a single graphical language for communicating the results of *any* OOAD process has come into wide use. This language, known as the \_\_\_\_\_, is now the most widely used graphical scheme for modeling object-oriented systems.
  - Tim Berners-Lee developed the \_\_\_\_\_ for sharing information via “hyperlinked” text documents on the web.
  - The CLR is a(n) \_\_\_\_\_ machine. It is software that manages the execution of programs and hides from them the underlying operating system and hardware.
  - Converting a program to run on a different platform from which it was originally intended is called \_\_\_\_\_.
  - Microsoft's Windows \_\_\_\_\_ is a cloud computing platform that allows you to develop, manage and distribute your apps in the cloud.
  - By using existing controls—which are objects—you can create powerful apps much faster than if you had to write all the code yourself. This is a key benefit of software \_\_\_\_\_.
- 1.10** State whether each of the following is *true* or *false*. If *false*, explain why.
- The smallest data item in a computer can assume the value 1 or the value 2. Such a data item is called a **bit** (short for “binary digit”—a digit that can assume either of *two* values).
  - The Unicode character set is a popular subset of ASCII that represents uppercase and lowercase letters, digits and some common special characters.
  - Each of the following is a form of computer output: data displayed on screens, printed on paper, played as audio or video on PCs and media players, used to control other devices, such as robots, 3D printers and “intelligent” appliances.
  - Reuse helps you build more reliable and effective systems, because existing classes and components often have gone through extensive testing, debugging and performance tuning.
  - One of the W3C's primary goals is to make the web universally accessible to everyone regardless of disabilities, language or culture.
  - C# is available only on Microsoft Windows.
  - The .NET Framework Class Library has millions of valuable prebuilt classes that have been tested and tuned to maximize performance.
  - .NET programs can run on any platform.

- i) Windows 8, released in 2012, is designed to provide a similar platform (the underlying system on which apps run) and user experience across all of your devices including personal computers, smartphones, tablets and Xbox Live.
- j) Most mobile apps are sold for a small fee.

- 1.11** What is a key advantage of interpreters over compilers? What is a key disadvantage?
- 1.12** What is the key advantage of using the new Async feature in preference to using old-style multithreading?
- 1.13** What are operating systems?
- 1.14** Why is using cloud computing resources sometimes preferable to purchasing all the hardware you need for your own computer?
- 1.15** Categorize each of the following items as either hardware or software:
  - a) CPU
  - b) Compiler
  - c) Input unit
  - d) A word-processor program
  - e) A C# program
- 1.16** Translator programs, such as assemblers and compilers, convert programs from one language (referred to as the source language) to another language (referred to as the target language). Determine which of the following statements are *true* and which are *false*:
  - a) An assembler translates source-language programs into machine-language programs.
  - b) High-level languages are generally machine dependent.
  - c) A machine-language program requires translation before it can be run on a computer.
  - d) The C# compiler translates high-level-language programs into SMIL.
- 1.17** Expand each of the following acronyms:
  - a) W3C
  - b) OOP
  - c) CLR
  - d) MSIL
  - e) UML
  - f) IDE
- 1.18** What are the key benefits of the .NET Framework and the CLR? What are the drawbacks?
- 1.19** What are the advantages to using object-oriented techniques?
- 1.20** You are probably wearing on your wrist one of the world's most common types of objects—a watch. Discuss how each of the following terms and concepts applies to the notion of a watch: object, attributes and behaviors.
- 1.21** What was the key reason that Visual Basic was developed as a special version of the BASIC programming language?
- 1.22** What is the key accomplishment of the UML?
- 1.23** What did the chief benefit of the early Internet prove to be?
- 1.24** What is the key capability of the web?
- 1.25** What is the key vision of Microsoft's .NET initiative?
- 1.26** How does the .NET Framework Class Library facilitate the development of .NET apps?
- 1.27** Besides the obvious benefits of reuse made possible by OOP, what do many organizations report as another key benefit of OOP?

## Making a Difference Exercises

**I.28** (*Test Drive: Carbon Footprint Calculator*) Some scientists believe that carbon emissions, especially from the burning of fossil fuels, contribute significantly to global warming and that this can be combatted if individuals take steps to limit their use of carbon-based fuels. Organizations and individuals are increasingly concerned about their “carbon footprints.” Websites such as TerraPass

[www.terrapass.com/carbon-footprint-calculator/](http://www.terrapass.com/carbon-footprint-calculator/)

and Carbon Footprint

[www.carbonfootprint.com/calculator.aspx](http://www.carbonfootprint.com/calculator.aspx)

provide carbon footprint calculators. Test drive these calculators to determine your carbon footprint. Exercises in later chapters will ask you to program your own carbon footprint calculator. To prepare for this, use the web to research the formulas for calculating carbon footprints.

**I.29** (*Test Drive: Body Mass Index Calculator*) Obesity causes significant increases in illnesses such as diabetes and heart disease. To determine whether a person is overweight or obese, you can use a measure called the body mass index (BMI). The United States Department of Health and Human Services provides a BMI calculator at [www.nhlbisupport.com/bmi/](http://www.nhlbisupport.com/bmi/). Use it to calculate your own BMI. A forthcoming exercise will ask you to program your own BMI calculator. To prepare for this, use the web to research the formulas for calculating BMI.

**I.30** (*Attributes of Hybrid Vehicles*) In this chapter you learned some basics of classes. Now you’ll “flesh out” aspects of a class called “Hybrid Vehicle.” Hybrid vehicles are becoming increasingly popular, because they often get much better mileage than purely gasoline-powered vehicles. Browse the web and study the features of four or five of today’s popular hybrid cars, then list as many of their hybrid-related attributes as you can. Some common attributes include city-miles-per-gallon and highway-miles-per-gallon. Also list the attributes of the batteries (type, weight, etc.).

**I.31** (*Gender Neutrality*) Many people want to eliminate sexism in all forms of communication. You’ve been asked to create a program that can process a paragraph of text and replace gender-specific words with gender-neutral ones. Assuming that you’ve been given a list of gender-specific words and their gender-neutral replacements (e.g., replace both “wife” and “husband” with “spouse,” “man” and “woman” with “person,” “daughter” and “son” with “child” and so on), explain the procedure you’d use to read through a paragraph of text and manually perform these replacements. How might your procedure generate a strange term like “woperchild?” You’ll soon learn that a more formal term for “procedure” is “algorithm,” and that an algorithm specifies the steps to be performed and the order in which to perform them.

# Dive Into® Visual Studio Express 2012 for Windows Desktop

# 2



*Seeing is believing.*

—Proverb

*Form ever follows function.*

—Louis Henri Sullivan

## Objectives

In this chapter you'll:

- Learn the basics of the Visual Studio Express 2012 for Windows Desktop Integrated Development Environment (IDE) for writing, running and debugging your apps.
- Use Visual Studio's help features.
- Learn key commands contained in the IDE's menus and toolbars.
- Understand the purpose of the various kinds of windows in the Visual Studio Express 2012 for Windows Desktop IDE.
- Understand what visual app development is and how it simplifies and speeds app development.
- Use visual app development to create, compile and execute a simple Visual C# app that displays text and an image.

2.1 Introduction	2.5 Using Help
2.2 Overview of the Visual Studio Express 2012 IDE	2.6 Using Visual App Development to Create a Simple App that Displays Text and an Image
2.3 Menu Bar and Toolbar	2.7 Wrap-Up
2.4 Navigating the Visual Studio IDE	2.8 Web Resources
2.4.1 Solution Explorer	
2.4.2 Toolbox	
2.4.3 Properties Window	

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 2.1 Introduction

Visual Studio 2012 is Microsoft’s Integrated Development Environment (IDE) for creating, running and debugging apps (also called applications) written in various .NET programming languages. This chapter provides an overview of the Visual Studio 2012 IDE and shows how to create a simple Visual C# app by dragging and dropping predefined building blocks into place—a technique known as **visual app development**.

## 2.2 Overview of the Visual Studio Express 2012 IDE

There are several versions of Visual Studio available. Most of this book’s examples are based on the **Visual Studio Express 2012 for Windows Desktop**. See the Before You Begin section that follows the Preface for information on installing the software. Our screen captures and discussions focus on Visual Studio Express 2012 for Windows Desktop. The examples will work on full versions of Visual Studio as well—though some options, menus and instructions might differ. From this point forward, we’ll refer to the Visual Studio Express 2012 for Windows Desktop IDE simply as “Visual Studio” or “the IDE.” We assume that you have some familiarity with Windows.

### *Introduction to Microsoft Visual Studio Express 2012 for Windows Desktop*

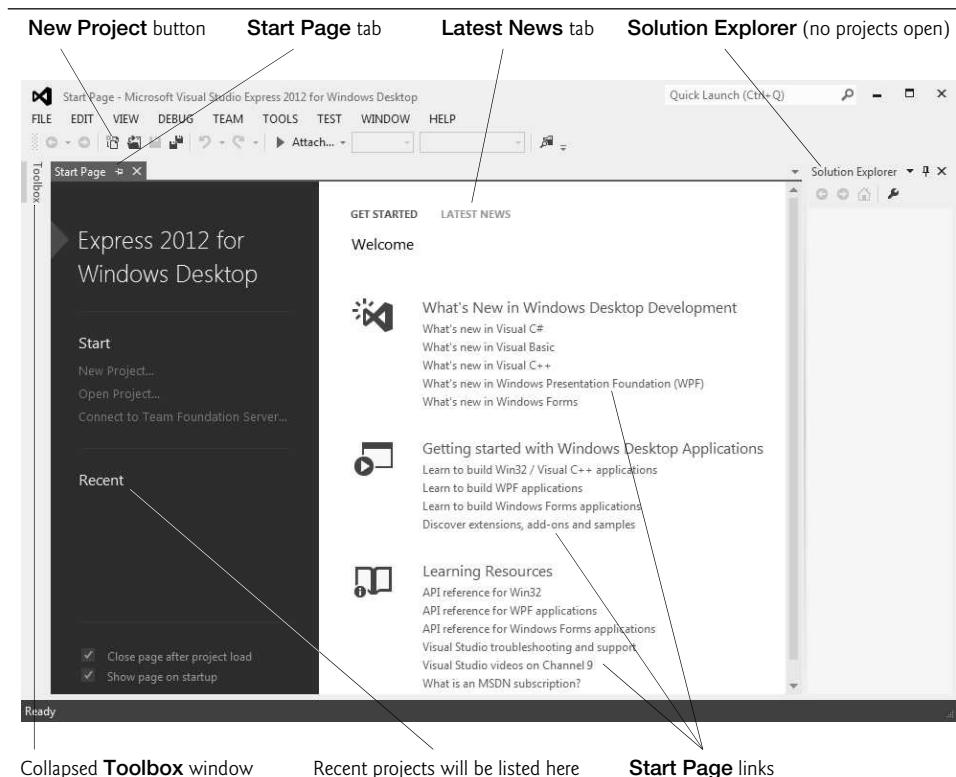
We use the > character to indicate the selection of a *menu item* from a *menu*. For example, we use the notation **FILE > Open File...** to indicate that you should select the **Open File...** menu item from the **FILE** menu.

To start the IDE, select **Start > All Programs > Microsoft Visual Studio 2012 Express > VS Express for Desktop** (on Windows 8, click the **VS for Desktop** tile on the **Start** screen). Once the Express Edition begins execution, the **Start Page** displays (Fig. 2.1). Depending on your version of Visual Studio, your **Start Page** may look different. The **Start Page** contains a list of links to Visual Studio resources and web-based resources. At any time, you can return to the **Start Page** by selecting **VIEW > Start Page**. [Note: Visual Studio supports both a *dark theme* (with dark window backgrounds and light text) and a *light theme* (with light window backgrounds and dark text). We use the light theme throughout this book. The Before You Begin section after the Preface explains how to set this option.]

### *Links on the Start Page*

The **Start Page** links are organized into two columns. The left column’s **Start** section contains options that enable you to start building new apps or to continue working on existing

ones. The **Recent** section contains links to projects you've recently created or modified. You can also create new projects or open existing ones by clicking the links in the **Start** section.



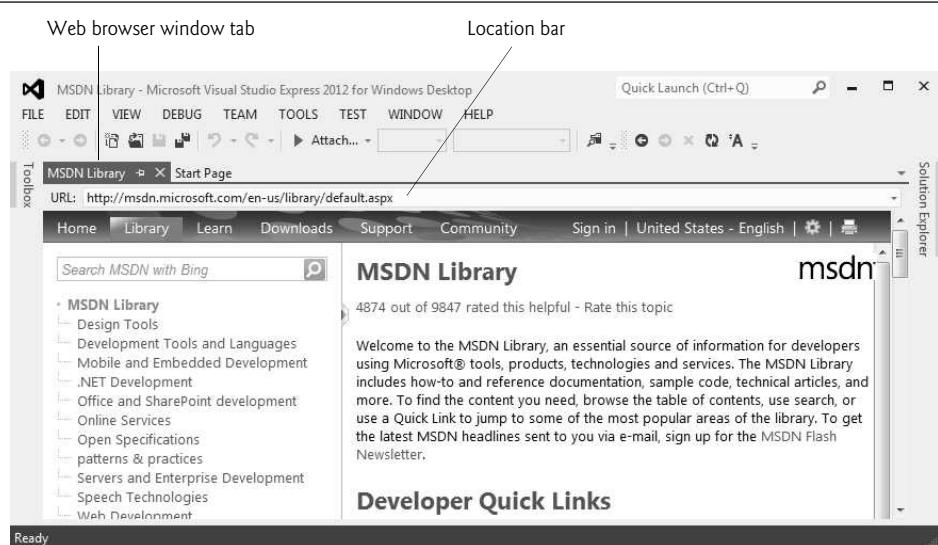
**Fig. 2.1 | Start Page in Visual Studio Express 2012 for Windows Desktop.**

The right column contains two tabs—**GET STARTED** (selected by default) and **LATEST NEWS**. The links in the **GET STARTED** tab provide information about the programming languages supported by Visual Studio and various learning resources. An Internet connection is required for the IDE to access most of this information.

The **LATEST NEWS** tab includes an **Enable RSS Feed** button. Once you click this button, the IDE will display links to the latest Visual Studio developments (such as updates and bug fixes) and to information on advanced app-development topics. To access more extensive information on Visual Studio, you can browse the **MSDN (Microsoft Developer Network)** Library at

```
msdn.microsoft.com/en-us/library/default.aspx
```

The MSDN site contains articles, downloads and tutorials on technologies of interest to Visual Studio developers. You can also browse the web from the IDE by selecting **VIEW > Other Windows > Web Browser**. To request a web page, type its URL into the location bar (Fig. 2.2) and press the *Enter* key—your computer, of course, must be connected to the Internet. The web page that you wish to view appears as another tab in the IDE (Fig. 2.2).



**Fig. 2.2 |** MSDN Library web page in Visual Studio.

### *Creating a New Project*

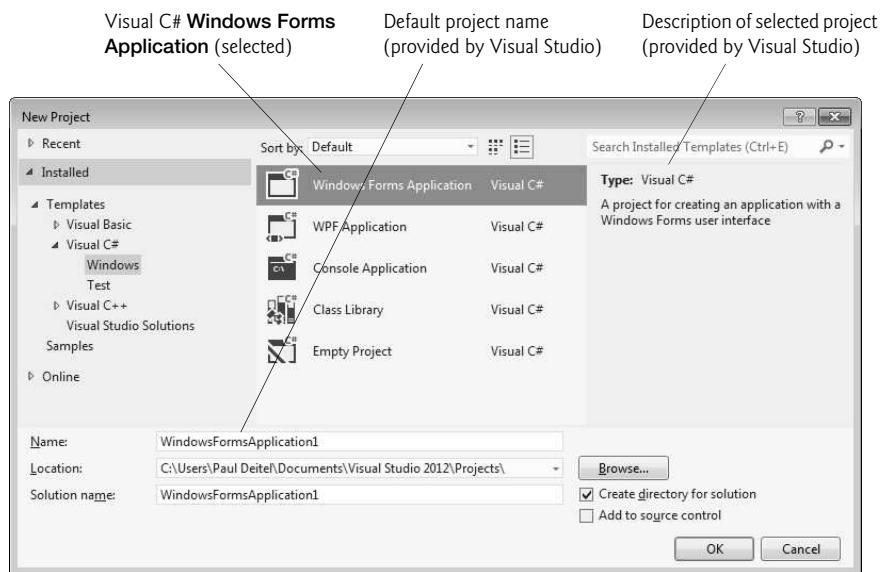
To begin app development in Visual C#, you must create a new project or open an existing one. You select **FILE > New Project...** to create a new project or **FILE > Open Project...** to open an existing one. From the **Start Page**'s **Start** section, you can also click the links **New Project...** or **Open Project....** **A project** is a group of related files, such as the **Visual C# code** and any **images** that might make up an app. Visual Studio organizes apps into projects and **solutions**, which contain one or more projects. Multiple-project solutions are used to create large-scale apps. Most apps we create in this book consist of a solution containing a single project.

### *New Project Dialog and Project Templates*

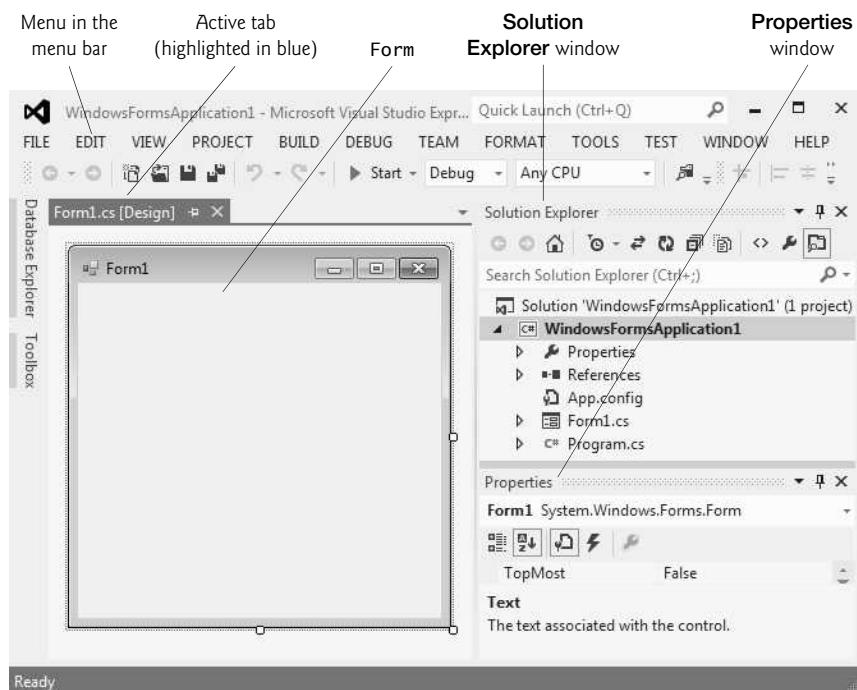
When you select **FILE > New Project...** or click the **New Project...** link on the **Start Page**, the **New Project** dialog (Fig. 2.3) displays. **DIALOGS** are windows that facilitate user-computer communication.

Visual Studio provides several **TEMPLATES** (Fig. 2.3)—the *project types* users can create in Visual C# and other languages. The templates include Windows Forms apps, WPF apps and others—full versions of Visual Studio provide many additional templates. In this chapter, you'll build a **Windows Forms Application**. **A Windows Forms app** is an app that executes within a Windows operating system (such as Windows 7 or Windows 8) and typically has a **graphical user interface (GUI)**—users interact with this *visual* part of the app. Windows apps include Microsoft software products like Microsoft Word, Internet Explorer and Visual Studio, software products created by other vendors, and customized software that you and other app developers create. You'll create many Windows apps in this text.

By default, Visual Studio assigns the name **WindowsFormsApplication1** to a new **Windows Forms Application** project and solution (Fig. 2.3). Select **Windows Forms Application**, then click **OK** to display the IDE in **Design** view (Fig. 2.4), which contains the features that enable you to create an app's GUI.



**Fig. 2.3** | New Project dialog.

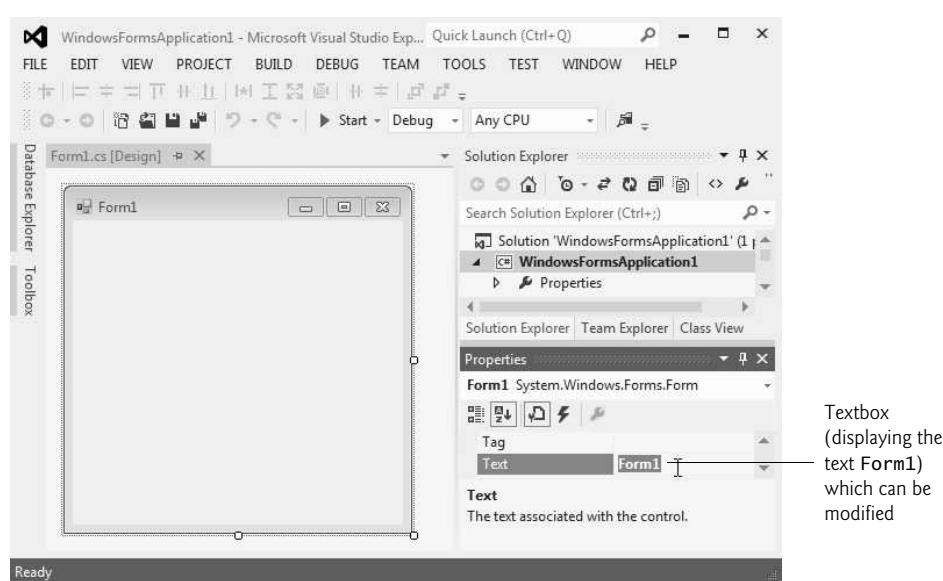


**Fig. 2.4** | Design view of the IDE.

### **Forms and Controls**

The rectangle in the Design area titled **Form1** (called a **Form**) represents the main window of the Windows Forms app that you’re creating. Visual C# apps can have multiple Forms (windows)—however, most apps you’ll create in this text will use only one Form. You’ll learn how to customize the Form by adding GUI controls—in this example, you’ll add a **Label** and a **PictureBox** (as you’ll see in Fig. 2.20). A **Label** typically contains descriptive text (for example, “Welcome to Visual C#!”), and a **PictureBox** displays an image. Visual Studio has many preexisting controls and other components you can use to build and customize your apps. Many of these controls are discussed and used throughout the book. Other controls are available from third parties.

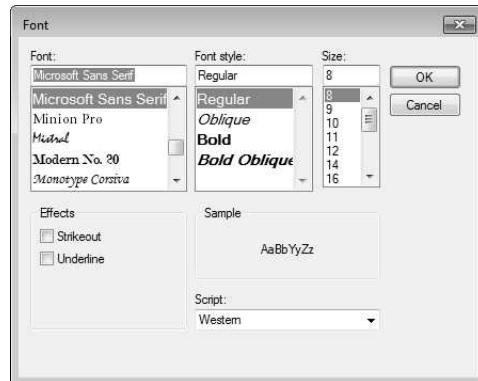
In this chapter, you’ll work with preexisting controls from the .NET Framework Class Library. As you place controls on the Form, you’ll be able to modify their properties (discussed in Section 2.4). For example, Fig. 2.5 shows where the Form’s title can be modified and Fig. 2.6 shows a dialog in which a control’s font properties can be modified.



**Fig. 2.5** | Textbox control for modifying a property in the Visual Studio IDE.

Collectively, the Form and controls make up the app’s GUI. Users enter data into the app by typing at the keyboard, by clicking the mouse buttons and in a variety of other ways. Apps use the GUI to display instructions and other information for users to view. For example, the **New Project** dialog in Fig. 2.3 presents a GUI where the user clicks the mouse button to select a template type, then inputs a project name from the keyboard (the figure is still showing the default project name **WindowsFormsApplication1** supplied by Visual Studio).

Each open document’s name is listed on a tab. To view a document when multiple documents are open, click its tab. The **active tab** (the tab of the currently displayed document) is highlighted in blue (for example, **Form1.cs [Design]** in Fig. 2.4).



**Fig. 2.6** | Dialog for modifying a control's font properties.

## 2.3 Menu Bar and Toolbar

Commands for managing the IDE and for developing, maintaining and executing apps are contained in menus, which are located on the **menu bar** of the IDE (Fig. 2.7). The set of menus displayed depends on what you're currently doing in the IDE.

FILE EDIT VIEW PROJECT BUILD DEBUG TEAM FORMAT TOOLS TEST WINDOW HELP

**Fig. 2.7** | Visual Studio menu bar.

Menus contain groups of related commands (also called menu items) that, when selected, cause the IDE to perform specific actions—for example, open a window, save a file, print a file and execute an app. For example, new projects are created by selecting **FILE > New Project....** The menus depicted in Fig. 2.7 are summarized in Fig. 2.8.

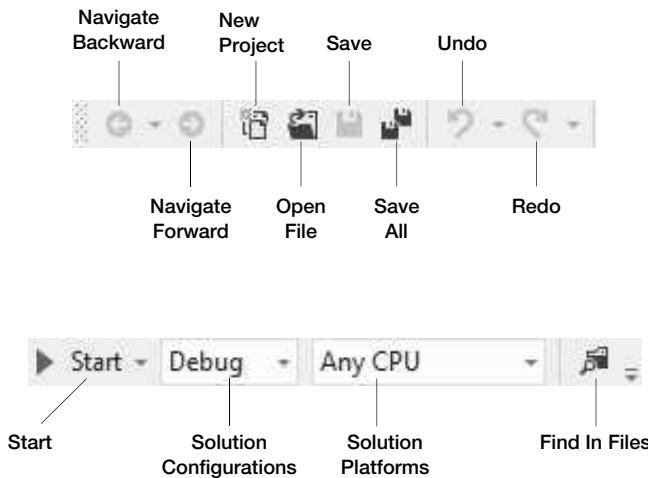
Menu	Description
FILE	Contains commands for opening, closing, adding and saving projects, as well as printing project data and exiting Visual Studio.
EDIT	Contains commands for editing apps, such as cut, copy, paste, undo, redo, delete, find and select.
VIEW	Contains commands for displaying IDE windows (for example, <b>Solution Explorer</b> , <b>Toolbox</b> , <b>Properties</b> window) and for adding toolbars to the IDE.
PROJECT	Contains commands for managing projects and their files.
BUILD	Contains options for turning your app into an executable program.

**Fig. 2.8** | Summary of Visual Studio menus that are displayed when a Form is in **Design** view. (Part I of 2.)

Menu	Description
DEBUG	Contains commands for compiling, debugging (that is, identifying and correcting problems in apps) and running apps.
TEAM	Allows you to connect to a Team Foundation Server—used by development teams that typically have multiple people working on the same app.
FORMAT	Contains commands for arranging and modifying a Form's controls. The Format menu appears <i>only</i> when a GUI component is selected in Design view.
TOOLS	Contains commands for accessing additional IDE tools and options for customizing the IDE.
TEST	Contains options for performing various types of automated testing on your app.
WINDOW	Contains commands for hiding, opening, closing and displaying IDE windows.
HELP	Contains commands for accessing the IDE's help features.

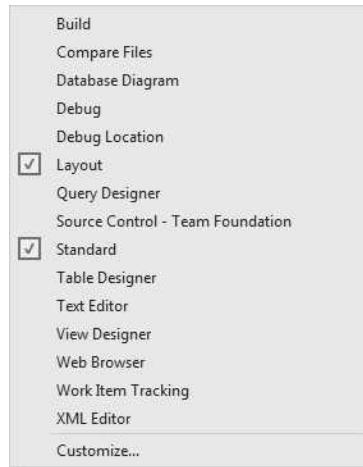
**Fig. 2.8** | Summary of Visual Studio menus that are displayed when a Form is in Design view. (Part 2 of 2.)

You can access many common menu commands from the **toolbar** (Fig. 2.9), which contains **icons** that graphically represent commands. By default, the standard toolbar is displayed when you run Visual Studio for the first time—it contains icons for the most commonly used commands, such as opening a file, adding an item to a project, saving files and running apps (Fig. 2.9). The icons that appear on the standard toolbar may vary, depending on the version of Visual Studio you're using. Some commands are initially disabled (grayed out or unavailable to use). These commands are enabled by Visual Studio only when they're necessary. For example, Visual Studio enables the command for *saving* a file once you begin *editing* a file.



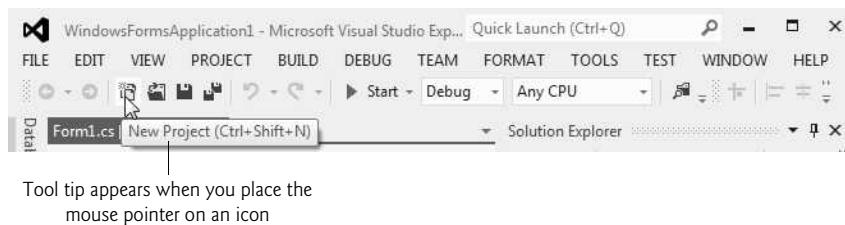
**Fig. 2.9** | Standard Visual Studio toolbar.

You can customize which toolbars are displayed by selecting **VIEW > Toolbars** then selecting a toolbar from the list in Fig. 2.10. Each toolbar you select is displayed with the other toolbars at the top of the Visual Studio window. You move a toolbar by dragging its handle (■) at the left side of the toolbar. To execute a command via the toolbar, click its icon.



**Fig. 2.10** | List of toolbars that can be added to the top of the IDE.

It can be difficult to remember what each toolbar icon represents. *Hovering* the mouse pointer over an icon highlights it and, after a brief pause, displays a description of the icon called a tool tip (Fig. 2.11). **Tool tips** help you become familiar with the IDE's features and serve as useful reminders for each toolbar icon's functionality.



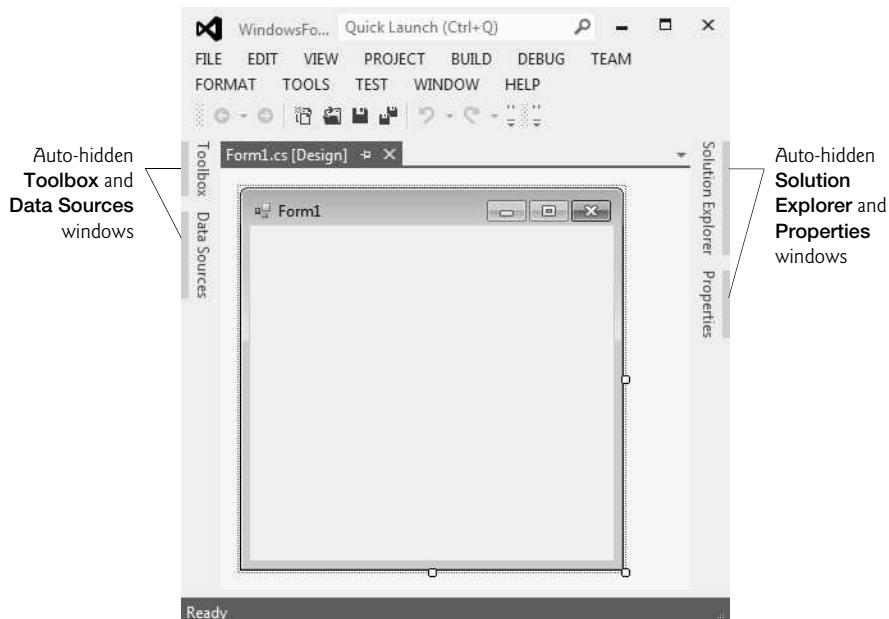
**Fig. 2.11** | Tool tip demonstration.

## 2.4 Navigating the Visual Studio IDE

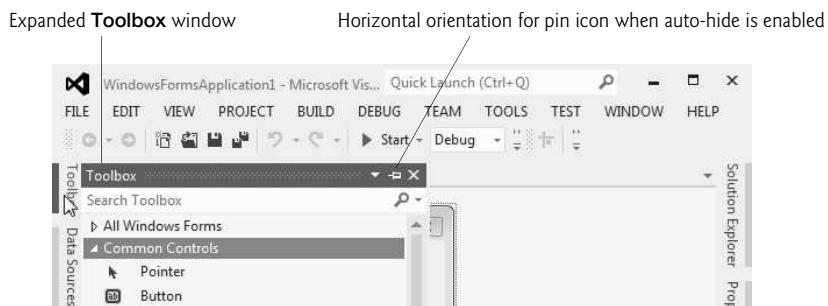
The IDE provides windows for accessing project files and customizing controls. This section introduces several windows that you'll use frequently when developing Visual C# apps. Each of the IDE's windows can be accessed by selecting its name in the **VIEW** menu.

### *Auto-Hide*

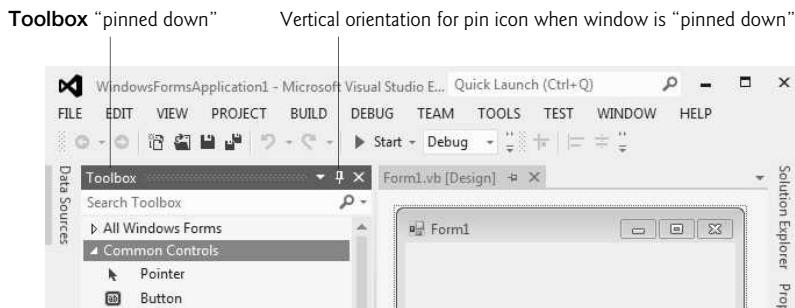
Visual Studio provides a space-saving feature called **auto-hide**. When auto-hide is enabled for a window, a tab containing the window's name appears along either the left, right or bottom edge of the IDE window (Fig. 2.12). Clicking the name of an auto-hidden window displays that window (Fig. 2.13). Clicking the name again (or clicking outside) hides the window. To “pin down” a window (that is, to disable auto-hide and keep the window open), click the pin icon. When auto-hide is enabled, the pin icon is horizontal (❑, Fig. 2.13)—when a window is “pinned down,” the pin icon is vertical (✚, Fig. 2.14).



**Fig. 2.12** | Auto-hide feature demonstration.



**Fig. 2.13** | Displaying the hidden **Toolbox** window when auto-hide is enabled.

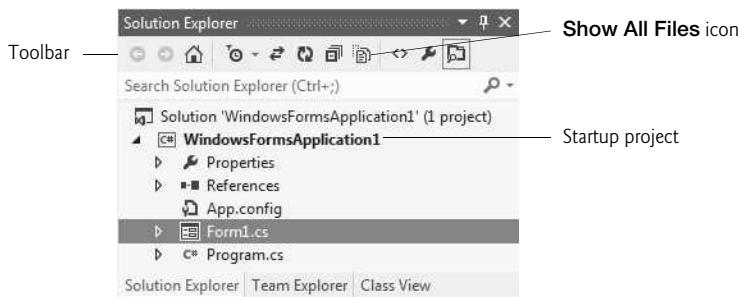


**Fig. 2.14** | Disabling auto-hide—“pinning down” a window.

The next few sections cover three of Visual Studio’s main windows—the **Solution Explorer**, the **Properties** window and the **Toolbox**. These windows display project information and include tools that help you build your apps.

## 2.4.1 Solution Explorer

The **Solution Explorer** window (Fig. 2.15) provides access to all of a solution’s files. If it’s not shown in the IDE, select **VIEW > Solution Explorer**. When you open a new or existing solution, the **Solution Explorer** displays the solution’s contents.

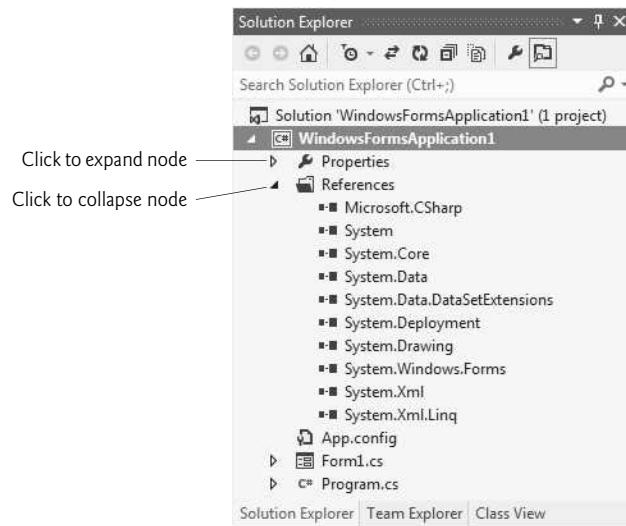


**Fig. 2.15** | Solution Explorer window with an open project.

The solution’s **startup project** is the one that runs when you select **DEBUG > Start Debugging** (or press the *F5* key). For a single-project solution like the examples in this book, the startup project is the only project (in this case, **WindowsFormsApplication1**). The startup project’s name appears in bold text in the **Solution Explorer** window. When you create an app for the first time, the **Solution Explorer** window appears as shown in Fig. 2.15. The Visual C# file that corresponds to the Form shown in Fig. 2.4 is named **Form1.cs** (selected in Fig. 2.15). Visual C# files use the **.cs** file-name extension, which is short for “C#.”

By default, the IDE displays only files that you may need to edit—other files that the IDE generates are hidden. The **Solution Explorer** window includes a toolbar that contains several icons. Clicking the **Show All Files** icon (Fig. 2.15) displays all the solution’s files, including those generated by the IDE. Clicking the arrows to the left of an node *expands* or *collapses* that node. Try clicking the arrow to the left of **References** to display items

grouped under that heading (Fig. 2.16). Click the arrow again to collapse the tree. Other Visual Studio windows also use this convention.



**Fig. 2.16 |** Solution Explorer with the References node expanded.

## 2.4.2 Toolbox

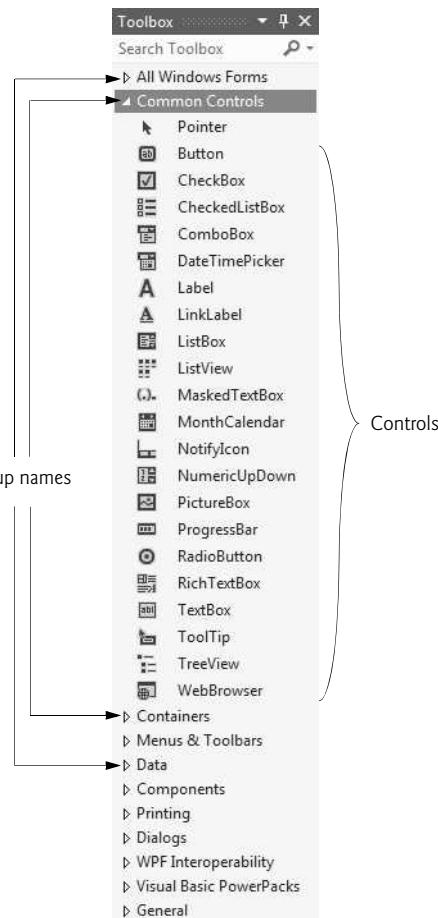
To display the **Toolbox** window, select **VIEW > Toolbox**. The **Toolbox** contains the controls used to customize **Forms** (Fig. 2.17). With visual app development, you can “drag and drop” controls onto the **Form** and the IDE will write the code that creates the controls for you. This is faster and simpler than writing this code yourself. Just as you do not need to know how to build an engine to drive a car, you do not need to know how to build controls to use them. *Reusing* preexisting controls saves time and money when you develop apps. You’ll use the **Toolbox** when you create your first app later in the chapter.

The **Toolbox** groups the prebuilt controls into categories—**All Windows Forms**, **Common Controls**, **Containers**, **Menus & Toolbars**, **Data**, **Components**, **Printing**, **Dialogs**, **WPF Interoperability**, **Visual Basic PowerPacks** and **General** are listed in Fig. 2.17. Again, note the use of arrows, which can expand or collapse a group of controls. We discuss many of the **Toolbox**’s controls and their functionality throughout the book.

## 2.4.3 Properties Window

If the **Properties** window is not displayed below the **Solution Explorer**, select **VIEW > Properties Window** to display it. The **Properties** window contains the properties for the currently selected **Form**, control or file in the IDE. **Properties** specify information about the **Form** or control, such as its size, color and position. Each **Form** or control has its own set of properties—a property’s description is displayed at the bottom of the **Properties** window whenever that property is selected.

Figure 2.18 shows **Form1**’s **Properties** window. The left column lists the **Form**’s properties—the right column displays the current value of each property. You can sort the

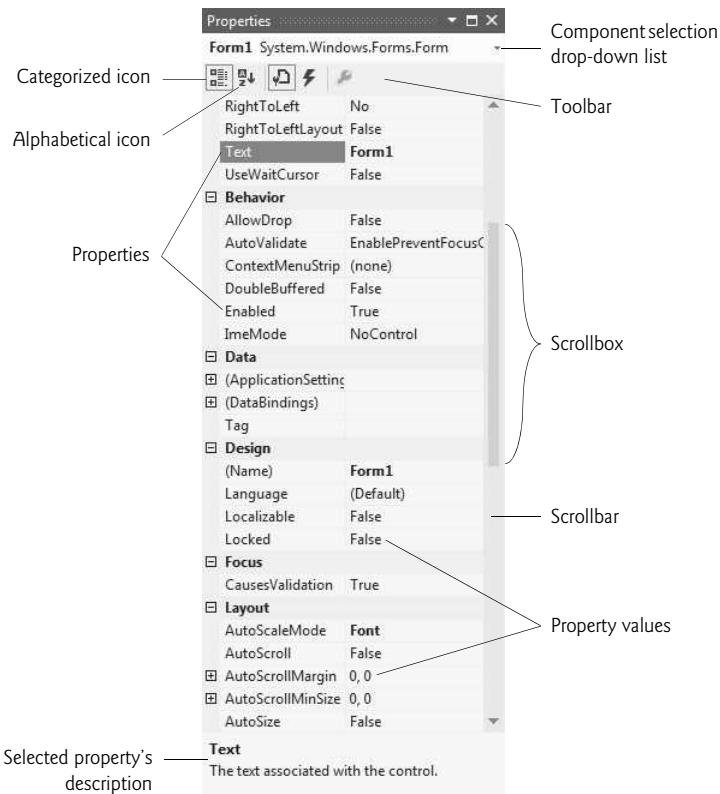


**Fig. 2.17** | Toolbox window displaying controls for the **Common Controls** group.

properties either *alphabetically* (by clicking the **Alphabetical** icon) or *categorically* (by clicking the **Categorized** icon). Depending on the size of the **Properties** window, some of the properties may be hidden from view on the screen. You can scroll through the list of properties by dragging the scrollbar up or down inside the scrollbar, or by clicking the arrows at the top and bottom of the scrollbar. We show how to set individual properties later in this chapter.

The **Properties** window is crucial to visual app development—it allows you to modify a control's properties visually, without writing code. You can see which properties are available for modification and, in many cases, can learn the range of acceptable values for a given property. The **Properties** window displays a brief description of the selected property, helping you understand its purpose. A property can be set quickly using this window, and no code needs to be written.

At the top of the **Properties** window is the **component selection drop-down list**, which allows you to select the Form or control whose properties you wish to display in the **Proper-**



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**Fig. 2.18 |** Properties window.

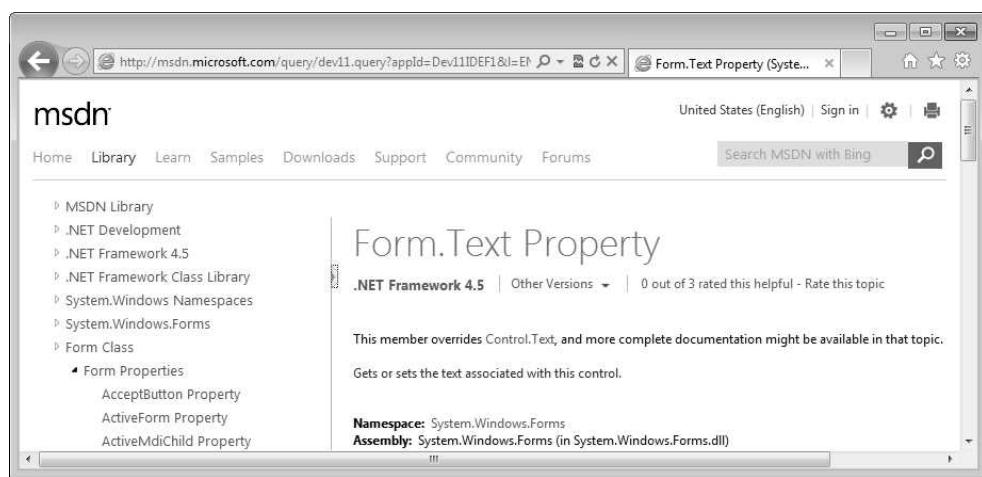
ties window. Using the component selection drop-down list is an alternative way to display a Form's or control's properties without clicking the actual Form or control in the GUI.

## 2.5 Using Help

Microsoft provides extensive help documentation via the **HELP** menu. Using **HELP** is an excellent way to get information quickly about Visual Studio, Visual C# and more.

### *Context-Sensitive Help*

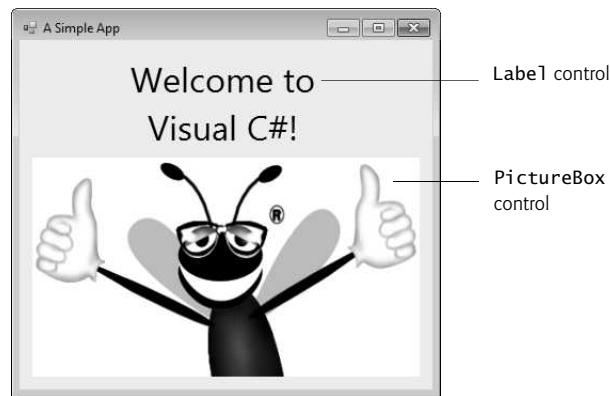
Visual Studio provides **context-sensitive help** pertaining to the “current content” (that is, the items around the location of the mouse cursor). To use context-sensitive help, click an item, then press the *F1* key. The help documentation is displayed in a web browser window. To return to the IDE, either close the browser window or select the IDE’s icon in your Windows task bar. Figure 2.19 shows the help page for a Form’s **Text** property. You can view this help by selecting the Form, clicking its **Text** property in the **Properties** window and pressing the *F1* key.



**Fig. 2.19** | Using context-sensitive help.

## 2.6 Using Visual App Development to Create a Simple App that Displays Text and an Image

Next, we create an app that displays the text "Welcome to Visual C#!" and an image of the Deitel & Associates bug mascot. The app consists of a Form that uses a Label and a PictureBox. Figure 2.20 shows the final app executing. The app and the bug image are available with this chapter's examples. See the Before You Begin section following the Preface for download instructions. We assume the examples are located at C:\examples on your computer.



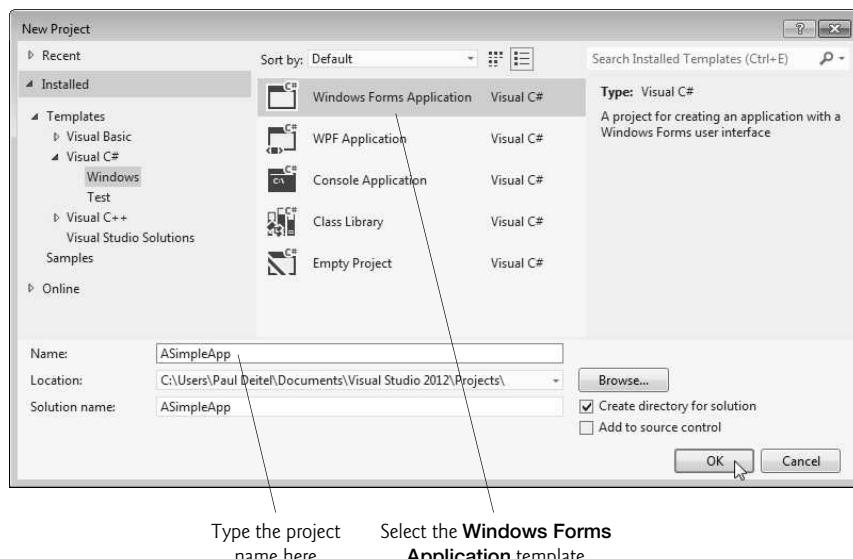
**Fig. 2.20** | Simple app executing.

You won't write a single line of code. Instead, you'll use visual app development techniques. Visual Studio processes your actions (such as mouse clicking, dragging and dropping) to generate app code. Chapter 3 begins our discussion of writing app code. Throughout the book, you produce increasingly substantial and powerful apps that usually

include a combination of code written by you and code generated by Visual Studio. The generated code can be difficult for novices to understand—but you'll rarely need to look at it.

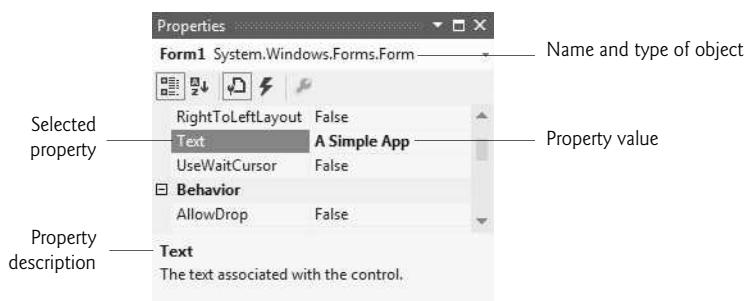
Visual app development is useful for building GUI-intensive apps that require a significant amount of user interaction. To create, save, run and terminate this first app, perform the following steps:

- 1. Closing the open project.** If the project you were working with earlier in this chapter is still open, close it by selecting **FILE > Close Solution**.
- 2. Creating the new project.** To create a new Windows Forms app, select **FILE > New Project...** to display the **New Project** dialog (Fig. 2.21). Select **Windows Forms Application**. Name the project **ASimpleApp**, specify the **Location** where you want to save it (we used the default location) and click **OK**. As you saw earlier in this chapter, when you first create a new Windows Forms app, the IDE opens in **Design** view (that is, the app is being designed and is not executing).

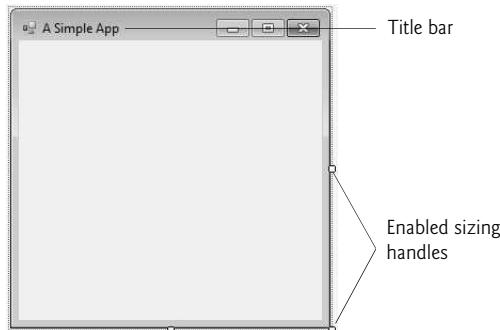


**Fig. 2.21 |** New Project dialog.

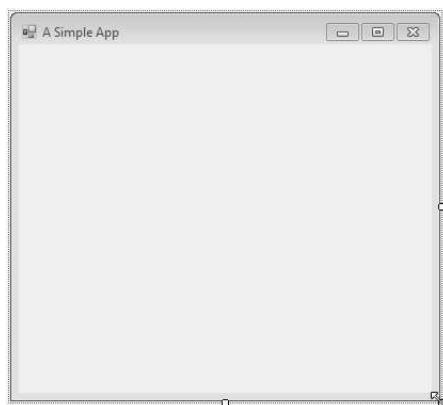
- 3. Setting the text in the Form's title bar.** The text in the Form's title bar is determined by the Form's **Text** property (Fig. 2.22). If the **Properties** window is not open, select **VIEW > Properties Window**. Click anywhere in the Form to display the Form's properties in the **Properties** window. In the textbox to the right of the **Text** property, type "A Simple App", as in Fig. 2.22. Press the *Enter* key—the Form's title bar is updated immediately (Fig. 2.23).
- 4. Resizing the Form.** Click and drag one of the Form's enabled **sizing handles** (the small white squares that appear around the Form, as shown in Fig. 2.23). Using the mouse, select the bottom-right sizing handle and drag it down and to the right to make the Form larger (Fig. 2.24).



**Fig. 2.22** | Setting the Form's Text property in the Properties window.



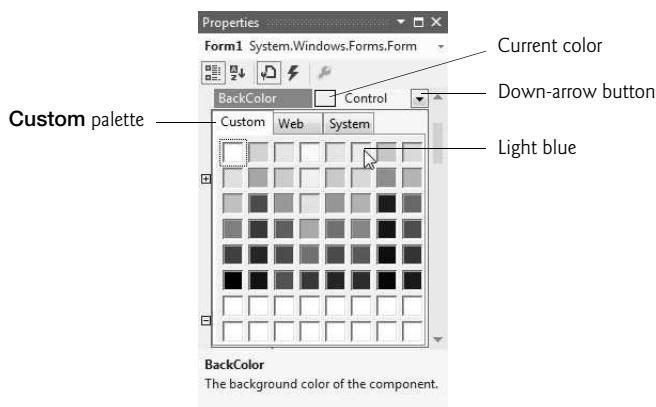
**Fig. 2.23** | Form with enabled sizing handles.



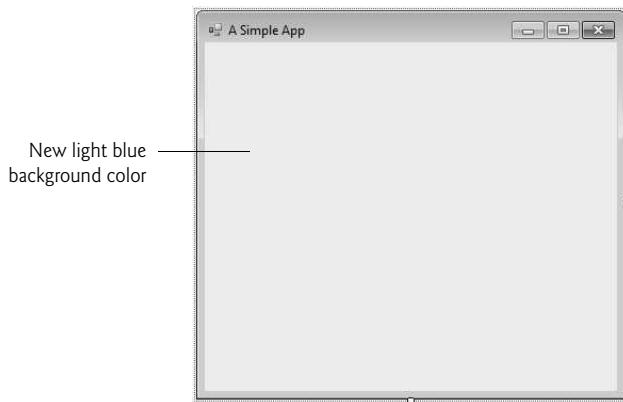
**Fig. 2.24** | Resized Form.

5. *Changing the Form's background color.* The **BackColor** property specifies a Form's or control's background color. Clicking **BackColor** in the **Properties** win-

dow causes a down-arrow button to appear next to the value of the property (Fig. 2.25). When clicked, the down-arrow button displays other options, which vary depending on the property. In this case, the arrow displays tabs for **Custom**, **Web** and **System** (the default). Click the **Custom** tab to display the palette (a grid of colors). Select the box that represents light blue. Once you select the color, the palette closes and the Form's background color changes to light blue (Fig. 2.26).



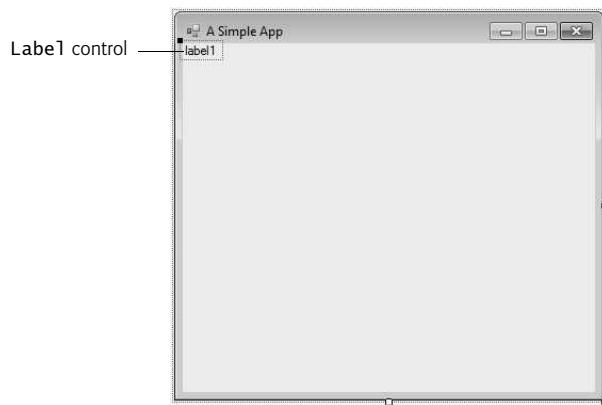
**Fig. 2.25** | Changing the Form's BackColor property.



**Fig. 2.26** | Form with new BackColor property applied.

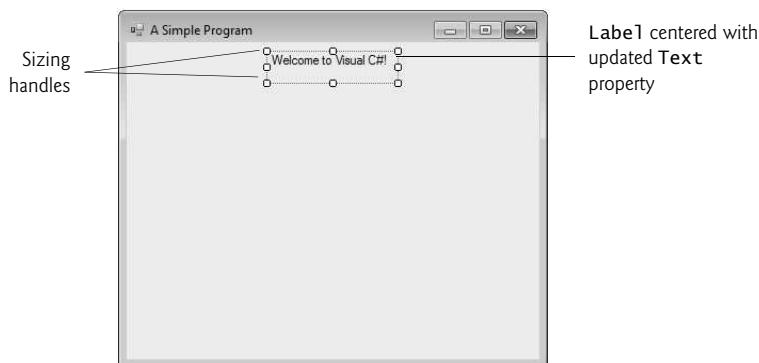
6. *Adding a Label control to the Form.* If the **Toolbox** is *not* already open, select **VIEW > Toolbox** to display the set of controls you'll use for creating your apps. For the type of app we're creating in this chapter, the typical controls we use are located in either the **All Windows Forms** group of the **Toolbox** or the **Common Controls** group. If either group name is collapsed, expand it by clicking the arrow to the left of the group name (the **All Windows Forms** and **Common Controls** groups are shown in Fig. 2.17). Next, double click the **Label** control in the **Toolbox**.

This action causes a **Label** to appear in the upper-left corner of the Form (Fig. 2.27). [Note: If the Form is behind the **Toolbox**, you may need to hide the **Toolbox** to see the **Label**.] Although double clicking any **Toolbox** control places the control on the Form, you also can “drag” controls from the **Toolbox** to the Form—you may prefer dragging the control because you can position it wherever you want. The **Label** displays the text **label1** by default. When you add a **Label** to the Form, the IDE sets the **Label**’s **BackColor** property to the Form’s **BackColor**. You can change the **Label**’s background color by changing its **BackColor** property.



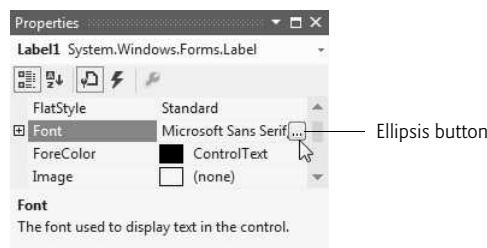
**Fig. 2.27** | Adding a **Label** to the Form.

7. *Customizing the **Label**’s appearance.* Select the **Label** by clicking it. Its properties now appear in the **Properties** window. The **Label**’s **Text** property determines the text (if any) that the **Label** displays. The Form and **Label** each have their own **Text** property—Forms and controls can have the *same* property names (such as **BackColor**, **Text**, etc.) without conflict. Set the **Label**’s **Text** property to **Welcome to Visual C#!**. The **Label** resizes to fit all the typed text on one line. By default, the **AutoSize** property of the **Label** is set to **True**, which allows the **Label** to update its size to fit all of the text if necessary. Set the **AutoSize** property to **False** so that you can resize the **Label** on your own. Resize the **Label** (using the sizing handles) so that the text fits. Move the **Label** to the top center of the Form by dragging it or by using the keyboard’s left and right arrow keys to adjust its position (Fig. 2.28). Alternatively, when the **Label** is selected, you can center the **Label** control horizontally by selecting **FORMAT > Center In Form > Horizontally**.
8. *Setting the **Label**’s font size.* To change the font type and appearance of the **Label**’s text, select the value of the **Font** property, which causes an **ellipsis button** to appear next to the value (Fig. 2.29). When the ellipsis button is clicked, a dialog that provides additional values—in this case, the **Font** dialog (Fig. 2.30)—is displayed. You can select the font name (the font options may be different, depending on your system), font style (**Regular**, **Italic**, **Bold**, etc.) and font size (**16**, **18**, **20**, etc.) in this dialog. The **Sample** text shows the selected font settings.

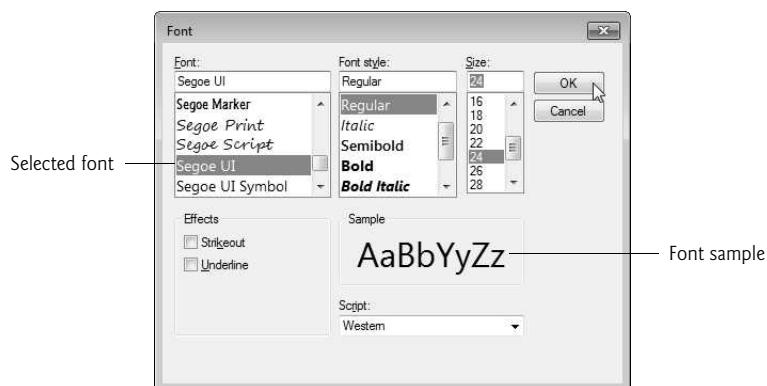


**Fig. 2.28** | GUI after the Form and Label have been customized.

Under **Font**, select **Segoe UI**, Microsoft's recommended font for user interfaces. Under **Size**, select **24** points and click **OK**. If the Label's text does not fit on a single line, it *wraps* to the next line. Resize the Label so that the words "Welcome to" appear on the Label's first line and the words "Visual C#!" appear on the second line. Re-center the Label horizontally.



**Fig. 2.29** | Properties window displaying the Label's Font property.



**Fig. 2.30** | Font dialog for selecting fonts, styles and sizes.

9. *Aligning the Label's text.* Select the Label's  **TextAlign** property, which determines how the text is aligned within the Label. A three-by-three grid of buttons representing alignment choices is displayed (Fig. 2.31). The position of each button corresponds to where the text appears in the Label. For this app, set the  **TextAlign** property to **MiddleCenter** in the three-by-three grid—this selection centers the text horizontally and vertically within the Label. The other  **TextAlign** values, such as **TopLeft**, **TopRight**, and **BottomCenter**, can be used to position the text anywhere within a Label. Certain alignment values may require that you resize the Label to fit the text better.

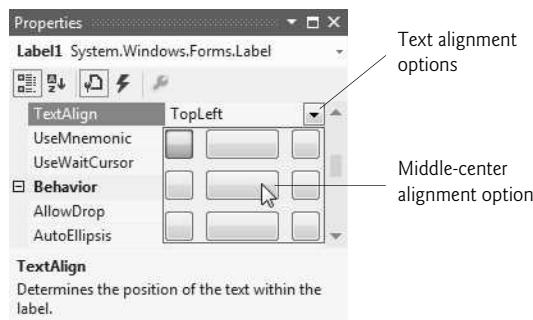


Fig. 2.31 | Centering the Label's text.

10. *Adding a PictureBox to the Form.* The PictureBox control displays images. The process involved in this step is similar to that of Step 6, in which we added a Label to the Form. Locate the PictureBox in the Toolbox (Fig. 2.17) and double click it to add it to the Form. When the PictureBox appears, move it underneath the Label, either by dragging it or by using the arrow keys (Fig. 2.32).

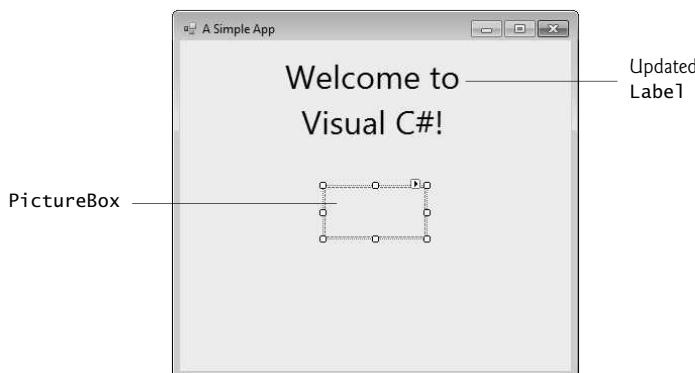
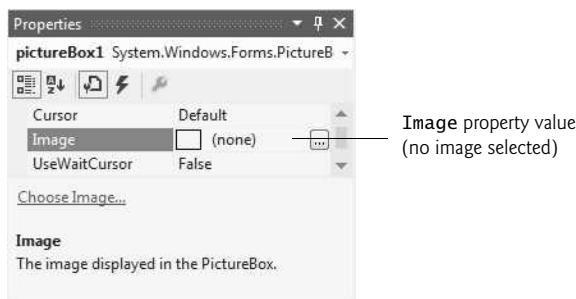


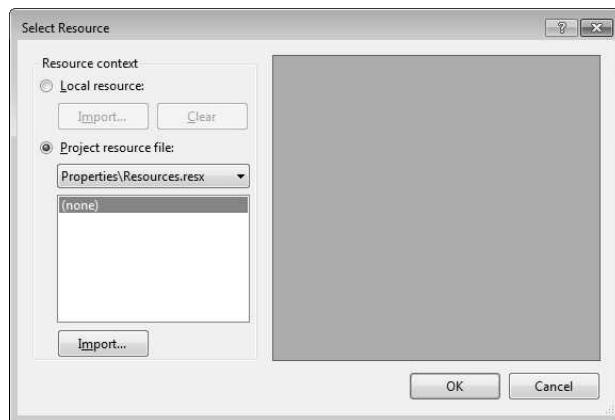
Fig. 2.32 | Inserting and aligning a PictureBox.

11. *Inserting an image.* Click the PictureBox to display its properties in the Properties window (Fig. 2.33). Locate and select the **Image** property, which displays a



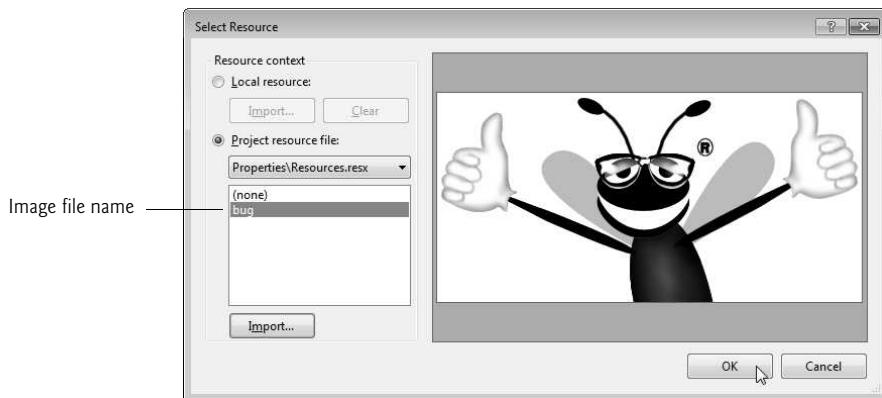
**Fig. 2.33** | Image property of the PictureBox.

preview of the selected image or (none) if no image is selected. Click the ellipsis button (or the Choose Image... link above the property description) to display the **Select Resource** dialog (Fig. 2.34), which is used to import files, such as images, for use in an app. Click the Import... button to browse for an image to insert, select the image file and click OK. We used bug.png from this chapter's examples folder. The image is previewed in the Select Resource dialog (Fig. 2.35). Click OK to use the image. Supported image formats include PNG (Portable Network Graphics), GIF (Graphic Interchange Format), JPEG (Joint Photographic Experts Group) and BMP (Windows bitmap). To scale the image to the PictureBox's size, change the **SizeMode** property to **StretchImage** (Fig. 2.36). Resize the PictureBox, making it larger (Fig. 2.37).



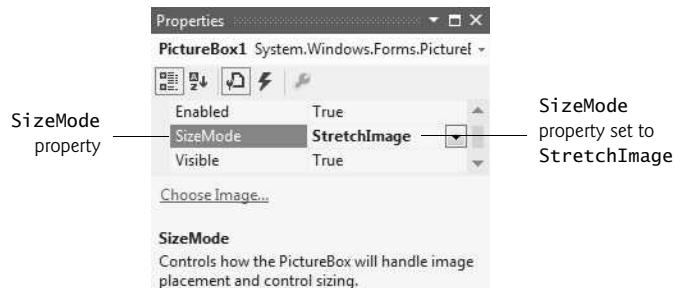
**Fig. 2.34** | Select Resource dialog to select an image for the PictureBox.

12. *Saving the project.* Select FILE > Save All to save the entire solution. The solution file (which has the filename extension .sln) contains the name and location of its project, and the project file (which has the filename extension .csproj) contains the names and locations of all the files in the project. If you want to reopen your project at a later time, simply open its .sln file.



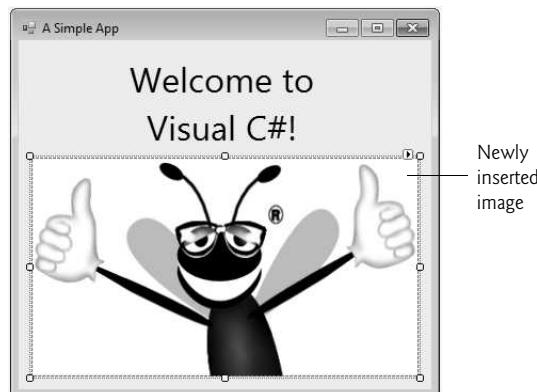
**Fig. 2.35** | Select Resource dialog displaying a preview of selected image.

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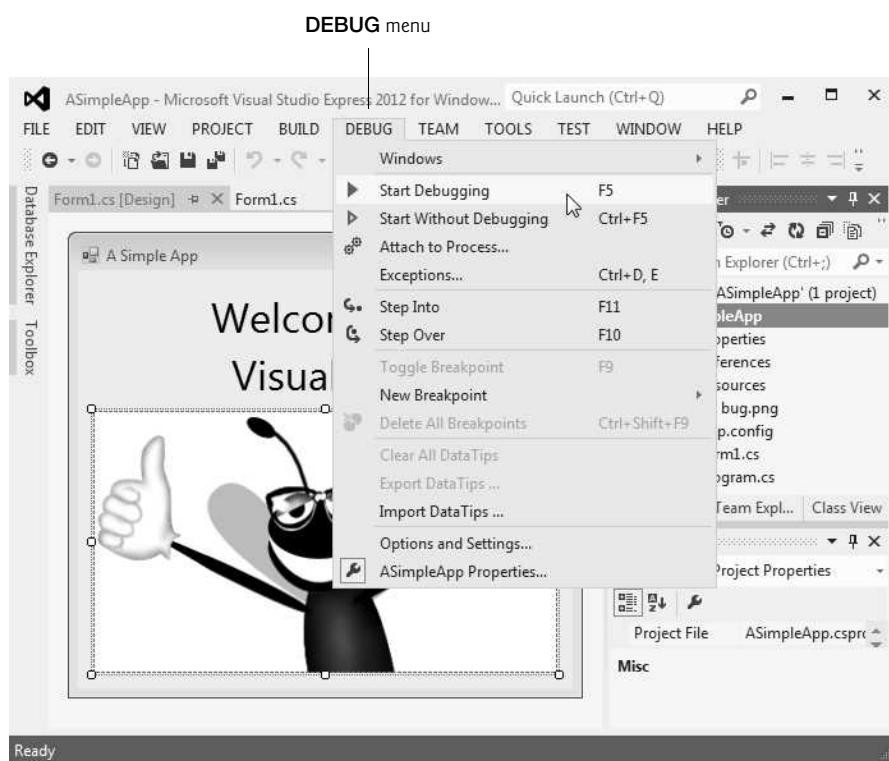
**Fig. 2.36** | Scaling an image to the size of the PictureBox.

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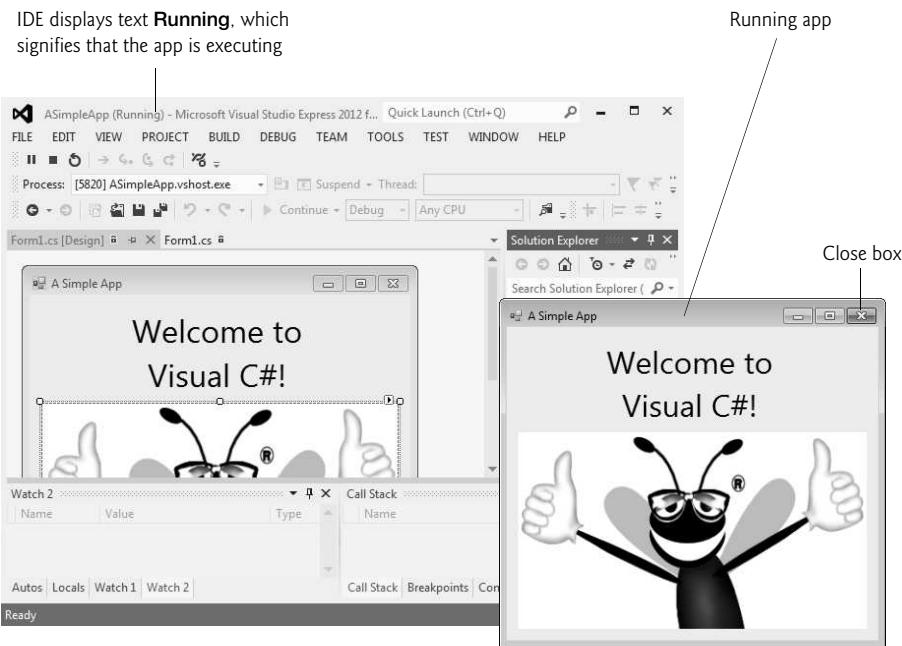
**Fig. 2.37** | PictureBox displaying an image.

**13. Running the project.** Recall that up to this point we have been working in the IDE design mode (that is, the app being created is not executing). In **run mode**, the app is executing, and you can interact with only a few IDE features—features that are not available are disabled (grayed out). The text **Form1.cs [Design]** in the project tab (Fig. 2.38) means that we’re designing the **Form visually** rather than **programmatically**. If we had been writing code, the tab would have contained only the text **Form1.cs**. If there is an asterisk (\*) at the end of the text in the tab, the file has been changed and should be saved. Select **DEBUG > Start Debugging** to execute the app (or you can press the **F5** key). Figure 2.39 shows the IDE in run mode (indicated by the title-bar text **ASimpleApp (Running) – Microsoft Visual Studio Express 2012 for Windows Desktop**). Many toolbar icons and menus are disabled, since they cannot be used while the app is running. The running app appears in a separate window outside the IDE as shown in the lower-right portion of Fig. 2.39.



**Fig. 2.38** | Debugging a solution.

**14. Terminating execution.** Click the running app’s close box (the **x** in the top-right corner of the running app’s window). This action stops the app’s execution and returns the IDE to design mode. You can also select **DEBUG > Stop Debugging** to terminate the app.



**Fig. 2.39** | IDE in run mode, with the running app in the foreground.

## 2.7 Wrap-Up

In this chapter, we introduced key features of the Visual Studio IDE. You visually designed a working Visual C# app without writing a single line of code. Visual C# app development is a mixture of the two styles: Visual app development allows you to develop GUIs easily and avoid tedious GUI programming. “Conventional” programming (which we introduce in Chapter 3) allows you to specify the behavior of your apps.

You created a Visual C# Windows Forms app with one Form. You worked with the IDE’s **Solution Explorer**, **Toolbox** and **Properties** windows, which are essential to developing Visual C# apps. We also demonstrated context-sensitive help, which displays help topics related to selected controls or text.

You used visual app development to design an app’s GUI quickly and easily, by dragging and dropping controls (a Label and a PictureBox) onto a Form or by double clicking controls in the Toolbox.

You used the Properties window to set a Form’s Text and BackColor properties. You learned that Label controls display text and that PictureBoxes display images. You displayed text in a Label and added an image to a PictureBox. You also worked with the Label’s AutoSize, TextAlign and Font properties and the PictureBox’s Image andSizeMode properties.

In the next chapter, we discuss “nonvisual,” or “conventional,” programming—you’ll create your first apps with Visual C# code that you write, instead of having Visual Studio write the code. You’ll also learn memory concepts, arithmetic and decision making.

## 2.8 Web Resources

Please take a moment to visit each of these sites.

[msdn.microsoft.com/vstudio](http://msdn.microsoft.com/vstudio)

This site is the home page for Microsoft Visual Studio. The site includes news, documentation, downloads and other resources.

[msdn.microsoft.com/en-us/vstudio/hh341490.aspx](http://msdn.microsoft.com/en-us/vstudio/hh341490.aspx)

This site provides information on the newest release of Visual C#, including downloads, community information and resources.

[social.msdn.microsoft.com/Forums/en-US/csharpgeneral/thread](http://social.msdn.microsoft.com/Forums/en-US/csharpgeneral/thread)

This site provides access to the Microsoft Visual C# forums, which you can use to get your Visual C# language and IDE questions answered.

[msdn.microsoft.com/en-us/magazine/default.aspx](http://msdn.microsoft.com/en-us/magazine/default.aspx)

This is the Microsoft Developer Network Magazine site. This site provides articles and code on many Visual C# and .NET app development topics. There is also an archive of past issues.

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## Summary

### *Section 2.1 Introduction*

- Visual Studio is Microsoft’s Integrated Development Environment (IDE) for creating, running and debugging apps written in a variety of .NET programming languages.
- Creating simple apps by dragging and dropping predefined building blocks into place is called visual app development.

### *Section 2.2 Overview of the Visual Studio Express 2012 IDE*

- The **Start Page** contains links to Visual Studio 2012 IDE resources and web-based resources.
- A project is a group of related files that compose a app.
- Visual Studio organizes apps into projects and solutions—a solution may contain one or more projects.
- Dialogs are windows that facilitate user–computer communication.
- Visual Studio provides templates for the project types you can create, including Windows Forms apps.
- A **Form** represents the main window of the Windows Forms app that you’re creating.
- Collectively, the **Form** and controls constitute the app’s graphical user interface (GUI), which is the visual part of the app with which the user interacts.

### *Section 2.3 Menu Bar and Toolbar*

- Commands for managing the IDE and for developing, maintaining and executing apps are contained in the menus, which are located on the menu bar.
- Menus contain groups of commands (menu items) that, when selected, cause the IDE to perform actions (for example, open a window, save a file, print a file and execute an app).
- Tool tips help you become familiar with the IDE’s features.

### *Section 2.4 Navigating the Visual Studio IDE*

- The **Solution Explorer** window lists all the files in the solution.
- The **Toolbox** contains controls for customizing **Forms**.

- By using visual app development, you can place predefined controls onto the Form instead of writing the code yourself.
- Clicking an auto-hidden window's name opens that window. Clicking the name again hides it. To “pin down” a window (that is, to disable auto-hide), click its pin icon.
- The **Properties** window displays the properties for a Form, control or file (in **Design** view). Properties are information about a Form or control, such as size, color and position. The **Properties** window allows you to modify Forms and controls visually, without writing code.
- Each control has its own set of properties. The left column of the **Properties** window shows the property names and the right column displays the property values. This window's toolbar contains options for organizing properties alphabetically when the **Alphabetical** icon is selected or categorically (for example, **Appearance**, **Behavior**, **Design**) when the **Categorized** icon is selected.

### **Section 2.5 Using Help**

- Extensive help documentation is available via **Help** menu.
- Context-sensitive help brings up a list of relevant help articles. To use context-sensitive help, select an item and press the *F1* key.

### **Section 2.6 Using Visual App Development to Create a Simple App that Displays Text and an Image**

- Visual C# app development usually involves a combination of writing a portion of the app code and having Visual Studio generate the remaining code.
- The text that appears at the top of the Form (the title bar) is specified in the Form's **Text** property.
- To resize the Form, click and drag one of the Form's enabled sizing handles (the small squares around the Form). Enabled sizing handles appear as white boxes.
- The **BackColor** property specifies the background color of a Form. The Form's background color is the default background color for any controls added to the Form.
- Double clicking any **Toolbox** control icon places a control of that type on the Form. Alternatively, you can drag and drop controls from the **Toolbox** to the Form.
- The **Label**'s **Text** property determines the text (if any) that the **Label** displays. The Form and Label each have their own **Text** property.
- A property's ellipsis button, when clicked, displays a dialog containing additional options.
- In the **Font** dialog, you can select the font for text in the user interface.
- The  **TextAlign** property determines how the text is aligned within a **Label**'s boundaries.
- The  **PictureBox** control displays images. The **Image** property specifies the image to displayed.
- An app that is in design mode is not executing.
- In run mode, the app is executing—you can interact with only a few IDE features.
- When designing an app visually, the name of the Visual C# file appears in the project tab, followed by **[Design]**.
- Terminate execution by clicking the close box.

## **Terminology**

active tab	<b>Categorized icon</b>
<b>Alphabetical</b> icon	component selection drop-down list
auto-hide	context-sensitive help
<b>AutoSize</b> property of <b>Label</b>	control
<b>BackColor</b> property of <b>Form</b>	<b>Custom</b> tab

Design view	scrollbar
dialog	scrollbox
dragging	Select Resource dialog
ellipsis button	Show All Files icon
Font dialog	SizeMode property of PictureBox
Font property of Label	sizing handle
Form	solution
graphical user interface (GUI)	Solution Explorer in Visual Studio
Help menu	Start Page
icon	startup project
Image property of PictureBox	StretchImage value
Label	templates for projects
New Project dialog	Text property
palette	TextAlign property of Label
PictureBox	tool tip
project	toolbar
Properties window	visual app development
property of a Form or control	Visual Studio 2012
run mode	Windows Forms app

## Self-Review Exercises

**2.1** Fill in the blanks in each of the following statements:

- a) The technique of \_\_\_\_\_ allows you to create GUIs without writing any code.
- b) A(n) \_\_\_\_\_ is a group of one or more projects that collectively form a Visual C# app.
- c) The \_\_\_\_\_ feature hides a window in the IDE.
- d) A(n) \_\_\_\_\_ appears when the mouse pointer hovers over an icon.
- e) The \_\_\_\_\_ window allows you to browse solution files.
- f) The properties in the Properties window can be sorted \_\_\_\_\_ or \_\_\_\_\_.
- g) A Form's \_\_\_\_\_ property specifies the text displayed in the Form's title bar.
- h) The \_\_\_\_\_ contains the controls that you can add to a Form.
- i) \_\_\_\_\_ displays relevant help articles, based on the current context.
- j) The \_\_\_\_\_ property specifies how text is aligned within a Label's boundaries.

**2.2** State whether each of the following is *true* or *false*. If *false*, explain why.

- a) toggles auto-hide for a window.
- b) The toolbar icons represent various menu commands.
- c) The toolbar contains icons that represent controls you can drag onto a Form.
- d) Both Forms and Labels have a title bar.
- e) Control properties can be modified only by writing code.
- f) Picture Boxes typically display images.
- g) Visual C# files use the file extension .csharp.
- h) A Form's background color is set using the BackColor property.

## Answers to Self-Review Exercises

**2.1** a) visual app development. b) solution. c) auto-hide. d) tool tip. e) Solution Explorer. f) alphabetically, categorically. g) Text. h) Toolbox. i) context-sensitive help. j) TextAlign.

**2.2** a) False. The pin icon () toggles auto-hide. closes a window. b) True. c) False. The Toolbox contains icons that represent such controls. d) False. Forms have a title bar but Labels do not (although they do have Label text). e) False. Control properties can be modified using the Properties window. f) True. g) False. Visual C# files use the file extension .cs. h) True.

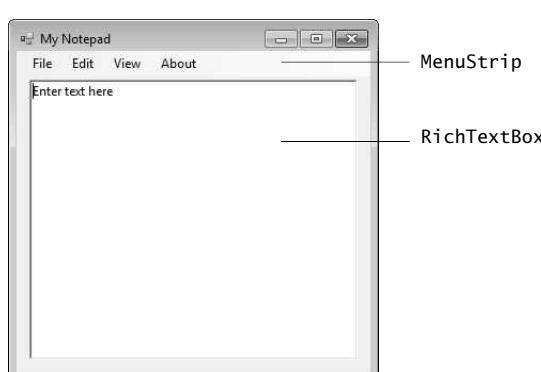
## Exercises

- 2.3** Fill in the blanks in each of the following statements:
- When an ellipsis button is clicked, a(n) \_\_\_\_\_ is displayed.
  - Using \_\_\_\_\_ help immediately displays a relevant help article.
  - GUI is an acronym for \_\_\_\_\_.
  - The \_\_\_\_\_ property specifies which image a PictureBox displays.
  - The \_\_\_\_\_ menu contains commands for arranging and displaying windows.
- 2.4** State whether each of the following is *true* or *false*. If *false*, explain why.
- You can add a control to a Form by double clicking its control icon in the **Toolbox**.
  - The **Form**, **Label** and **PictureBox** have identical properties.
  - If your machine is connected to the Internet, you can browse websites from the Visual Studio IDE.
  - Visual C# app developers usually create complex apps without writing any code.
  - Sizing handles are visible during execution.
- 2.5** Some features that appear throughout Visual Studio perform similar actions in different contexts. Explain and give examples of how the ellipsis buttons, down-arrow buttons and tool tips act in this manner. Why do you think the Visual Studio IDE was designed this way?
- 2.6** Briefly describe each of the following terms:
- toolbar
  - menu bar
  - Toolbox**
  - control
  - Form
  - solution

### Note Regarding Exercises 2.7–2.11

In the following exercises, you're asked to create GUIs using controls that we have not yet discussed in this book. These exercises give you practice with visual app development only—the apps do not perform any actions. You place controls from the **Toolbox** on a Form to familiarize yourself with what each control looks like. We have provided step-by-step instructions for you. If you follow these, you should be able to replicate the screen images we provide.

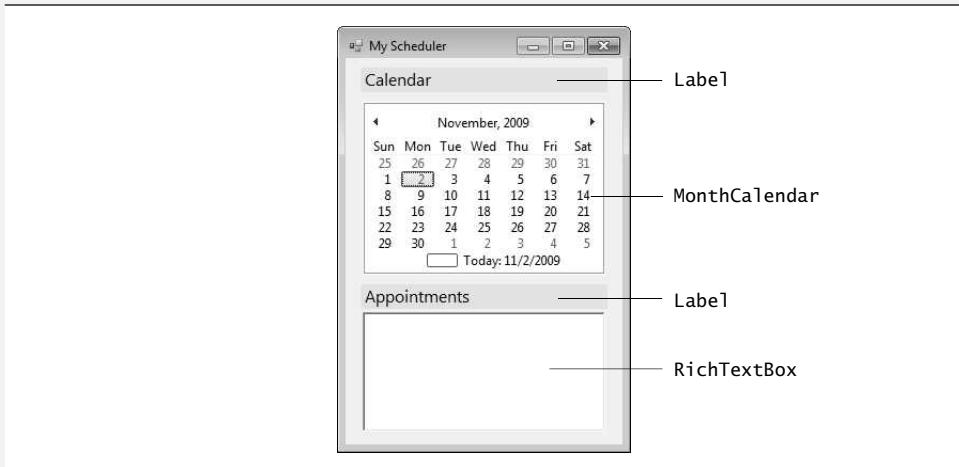
- 2.7** (*Notepad GUI*) Create the GUI for the notepad as shown in Fig. 2.40.



**Fig. 2.40** | Notepad GUI.

- Manipulating the Form's properties.* Change the Text property of the Form to My Note-pad. Change the Font property to 9pt Segoe UI.
- Adding a ToolStrip control to the Form.* Add a ToolStrip to the Form. After inserting the ToolStrip, add items by clicking the Type Here section, typing a menu name (for example, File, Edit, View and About) and then pressing Enter.
- Adding a RichTextBox to the Form.* Drag this control onto the Form. Use the sizing handles to resize and position the RichTextBox as shown in Fig. 2.40. Change the Text property to Enter text here.

**2.8** (*Calendar and Appointments GUI*) Create the GUI for the calendar as shown in Fig. 2.41.

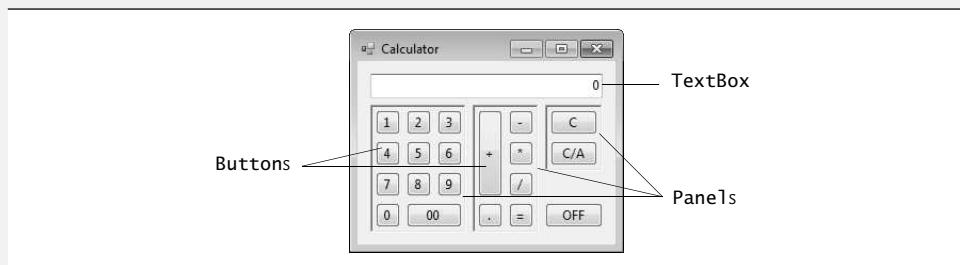


**Fig. 2.41** | Calendar and appointments GUI.

- Manipulating the Form's properties.* Change the Text property of the Form to My Scheduler. Change the Font property to 9pt Segoe UI. Set the Form's Size property to 275, 400.
- Adding Labels to the Form.* Add two Labels to the Form. Both should be of equal size (231, 23; remember to set the AutoSize property to False) and should be centered in the Form horizontally, as shown. Set the Label's Text properties to match Fig. 2.41. Use 12-point font size. Also, set the BackColor property to Yellow.
- Adding a MonthCalendar control to the Form.* Add this control to the Form and center it horizontally in the appropriate place between the two Labels.
- Adding a RichTextBox control to the Form.* Add a RichTextBox control to the Form and center it below the second Label. Resize the RichTextBox accordingly.

**2.9** (*Calculator GUI*) Create the GUI for the calculator as shown in Fig. 2.42.

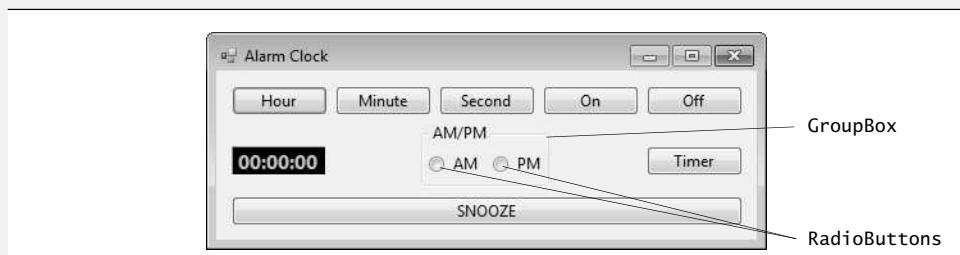
- Manipulating the Form's properties.* Change the Text property of the Form to Calculator. Change the Font property to 9pt Segoe UI. Change the Size property of the Form to 258, 210.
- Adding a TextBox to the Form.* Set the TextBox's Text property in the Properties window to 0. Stretch the TextBox and position it as shown in Fig. 2.42. Set the TextAlign property to Right—this right aligns text displayed in the TextBox.
- Adding the first Panel to the Form.* Panel controls are used to group other controls. Add a Panel to the Form. Change the Panel's BorderStyle property to Fixed3D to make the inside of the Panel appear recessed. Change the Size property to 90, 120. This Panel will contain the calculator's numeric keys.



**Fig. 2.42** | Calculator GUI.

- d) **Adding the second Panel to the Form.** Change the Panel's BorderStyle property to Fixed3D. Change the Size property to 62, 120. This Panel will contain the calculator's operator keys.
- e) **Adding the third (and last) Panel to the Form.** Change the Panel's BorderStyle property to Fixed3D. Change the Size property to 54, 62. This Panel contains the calculator's C (clear) and C/A (clear all) keys.
- f) **Adding Buttons to the Form.** There are 20 Buttons on the calculator. Add a Button to the Panel by dragging and dropping it on the Panel. Change the Text property of each Button to the calculator key it represents. The value you enter in the Text property will appear on the face of the Button. Finally, resize the Buttons, using their Size properties. Each Button labeled 0–9, \*, /, -, = and . should have a size of 23, 23. The 00 Button has size 52, 23. The OFF Button has size 54, 23. The + Button is sized 23, 81. The C (clear) and C/A (clear all) Buttons are sized 44, 23.

**2.10** (*Alarm Clock GUI*) Create the GUI for the alarm clock as shown in Fig. 2.43.



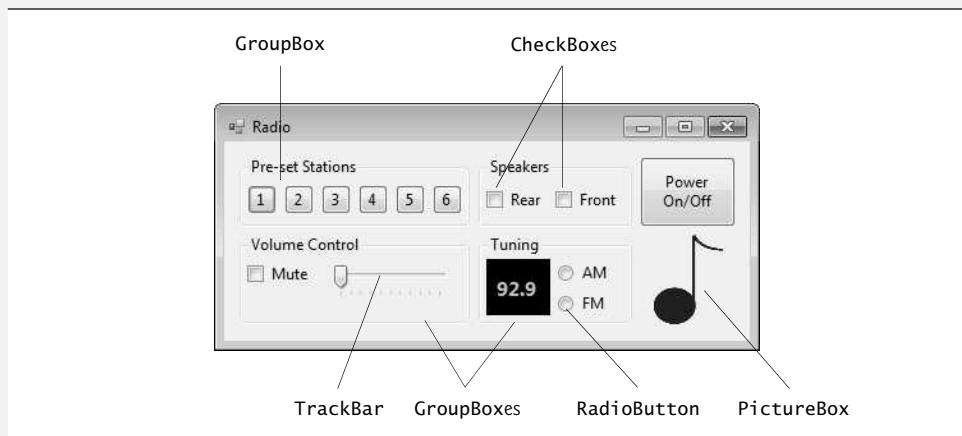
**Fig. 2.43** | Alarm clock GUI.

- a) **Manipulating the Form's properties.** Change the Text property of the Form to Alarm Clock. Change the Font property to 9pt Segoe UI. Change the Size property of the Form to 438, 170.
- b) **Adding Buttons to the Form.** Add seven Buttons to the Form. Change the Text property of each Button to the appropriate text. Align the Buttons as shown.
- c) **Adding a GroupBox to the Form.** GroupBoxes are like Panels, except that GroupBoxes display a title. Change the Text property to AM/PM, and set the Size property to 100, 50. Center the GroupBox horizontally on the Form.
- d) **Adding AM/PM RadioButtons to the GroupBox.** Place two RadioButtons in the GroupBox. Change the Text property of one RadioButton to AM and the other to PM. Align the RadioButtons as shown.

- e) *Adding the time Label to the Form.* Add a Label to the Form and change its Text property to 00:00:00. Change the BorderStyle property to Fixed3D and the BackColor to Black. Use the Font property to make the time bold and 12pt. Change the ForeColor to Silver (located in the Web tab) to make the time stand out against the black background. Position the Label as shown.

**2.11 (Radio GUI)** Create the GUI for the radio as shown in Fig. 2.44. [Note: The image used in this exercise is located in the examples folder for Chapter 2.]

- a) *Manipulating the Form's properties.* Change the Font property to 9pt Segoe UI. Change the Form's Text property to Radio and the Size to 427, 194.



**Fig. 2.44** | Radio GUI.

- b) *Adding the Pre-set Stations GroupBox and Buttons.* Set the GroupBox's Size to 180, 55 and its Text to Pre-set Stations. Add six Buttons to the GroupBox. Set each one's Size to 23, 23. Change the Buttons' Text properties to 1, 2, 3, 4, 5, 6, respectively.
- c) *Adding the Speakers GroupBox and Checkboxes.* Set the GroupBox's Size to 120, 55 and its Text to Speakers. Add two CheckBoxes to the GroupBox. Set the Text properties for the CheckBoxes to Rear and Front.
- d) *Adding the Power On/Off Button.* Add a Button to the Form. Set its Text to Power On/Off and its Size to 75, 55.
- e) *Adding the Volume Control GroupBox, the Mute CheckBox and the Volume TrackBar.* Add a GroupBox to the Form. Set its Text to Volume Control and its Size to 180, 70. Add a CheckBox to the GroupBox. Set its Text to Mute. Add a TrackBar to the GroupBox.
- f) *Adding the Tuning GroupBox, the radio station Label and the AM/FM RadioButtons.* Add a GroupBox to the Form. Set its Text to Tuning and its Size to 120, 70. Add a Label to the GroupBox. Set its AutoSize to False, its Size to 50, 44, its BackColor to Black, its ForeColor to Silver, its font to 12pt bold and its TextAlign to MiddleCenter. Set its Text to 92.9. Place the Label as shown in the figure. Add two RadioButtons to the GroupBox. Set the Text of one to AM and of the other to FM.
- g) *Adding the image.* Add a PictureBox to the Form. Set itsSizeMode to StretchImage and its Size to 55, 70. Set the Image property to MusicNote.gif (located in the examples folder for Chapter 2).

# 3

## Introduction to C# Apps



*What's in a name?  
That which we call a rose  
by any other name  
would smell as sweet.*  
—William Shakespeare

### Objectives

In this chapter you'll:

- Write simple C# apps using code rather than visual programming.
- Input data from the keyboard and output data to the screen.
- Declare and use data of various types.
- Store data in memory and retrieve it.
- Use arithmetic operators.
- Determine the order in which operators are applied.
- Write decision-making statements.
- Use relational and equality operators.

- |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>3.1</b> Introduction<br><b>3.2</b> A Simple C# App: Displaying a Line of Text<br><b>3.3</b> Creating a Simple App in Visual Studio<br><b>3.4</b> Modifying Your Simple C# App<br><b>3.5</b> Formatting Text with <code>Console.WriteLine</code> and <code>Console.WriteLine</code> | <b>3.6</b> Another C# App: Adding Integers<br><b>3.7</b> Memory Concepts<br><b>3.8</b> Arithmetic<br><b>3.9</b> Decision Making: Equality and Relational Operators<br><b>3.10</b> Wrap-Up |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 3.1 Introduction

We now introduce C# app programming. Most of the C# apps you'll study in this book process information and display results. In this chapter, we introduce **console apps**—these input and output text in a *console window*, which in Windows is known as the **Command Prompt**.

We begin with several examples that simply display messages on the screen. We then demonstrate an app that obtains two numbers from a user, calculates their sum and displays the result. You'll perform various arithmetic calculations and save the results for later use. Many apps contain logic that makes *decisions*—the last example in this chapter demonstrates decision-making fundamentals by showing you how to compare numbers and display messages based on the comparison results. For example, the app displays a message indicating that two numbers are equal only if they have the same value. We analyze each code example one line at a time.

## 3.2 A Simple C# App: Displaying a Line of Text

Let's consider a simple app that displays a line of text. The app and its output are shown in Fig. 3.1, which illustrates several important C# language features. Each program we present in this book includes line numbers, which are *not* part of actual C# code. In the Before You Begin section that follows the Preface, we show how to display line numbers for your C# code. We'll soon see that line 10 does the real work of the app—namely, displaying the phrase `Welcome to C# Programming!` on the screen. We now discuss each line of the app—this process is called a **code walkthrough**.

### Comments

Line 1

```
// Fig. 3.1: Welcome1.cs
```

begins with `//`, indicating that the remainder of the line is a **comment**. You'll insert comments to document your apps and improve their readability. The C# compiler ignores comments, so they do *not* cause the computer to perform any action when the app is run. We begin every app with a comment indicating the figure number and the name of the file in which the app is stored.

A comment that begins with `//` is called a **single-line comment**, because it terminates at the end of the line on which it appears. A `//` comment also can begin in the middle of a line and continue until the end of that line (as in lines 7, 11 and 12).

```

1 // Fig. 3.1: Welcome1.cs
2 // Text-displaying app.
3 using System;
4
5 public class Welcome1
6 {
7     // Main method begins execution of C# app
8     public static void Main( string[] args )
9     {
10         Console.WriteLine( "Welcome to C# Programming!" );
11     } // end Main
12 } // end class Welcome1

```

Welcome to C# Programming!

**Fig. 3.1** | Text-displaying app.

**Delimited comments** such as

```

/* This is a delimited comment.
It can be split over many lines */

```

can be split over several lines. This type of comment begins with the delimiter **/\*** and ends with the delimiter **\*/**. All text between the delimiters is ignored by the compiler.



### Common Programming Error 3.1

*Forgetting one of the delimiters of a delimited comment is a syntax error. The syntax of a programming language specifies the rules for creating a proper app in that language. A syntax error occurs when the compiler encounters code that violates C#'s language rules. In this case, the compiler does not produce an executable file. Instead, it issues one or more error messages to help you identify and fix the incorrect code. Syntax errors are also called compiler errors, compile-time errors or compilation errors, because the compiler detects them during the compilation phase. You'll be unable to execute your app until you correct all the syntax errors in it.*

Line 2

```
// Text-displaying app.
```

is a single-line comment that describes the purpose of the app.

**using Directive**

Line 3

```
using System;
```

is a **using** directive that tells the compiler where to look for a class that's used in this app. A great strength of Visual C# is its rich set of predefined classes that you can reuse rather than “reinventing the wheel.” These classes are organized under namespaces—named collections of related classes. Collectively, .NET’s namespaces are referred to as the .NET Framework Class Library. Each **using** directive identifies a namespace containing predefined classes that a C# app should be able to use. The **using** directive in line 3 indicates that this example in-

tends to use classes from the `System` namespace, which contains the predefined `Console` class (discussed shortly) used in line 10, and many other useful classes.



### Error-Prevention Tip 3.1

*Forgetting to include a `using` directive for a namespace that contains a class used in your app typically results in a compilation error, containing a message such as “The name ‘Console’ does not exist in the current context.” When this occurs, check that you provided the proper `using` directives and that the names in the `using` directives are spelled correctly, including proper use of uppercase and lowercase letters.*

For each new .NET class we use, we indicate the namespace in which it's located. This information is important, because it helps you locate descriptions of each class in the .NET documentation. A web-based version of this documentation can be found at

[msdn.microsoft.com/en-us/library/ms229335.aspx](http://msdn.microsoft.com/en-us/library/ms229335.aspx)

This can also be accessed via the **Help** menu. You can click the name of any .NET class or method, then press the *F1* key to get more information. Finally, you can learn about the contents of a given namespace by going to

[msdn.microsoft.com/namespace](http://msdn.microsoft.com/namespace)

So, `msdn.microsoft.com/System` takes you to namespace `System`'s documentation.

### Blank Lines and Whitespace

Line 4 is simply a *blank line*. Blank lines and space characters make code easier to read, and together with tab characters are known as **whitespace**. Space characters and tabs are known specifically as **whitespace characters**. Whitespace is ignored by the compiler.

### Class Declaration

Line 5

`public class Welcome1`

begins a **class declaration** for the class `Welcome1`. Every app consists of at least one class declaration that's defined by you—the programmer. These are known as **user-defined classes**. The **class keyword** introduces a class declaration and is immediately followed by the **class name** (`Welcome1`). Keywords (sometimes called **reserved words**) are reserved for use by C# and are always spelled with all lowercase letters. The complete list of C# keywords is shown in Fig. 3.2.

### C# Keywords and contextual keywords

<code>abstract</code>	<code>as</code>	<code>base</code>	<code>bool</code>	<code>break</code>
<code>byte</code>	<code>case</code>	<code>catch</code>	<code>char</code>	<code>checked</code>
<b>class</b>	<code>const</code>	<code>continue</code>	<code>decimal</code>	<code>default</code>
<code>delegate</code>	<code>do</code>	<code>double</code>	<code>else</code>	<code>enum</code>
<code>event</code>	<code>explicit</code>	<code>extern</code>	<code>false</code>	<code>finally</code>
<code>fixed</code>	<code>float</code>	<code>for</code>	<code>foreach</code>	<code>goto</code>

**Fig. 3.2** | C# keywords and contextual keywords. (Part 1 of 2.)

C# Keywords and contextual keywords				
if	implicit	in	int	interface
internal	is	lock	long	namespace
new	null	object	operator	out
override	params	private	protected	<b>public</b>
readonly	ref	return	sbyte	sealed
short	sizeof	stackalloc	<b>static</b>	string
struct	switch	this	throw	true
try	typeof	uint	ulong	unchecked
unsafe	ushort	<b>using</b>	virtual	<b>void</b>
volatile	while			
<i>Contextual Keywords</i>				
add	alias	ascending	async	await
by	descending	dynamic	equals	from
get	global	group	into	join
let	on	orderby	partial	remove
select	set	value	var	where
yield				

**Fig. 3.2** | C# keywords and contextual keywords. (Part 2 of 2.)

### Class Name Convention

By convention, all class names begin with a capital letter and capitalize the first letter of each word they include (e.g., `SampleClassName`). This convention is known as **upper camel casing**. A class name is an **identifier**—a series of characters consisting of letters, digits and underscores (`_`) that does not begin with a digit and does not contain spaces. Some valid identifiers are `Welcome1`, `identifier`, `_value` and `m_inputField1`. The name `7button` is *not* a valid identifier because it begins with a digit, and the name `input field` is *not* a valid identifier because it contains a space. Normally, an identifier that does not begin with a capital letter is not the name of a class. C# is **case sensitive**—that is, uppercase and lowercase letters are distinct, so `a1` and `A1` are different (but both valid) identifiers.<sup>1</sup>



### Good Programming Practice 3.1

*By convention, always begin a class name's identifier with a capital letter and start each subsequent word in the identifier with a capital letter.*



### Common Programming Error 3.2

*C# is case sensitive. Not using the proper uppercase and lowercase letters for an identifier normally causes a compilation error.*

- Identifiers may also be preceded by the @ character. This indicates that a word should be interpreted as an identifier, even if it's a keyword (e.g., `@int`). This allows C# code to use code written in other .NET languages where an identifier might have the same name as a C# keyword. The **contextual keywords** in Fig. 3.2 can be used as identifiers outside the contexts in which they're keywords, but for clarity this is not recommended.

***public Class***

In Chapters 3–9, every class we define begins with the keyword **public**. For now, we'll simply require this keyword. You'll learn more about classes in Chapter 10. When you save your **public** class declaration in a file, the file name is usually the class name followed by the **.cs** file-name extension. For our app, the file name is **Welcome1.cs**.

**Good Programming Practice 3.2**

*By convention, a file that contains a single **public** class should have a name that's identical to the class name (plus the **.cs** extension) in both spelling and capitalization.*

***Body of a Class Declaration***

A **left brace** (in line 6 in Fig. 3.1), **{**, begins the **body** of every class declaration. A corresponding **right brace** (in line 12), **}**, must end each class declaration. Lines 7–11 are indented. This indentation is a *spacing convention*. We define each spacing convention as a *Good Programming Practice*.

**Error-Prevention Tip 3.2**

*Whenever you type an opening left brace, **{**, in your app, immediately type the closing right brace, **}**, then reposition the cursor between the braces and indent to begin typing the body. This practice helps prevent errors due to missing braces.*

**Good Programming Practice 3.3**

*Indent the entire body of each class declaration one “level” of indentation between the left and right braces that delimit the body of the class. This format emphasizes the class declaration’s structure and makes it easier to read. You can let the IDE format your code by selecting **Edit > Advanced > Format Document**.*

**Good Programming Practice 3.4**

*Set a convention for the indent size you prefer, then uniformly apply that convention. The Tab key may be used to create indents, but tab stops vary among text editors. We recommend using three spaces to form each level of indentation. We show how to do this in the Before You Begin section that follows the Preface.*

**Common Programming Error 3.3**

*It's a syntax error if braces do not occur in matching pairs.*

***Main Method***

Line 7

```
// Main method begins execution of C# app
```

is a comment indicating the purpose of lines 8–11 of the app. Line 8

```
public static void Main( string[] args )
```

is the starting point of every app. The parentheses after the identifier **Main** indicate that it's an app building block called a **method**. Class declarations normally contain one or more methods. Method names usually follow the same capitalization conventions used for

class names. For each app, one of the methods in a class *must* be called `Main` (which is typically defined as shown in line 8); otherwise, the app will not execute. Methods are able to perform tasks and return information when they complete their tasks. Keyword `void` (line 8) indicates that this method will *not* return any information after it completes its task. Later, we'll see that many methods do return information. You'll learn more about methods in Chapters 4 and 7. We discuss the contents of `Main`'s parentheses in Chapter 8. For now, simply mimic `Main`'s first line in your apps.

### *Body of a Method Declaration*

The left brace in line 9 begins the **body of the method declaration**. A corresponding right brace must end the method's body (line 11). Line 10 in the body of the method is indented between the braces.



### Good Programming Practice 3.5

*As with class declarations, indent the entire body of each method declaration one “level” of indentation between the left and right braces that define the method body.*

### *Displaying a Line of Text*

Line 10

```
Console.WriteLine( "Welcome to C# Programming!" );
```

instructs the computer to **perform an action**—namely, to display the **string** of characters between the double quotation marks, which *delimit* the string. A string is sometimes called a **character string**, a **message** or a **string literal**. We refer to them simply as strings. Whitespace characters in strings are *not* ignored by the compiler.

Class `Console` provides **standard input/output** capabilities that enable apps to read and display text in the console window from which the app executes. The **Console.WriteLine** method displays a line of text in the console window. The string in the parentheses in line 10 is the **argument** to the method. Method `Console.WriteLine` performs its task by displaying its argument in the console window. When `Console.WriteLine` completes its task, it positions the **screen cursor** (the blinking symbol indicating where the next character will be displayed) at the beginning of the next line in the console window. This movement of the cursor is similar to what happens when a user presses the *Enter* key while typing in a text editor—the cursor moves to the beginning of the next line in the file.

### *Statements*

The entire line 10, including `Console.WriteLine`, the parentheses, the argument "Welcome to C# Programming!" in the parentheses and the **semicolon** (;), is called a **statement**. Most statements end with a semicolon. When the statement in line 10 executes, it displays the message `Welcome to C# Programming!` in the console window. A method is typically composed of one or more statements that perform the method's task.



### Error-Prevention Tip 3.3

*When the compiler reports a syntax error, the error may not be in the line indicated by the error message. First, check the line for which the error was reported. If that line does not contain syntax errors, check several preceding lines.*

### *Matching Left { and Right } Braces*

You may find it difficult when reading or writing an app to match the left and right braces ({ and }) that delimit the body of a class declaration or a method declaration. To help, you can include a comment after each closing right brace (}) that ends a method declaration and after each closing right brace that ends a class declaration. For example, line 11

```
 } // end Main
```

specifies the closing right brace of method `Main`, and line 12

```
 } // end class Welcome1
```

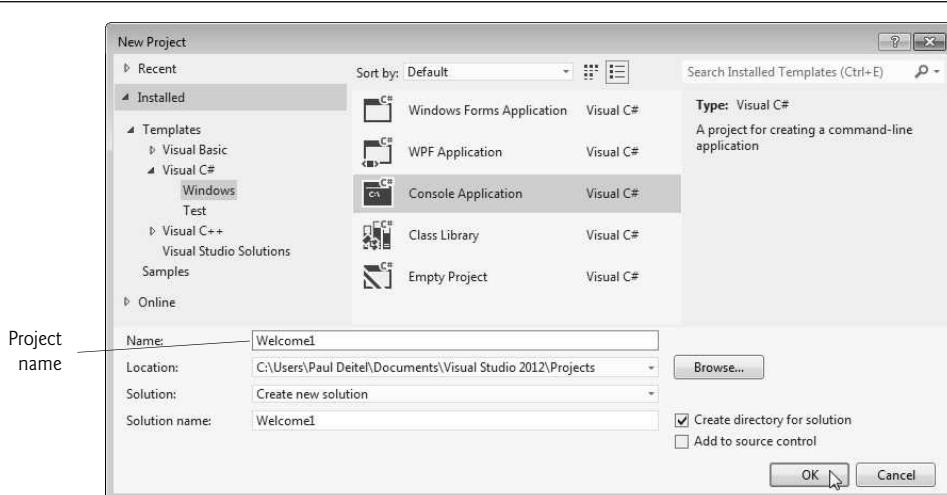
specifies the closing right brace of class `Welcome1`. Each of these comments indicates the method or class that the right brace terminates. Visual Studio can help you locate matching braces in your code. Simply place the cursor immediately in front of the left brace or immediately after the right brace, and Visual Studio will highlight both.

## 3.3 Creating a Simple App in Visual Studio

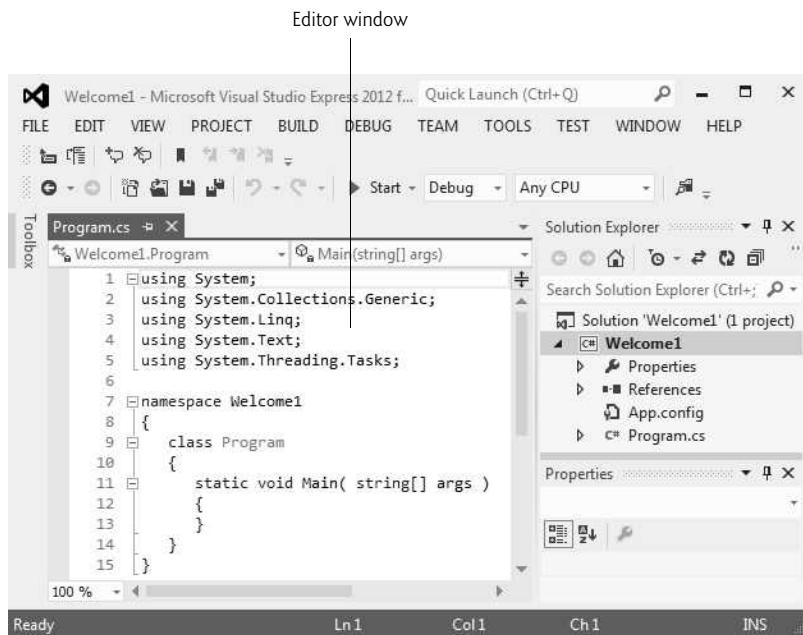
Now that we've presented our first console app (Fig. 3.1), we provide a step-by-step explanation of how to create, compile and execute it using Visual Studio 2012 Express for Windows Desktop, which we'll refer to simply as Visual Studio from this point forward.

### *Creating the Console App*

After opening Visual Studio, select **FILE > New Project...** to display the **New Project** dialog (Fig. 3.3). At the left side of the dialog, under **Installed > Templates > Visual C#** select the **Windows** category, then in the middle of the dialog select the **Console Application** template. In the dialog's **Name** field, type `Welcome1`, then click **OK** to create the project. By default, the project's folder will be placed in your account's Documents folder under `Visual Studio 2012\Projects`. The IDE now contains the open console app, as shown in Fig. 3.4. The editor window already contains some code provided by the IDE. Some of



**Fig. 3.3** | Creating a **Console Application** with the **New Project** dialog.



**Fig. 3.4** | IDE with an open console app.

this code is similar to that of Fig. 3.1. Some is not, and uses features that we have not yet discussed. The IDE inserts this extra code to help organize the app and to provide access to some common classes in the .NET Framework Class Library—at this point in the book, this code is neither required nor relevant to the discussion of this app; delete all of it.

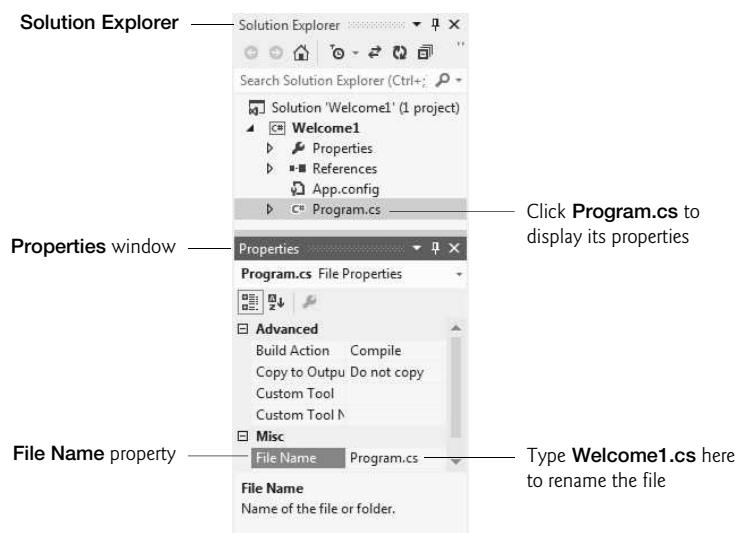
The code coloring scheme used by the IDE is called **syntax-color highlighting** and helps you visually differentiate app elements. For example, keywords appear in blue and comments appear in green. We syntax-shade our code similarly—bold for keywords, gray for comments, bold gray for literals and constants, and black for other text. One example of a literal is the string passed to `Console.WriteLine` in line 10 of Fig. 3.1. You can customize the colors shown in the code editor by selecting **Tools > Options....** This displays the **Options** dialog. Then expand the **Environment** node and select **Fonts and Colors**. Here you can change the colors for various code elements.

### Configuring the Editor Window

Visual Studio provides many ways to personalize your coding experience. In the Before You Begin section that follows the Preface, we show how to configure the IDE to display line numbers at the left side of the editor window and how to specify indent sizes that match our code examples.

### Changing the Name of the App File

For the apps we create in this book, we change the default name of the source-code file (i.e., `Program.cs`) to a more descriptive name. To rename the file, click `Program.cs` in the **Solution Explorer** window. This displays the app file's properties in the **Properties** window (Fig. 3.5). Change the **File Name** property to `Welcome1.cs` and press *Enter*.

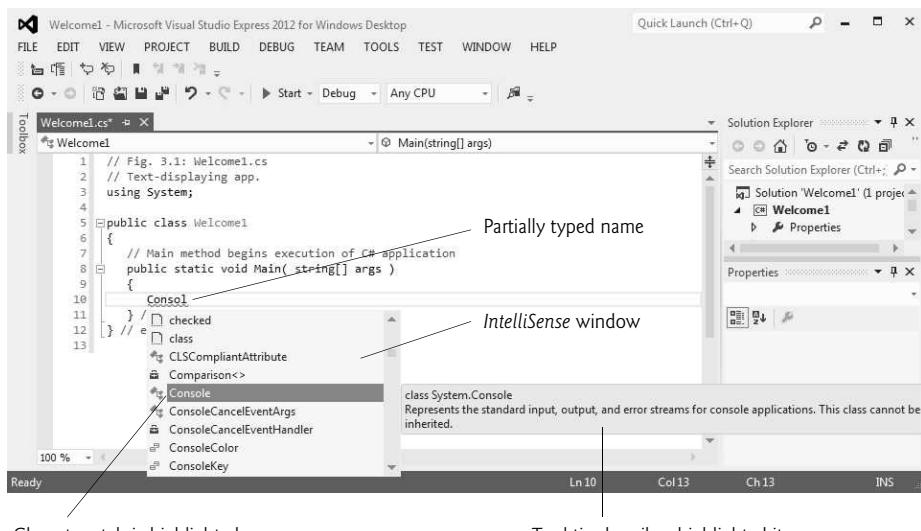


**Fig. 3.5** | Renaming the program file in the **Properties** window.

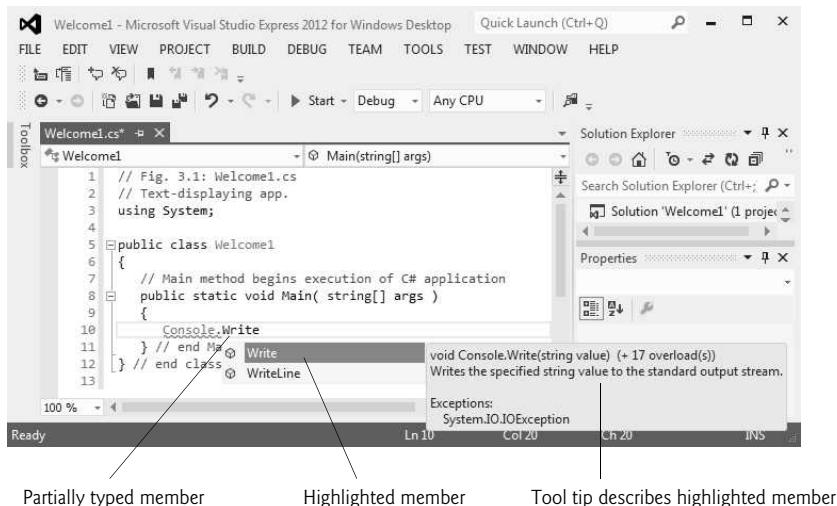
### Writing Code and Using IntelliSense

In the editor window (Fig. 3.4), replace the IDE-generated code with the code from Fig. 3.1. As you begin typing the class name `Console` (line 10), an *IntelliSense* window is displayed (Fig. 3.6(a)). As you type, *IntelliSense* lists various items that start with or contain the letters you've typed so far. *IntelliSense* also displays a tool tip containing a description of the first

a) *IntelliSense* window displayed as you type



**Fig. 3.6** | *IntelliSense*. (Part 1 of 2.)

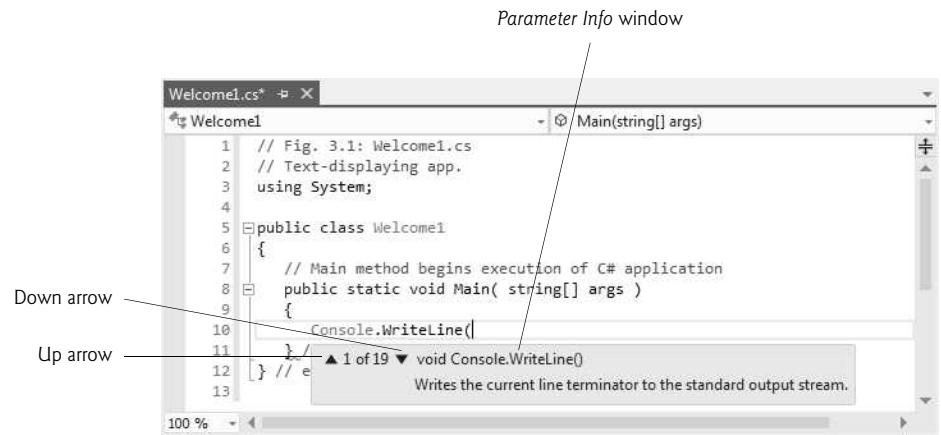
b) *IntelliSense* window showing method names that start with `Write`**Fig. 3.6** | *IntelliSense*. (Part 2 of 2.)

**matching item.** You can either type the complete item name (e.g., `Console`), double click the item name in the member list or press the *Tab* key to complete the name. Once the complete name is provided, the *IntelliSense* window closes. While the *IntelliSense* window is displayed, **pressing the *Ctrl* key makes the window transparent so you can see the code behind the window.**

When you type the dot (.) after `Console`, the *IntelliSense* window reappears and shows only the **members of class `Console` that can be used on the right of the dot** (Fig. 3.6(b)). When you type the open parenthesis character, (, after `Console.WriteLine`, the *Parameter Info* window is displayed (Fig. 3.7). This window contains information about the method's parameters. As you'll learn in Chapter 7, there can be several versions of a method. That is, a class can define several methods that have the *same* name, as long as they have *different* numbers and/or types of parameters—a concept known as *overloaded methods*. These methods normally all perform similar tasks. The *Parameter Info* window indicates how many versions of the selected method are available and provides up and down arrows for scrolling through the different versions. For example, there are 19 versions of the `WriteLine` method—we use one of these 19 versions in our app. The *Parameter Info* window is one of many features provided by the IDE to facilitate app development. In the next several chapters, you'll learn more about the information displayed in these windows. The *Parameter Info* window is especially helpful when you want to see the different ways in which a method can be used. From the code in Fig. 3.1, we already know that we intend to display one string with `WriteLine`, so, because you know exactly which version of `WriteLine` you want to use, you can simply close the *Parameter Info* window by pressing the *Esc* key.

### Saving the App

After you type the app's code, select **FILE > Save All** to save the project.



**Fig. 3.7** | Parameter Info window.

### Compiling and Running the App

You're now ready to compile and execute your app. Depending on the project's type, the compiler may compile the code into files with the **.exe (executable) extension**, the **.dll (dynamically linked library) extension** or one of several other extensions. Such files are called **assemblies** and are the packaging units for compiled C# code. These assemblies contain the Microsoft Intermediate Language (MSIL) code for the app.

To compile the app, select **BUILD > Build Solution**. If the app contains no syntax errors, this will compile your app and build it into an executable file (named `Welcome1.exe`, in one of the project's subdirectories). To execute it, type **Ctrl + F5**, which invokes the `Main` method (Fig. 3.1). If you attempt to run the app before building it, the IDE will build the app first, then run it only if there are no compilation errors. The statement in line 10 of `Main` displays `Welcome to C# Programming!`. Figure 3.8 shows the results of executing this app, displayed in a console (Command Prompt) window. Leave the app's project open in Visual Studio; we'll go back to it later in this section. [Note: The console window normally has a black background and white text. We reconfigured it to have a white background and black text for readability. If you'd like to do this, click the icon in the upper-left corner of the console window, then select **Properties**. You can change the colors in the **Colors** tab of the dialog that appears.]



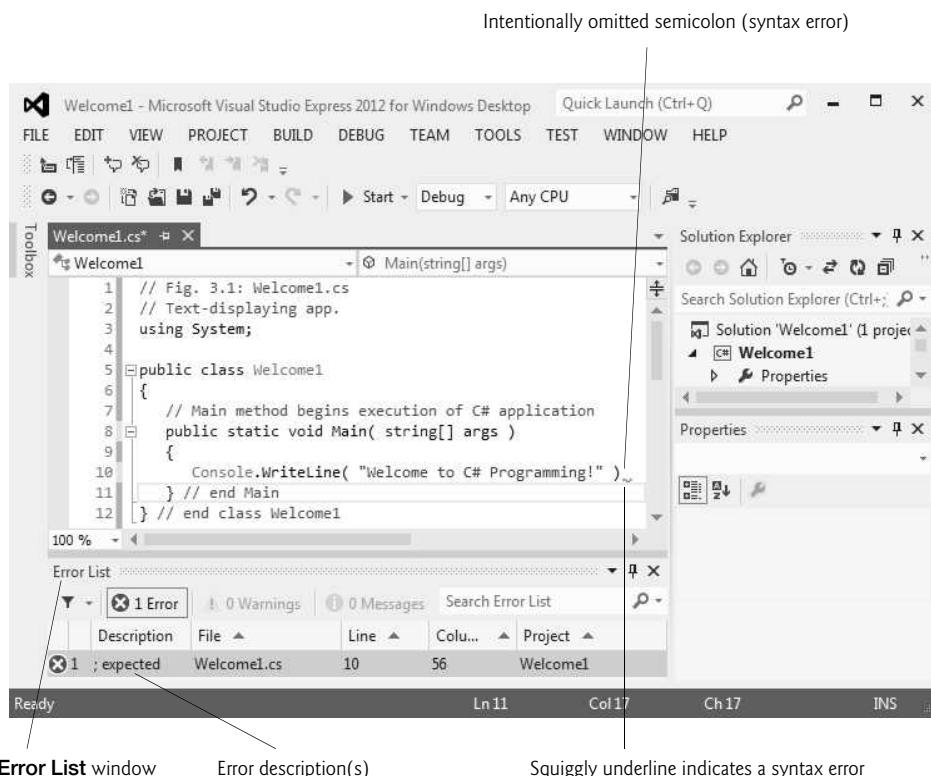
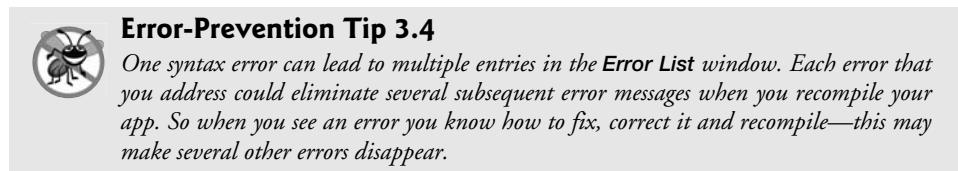
**Fig. 3.8** | Executing the app shown in Fig. 3.1.

### Syntax Errors, Error Messages and the Error List Window

Go back to the app in Visual Studio. As you type code, the IDE responds either by applying syntax-color highlighting or by generating a **syntax error**, which indicates a violation of Visual C#'s rules for creating correct apps (i.e., one or more statements are not written

correctly). Syntax errors occur for various reasons, such as missing parentheses and misspelled keywords.

When a syntax error occurs, the IDE underlines the location of the error with a red squiggly line and provides a description of it in the **Error List** window (Fig. 3.9). If the **Error List** window is not visible in the IDE, select **VIEW > Error List** to display it. In Figure 3.9, we intentionally omitted the semicolon at the end of the statement in line 10. The error message indicates that the semicolon is missing. You can double click an error message in the **Error List** to jump to the error's location in the code.



**Fig. 3.9** | Syntax error indicated by the IDE.

## 3.4 Modifying Your Simple C# App

This section continues our introduction to C# programming with two examples that modify the example of Fig. 3.1.

*Displaying a Single Line of Text with Multiple Statements*

Class `Welcome2`, shown in Fig. 3.10, uses two statements to produce the same output as that shown in Fig. 3.1. From this point forward, we highlight the new and key features in each code listing, as shown in lines 10–11 of Fig. 3.10.

```

1 // Fig. 3.10: Welcome2.cs
2 // Displaying one line of text with multiple statements.
3 using System;
4
5 public class Welcome2
6 {
7     // Main method begins execution of C# app
8     public static void Main( string[] args )
9     {
10         Console.WriteLine( "Welcome to " );
11         Console.WriteLine( "C# Programming!" );
12     } // end Main
13 } // end class Welcome2

```



Welcome to C# Programming!

**Fig. 3.10** | Displaying one line of text with multiple statements.

The app is almost identical to Fig. 3.1. We discuss the changes here. Line 2

```
// Displaying one line of text with multiple statements.
```

states the purpose of this app. Line 5 begins the `Welcome2` class declaration.

Lines 10–11 of method `Main`

```

Console.WriteLine( "Welcome to " );
Console.WriteLine( "C# Programming!" );

```

display one line of text in the console window. The first statement uses `Console`'s method `Write` to display a string. Unlike `WriteLine`, after displaying its argument, `Write` does *not* position the screen cursor at the beginning of the next line in the console window—the next character the app displays will appear immediately after the last character that `Write` displays. Thus, line 11 positions the first character in its argument (the letter “C”) immediately *after* the last character that line 10 displays (the space character before the string’s closing double-quote character). Each `Write` statement resumes displaying characters from where the last `Write` statement displayed its last character.

*Displaying Multiple Lines of Text with a Single Statement*

A single statement can display multiple lines by using newline characters, which indicate to `Console` methods `Write` and `WriteLine` when they should position the screen cursor to the beginning of the next line in the console window. Like space characters and tab characters, newline characters are whitespace characters. The app of Fig. 3.11 outputs four lines of text, using newline characters to indicate when to begin each new line.

```

1 // Fig. 3.11: Welcome3.cs
2 // Displaying multiple lines with a single statement.
3 using System;
4
5 public class Welcome3
6 {
7     // Main method begins execution of C# app
8     public static void Main( string[] args )
9     {
10         Console.WriteLine( "Welcome\\nto\\nC#\\nProgramming!" );
11     } // end Main
12 } // end class Welcome3

```

```

Welcome
to
C#
Programming!

```

**Fig. 3.11** | Displaying multiple lines with a single statement.

Most of the app is identical to the apps of Fig. 3.1 and Fig. 3.10, so we discuss only the changes here. Line 2

```
// Displaying multiple lines with a single statement.
```

states the purpose of this app. Line 5 begins the `Welcome3` class declaration.

Line 10

```
Console.WriteLine( "Welcome\\nto\\nC#\\nProgramming!" );
```

displays four separate lines of text in the console window. Normally, the characters in a string are displayed exactly as they appear in the double quotes. Note, however, that the two characters \ and n (repeated three times in the statement) do *not* appear on the screen. The backslash (\) is called an **escape character**. It indicates to C# that a “special character” is in the string. When a backslash appears in a string of characters, C# combines the next character with the backslash to form an **escape sequence**. The escape sequence \n represents the **newline character**. When a newline character appears in a string being output with `Console` methods, the newline character causes the screen cursor to move to the beginning of the next line in the console window. Figure 3.12 lists several common escape sequences and describes how they affect the display of characters in the console window.

Escape sequence	Description
\n	Newline. Positions the screen cursor at the beginning of the next line.
\t	Horizontal tab. Moves the screen cursor to the next tab stop.
\"	Double quote. Used to place a double-quote character ("") in a string—e.g., <code>Console.WriteLine( "\\\"in quotes\\\"");</code> displays "in quotes".

**Fig. 3.12** | Some common escape sequences. (Part 1 of 2.)

Escape sequence	Description
\r	Carriage return. Positions the screen cursor at the beginning of the current line—does not advance the cursor to the next line. Any characters output after the carriage return overwrite the characters previously output on that line.
\\"	Backslash. Used to place a backslash character in a string.

**Fig. 3.12** | Some common escape sequences. (Part 2 of 2.)

## 3.5 Formatting Text with `Console.WriteLine`

`Console` methods `Write` and `WriteLine` also have the capability to display formatted data. Figure 3.13 outputs the strings "Welcome to" and "C# Programming!" with `WriteLine`.

```

1 // Fig. 3.13: Welcome4.cs
2 // Displaying multiple lines of text with string formatting.
3 using System;
4
5 public class Welcome
6 {
7     // Main method begins execution of C# app
8     public static void Main( string[] args )
9     {
10         Console.WriteLine( "{0}\n{1}", "Welcome to", "C# Programming!" );
11     } // end Main
12 } // end class Welcome

```

Welcome to  
C# Programming!

**Fig. 3.13** | Displaying multiple lines of text with string formatting.

Line 10

```
Console.WriteLine( "{0}\n{1}", "Welcome to", "C# Programming!" );
```

calls method `Console.WriteLine` to display the app's output. The method call specifies three arguments. When a method requires multiple arguments, the arguments are separated with **commas (,)**—this is known as a **comma-separated list**.



### Good Programming Practice 3.6

Place a space after each comma (,) in an argument list to make apps more readable.

Most statements end with a semicolon (;). Therefore, line 10 represents only one statement. Large statements can be split over many lines, but there are some restrictions.



### Common Programming Error 3.4

Splitting a statement in the middle of an identifier or a string is a syntax error.

#### Format Strings and Format Items

Method `WriteLine`'s first argument is a **format string** that may consist of **fixed text** and **format items**. Fixed text is output by `WriteLine`, as in Fig. 3.1. Each format item is a placeholder for a value. Format items also may include optional formatting information.

Format items are enclosed in curly braces and contain characters that tell the method which argument to use and how to format it. For example, the format item `{0}` is a *placeholder* for the first additional argument (because C# starts counting from 0), `{1}` is a *placeholder* for the second, and so on. The format string in line 10 specifies that `WriteLine` should output two arguments and that the first one should be followed by a newline character. So this example substitutes "Welcome to" for the `{0}` and "C# Programming!" for the `{1}`. The output shows that two lines of text are displayed. Because braces in a formatted string normally indicate a placeholder for text substitution, you must type two left braces (`{ {`) or two right braces (`} }`) to insert a single left or right brace into a formatted string, respectively. We introduce additional formatting features as they're needed in our examples.

## 3.6 Another C# App: Adding Integers

Our next app reads (or inputs) two **integers** (whole numbers, like -22, 7, 0 and 1024) typed by a user at the keyboard, computes the sum of the values and displays the result. This app must keep track of the numbers supplied by the user for the calculation later in the app. Apps remember numbers and other data in the computer's memory and access that data through app elements called **variables**. The app of Fig. 3.14 demonstrates these concepts. In the sample output, we highlight data the user enters at the keyboard in bold.

```
1 // Fig. 3.14: Addition.cs
2 // Displaying the sum of two numbers input from the keyboard.
3 using System;
4
5 public class Addition
6 {
7     // Main method begins execution of C# app
8     public static void Main( string[] args )
9     {
10         int number1; // declare first number to add
11         int number2; // declare second number to add
12         int sum; // declare sum of number1 and number2
13
14         Console.Write( "Enter first integer: " ); // prompt user
15         // read first number from user
16         number1 = Convert.ToInt32( Console.ReadLine() );
17
18         Console.Write( "Enter second integer: " ); // prompt user
```

**Fig. 3.14** | Displaying the sum of two numbers input from the keyboard. (Part 1 of 2.)

---

```

19     // read second number from user
20     number2 = Convert.ToInt32( Console.ReadLine() );
21
22     sum = number1 + number2; // add numbers
23
24     Console.WriteLine( "Sum is {0}", sum ); // display sum
25 } // end Main
26 } // end class Addition

```

```

Enter first integer: 45
Enter second integer: 72
Sum is 117

```

**Fig. 3.14** | Displaying the sum of two numbers input from the keyboard. (Part 2 of 2.)

### Comments

Lines 1–2

```
// Fig. 3.14: Addition.cs
// Displaying the sum of two numbers input from the keyboard.
```

state the figure number, file name and purpose of the app.

### Class Addition

Line 5

```
public class Addition
```

begins the declaration of class `Addition`. Remember that the body of each class declaration starts with an opening left brace (line 6) and ends with a closing right brace (line 26).

### Function Main

The app begins execution with `Main` (lines 8–25). The left brace (line 9) marks the beginning of `Main`'s body, and the corresponding right brace (line 25) marks the end of `Main`'s body. Method `Main` is indented one level within the body of class `Addition` and the code in the body of `Main` is indented another level for readability.

### Declaring Variable `number1`

Line 10

```
int number1; // declare first number to add
```

is a **variable declaration statement** (also called a **declaration**) that specifies the name (`number1`) and type of a variable (`int`) used in this app. A **variable** is a location in the computer's memory where a value can be stored for use later in an app. Variables are typically declared with a **name** and a **type** before they're used. A variable's name enables the app to access the value of the variable in memory—the name can be any valid identifier. (See Section 3.2 for identifier naming requirements.) A variable's type specifies what kind of information is stored at that location in memory and how much space should be set aside to store that value. Like other statements, declaration statements end with a semicolon (`;`).

**Type int**

The declaration in line 10 specifies that the variable named `number1` is of type `int`—it will hold `integer` values (whole numbers such as 7, -11, 0 and 31914). The range of values for an `int` is `-2,147,483,648` (`int.MinValue`) to `+2,147,483,647` (`int.MaxValue`). We'll soon discuss types `float`, `double` and `decimal`, for specifying real numbers, and type `char`, for specifying characters. Real numbers contain decimal points, as in 3.4, 0.0 and -11.19. Variables of type `float` and `double` store approximations of real numbers in memory. Variables of type `decimal` store real numbers precisely (to 28–29 significant digits), so `decimal` variables are often used with *monetary calculations*. Variables of type `char` represent individual characters, such as an uppercase letter (e.g., A), a digit (e.g., 7), a special character (e.g., \* or %) or an escape sequence (e.g., the newline character, \n). Types such as `int`, `float`, `double`, `decimal` and `char` are often called **simple types**. Simple-type names are keywords and must appear in all lowercase letters. Appendix B summarizes the characteristics of the simple types (`bool`, `byte`, `sbyte`, `char`, `short`, `ushort`, `int`, `uint`, `long`, `ulong`, `float`, `double` and `decimal`).

**Declaring Variables `number2` and `sum`**

The variable declaration statements at lines 11–12

```
int number2; // declare second number to add
int sum; // declare sum of number1 and number2
```

similarly declare variables `number2` and `sum` to be of type `int`.

Variable declaration statements can be split over several lines, with the variable names separated by commas (i.e., a comma-separated list of variable names). Several variables of the same type may be declared in one declaration or in multiple declarations. For example, lines 10–12 can also be written as follows:

```
int number1, // declare first number to add
    number2, // declare second number to add
    sum; // declare sum of number1 and number2
```

**Good Programming Practice 3.7**

*Declare each variable on a separate line. This format allows a comment to be easily inserted next to each declaration.*

**Good Programming Practice 3.8**

*Choosing meaningful variable names helps code to be self-documenting (i.e., one can understand the code simply by reading it rather than by reading documentation manuals or viewing an excessive number of comments).*

**Good Programming Practice 3.9**

*By convention, variable-name identifiers begin with a lowercase letter, and every word in the name after the first word begins with a capital letter. This naming convention is known as lower camel casing.*

**Prompting the User for Input**

Line 14

```
Console.WriteLine("Enter first integer: "); // prompt user
```

uses `Console.WriteLine` to display the message "Enter first integer: ". This message is called a **prompt** because it directs the user to take a specific action.

### *Reading a Value into Variable **number1***

Line 16

```
number1 = Convert.ToInt32( Console.ReadLine() );
```

works in two steps. First, it calls the `Console`'s **ReadLine** method, which waits for the user to type a string of characters at the keyboard and press the *Enter* key. As we mentioned, some methods perform a task then return the result of that task. In this case, `ReadLine` returns the text the user entered. Then, the `string` is used as an argument to class **Convert**'s **ToInt32** method, which converts this sequence of characters into data of type `int`. In this case, method `ToInt32` returns the `int` representation of the user's input.

### *Possible Erroneous User Input*

Technically, the user can type anything as the input value. `ReadLine` will accept it and pass it off to the `ToInt32` method. This method assumes that the string contains a valid integer value. In this app, if the user types a noninteger value, a runtime logic error called an exception will occur and the app will terminate. C# offers a technology called *exception handling* that will help you make your apps more robust by enabling them to handle exceptions and continue executing. This is also known as making your app **fault tolerant**. We introduce exception handling in Section 8.4, then use it again in Chapter 10. We take a deeper look at exception handling in Chapter 13.

### *Assigning a Value to a Variable*

In line 16, the result of the call to method `ToInt32` (an `int` value) is placed in variable `number1` by using the **assignment operator**, `=`. The statement is read as "number1 gets the value returned by `Convert.ToInt32`." Operator `=` is a **binary operator**, because it works on two pieces of information. These are known as its **operands**—in this case, the operands are `number1` and the result of the method call `Convert.ToInt32`. This statement is called an **assignment statement**, because it assigns a value to a variable. Everything to the right of the assignment operator, `=`, is always evaluated *before* the assignment is performed.



### Good Programming Practice 3.10

*Place spaces on either side of a binary operator to make the code more readable.*

### *Prompting the User for Input and Reading a Value into Variable **number2***

Line 18

```
Console.WriteLine( "Enter second integer: " ); // prompt user
```

prompts the user to enter the second integer. Line 20

```
number2 = Convert.ToInt32( Console.ReadLine() );
```

reads a second integer and assigns it to the variable `number2`.

### *Summing the **number1** and **number2***

Line 22

```
sum = number1 + number2; // add numbers
```

calculates the sum of `number1` and `number2` and assigns the result to variable `sum` by using the assignment operator, `=`. The statement is read as “`sum` gets the value of `number1 + number2`.” Most calculations are performed in assignment statements. When `number1 + number2` is encountered, the values stored in the variables are used in the calculation. The addition operator is a binary operator—its two **operands** are `number1` and `number2`. Portions of statements that contain calculations are called **expressions**. In fact, an expression is any portion of a statement that has a value associated with it. For example, the value of the expression `number1 + number2` is the sum of the numbers. Similarly, the value of the expression `Console.ReadLine()` is the string of characters typed by the user.

### *Displaying the sum*

After the calculation has been performed, line 24

```
Console.WriteLine( "Sum is {0}", sum ); // display sum
```

uses method `Console.WriteLine` to display the `sum`. The format item `{0}` is a placeholder for the first argument after the format string. Other than the `{0}` format item, the remaining characters in the format string are all *fixed* text. So method `WriteLine` displays “`Sum is` ”, followed by the value of `sum` (in the position of the `{0}` format item) and a newline.

### *Performing Calculations in Output Statements*

Calculations can also be performed inside output statements. We could have combined the statements in lines 22 and 24 into the statement

```
Console.WriteLine( "Sum is {0}", ( number1 + number2 ) );
```

The parentheses around the expression `number1 + number2` are not required—they’re included for clarity to emphasize that the value of the expression `number1 + number2` is output in the position of the `{0}` format item.

## 3.7 Memory Concepts

Variable names such as `number1`, `number2` and `sum` actually correspond to **locations** in the computer’s memory. Every variable has a **name**, a **type**, a **size** (determined by the type) and a **value**.

In the addition app of Fig. 3.14, when the statement (line 16)

```
number1 = Convert.ToInt32( Console.ReadLine() );
```

executes, the number typed by the user is placed into a **memory location** to which the name `number1` has been assigned by the compiler. Suppose that the user enters 45. The computer places that integer value into location `number1`, as shown in Fig. 3.15. Whenever a value is placed in a memory location, the value *replaces* the previous value in that location—the previous value is lost.



**Fig. 3.15** | Memory location showing the name and value of variable `number1`.

When the statement (line 20)

```
number2 = Convert.ToInt32( Console.ReadLine() );
```

executes, suppose that the user enters 72. The computer places that integer value into location `number2`. The memory now appears as shown in Fig. 3.16.

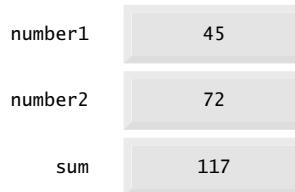


**Fig. 3.16** | Memory locations after storing values for `number1` and `number2`.

After the app of Fig. 3.14 obtains values for `number1` and `number2`, it adds the values and places the sum into variable `sum`. The statement (line 22)

```
sum = number1 + number2; // add numbers
```

performs the addition, then *replaces* `sum`'s previous value. After `sum` has been calculated, memory appears as shown in Fig. 3.17. The values of `number1` and `number2` appear exactly as they did *before* they were used in the calculation of `sum`. These values were used, but *not* destroyed, as the computer performed the calculation—when a value is read from a memory location, the process is *nondestructive*.



**Fig. 3.17** | Memory locations after calculating and storing the sum of `number1` and `number2`.

## 3.8 Arithmetic

Most apps perform arithmetic calculations. The **arithmetic operators** are summarized in Fig. 3.18. Note the various special symbols not used in algebra. The **asterisk** (\*) indicates multiplication, and the **percent sign** (%) is the **remainder operator** (called *modulus* in some languages), which we'll discuss shortly. The arithmetic operators in Fig. 3.18 are binary operators—for example, the expression `f + 7` contains the binary operator `+` and the two operands `f` and `7`.

If both operands of the division operator (/) are integers, **integer division** is performed and the result is an integer—for example, the expression `7 / 4` evaluates to 1, and the expression `17 / 5` evaluates to 3. Any fractional part in integer division is simply *truncated* (i.e., discarded)—*no rounding* occurs. C# provides the remainder operator, %, which yields the remainder after division. The expression `x % y` yields the remainder after `x` is

C# operation	Arithmetic operator	Algebraic expression	C# expression
Addition	<code>+</code>	$f + 7$	<code>f + 7</code>
Subtraction	<code>-</code>	$p - c$	<code>p - c</code>
Multiplication	<code>*</code>	$b \cdot m$	<code>b * m</code>
Division	<code>/</code>	$x / y$ or $\frac{x}{y}$ or $x \div y$	<code>x / y</code>
Remainder	<code>%</code>	$r \bmod s$	<code>r % s</code>

**Fig. 3.18** | Arithmetic operators.

divided by  $y$ . Thus,  $7 \% 4$  yields 3, and  $17 \% 5$  yields 2. This operator is most commonly used with integer operands but can also be used with `floats`, `doubles`, and `decimals`. In this chapter's exercises and in later chapters, we consider several interesting applications of the remainder operator, such as determining whether one number is a multiple of another.

### Arithmetic Expressions in Straight-Line Form

Arithmetic expressions must be written in **straight-line form** to facilitate entering apps into the computer. Thus, expressions such as “ $a$  divided by  $b$ ” must be written as  $a / b$ , so that all constants, variables and operators appear in a straight line. The following algebraic notation is not acceptable to compilers:

$\frac{a}{b}$

### Parentheses for Grouping Subexpressions

Parentheses are used to group terms in C# expressions in the same manner as in algebraic expressions. For example, to multiply  $a$  times the quantity  $b + c$ , we write

`a * ( b + c )`

If an expression contains **nested parentheses**, such as

`( ( a + b ) * c )`

the expression in the *innermost* set of parentheses ( $a + b$  in this case) is evaluated first.

### Rules of Operator Precedence

C# applies the operators in arithmetic expressions in a precise sequence determined by the following **rules of operator precedence**, which are generally the same as those followed in algebra (Fig. 3.19). These rules enable C# to apply operators in the correct order.<sup>2</sup>

---

2. We discuss simple examples here to explain the order of evaluation of expressions. More subtle order of evaluation issues occur in the increasingly complex expressions you'll encounter later. For more information, see the following blog posts from Eric Lippert: [blogs.msdn.com/ericlippert/archive/2008/05/23/precedence-vs-associativity-vs-order.aspx](http://blogs.msdn.com/ericlippert/archive/2008/05/23/precedence-vs-associativity-vs-order.aspx) and [blogs.msdn.com/oldnewthing/archive/2007/08/14/4374222.aspx](http://blogs.msdn.com/oldnewthing/archive/2007/08/14/4374222.aspx).

Operators	Operations	Order of evaluation (associativity)
<i>Evaluated first</i>		
*	Multiplication	If there are several operators of this type, they're evaluated from left to right.
/	Division	
%	Remainder	
<i>Evaluated next</i>		
+	Addition	If there are several operators of this type, they're evaluated from left to right.
-	Subtraction	

**Fig. 3.19** | Precedence of arithmetic operators.

When we say that operators are applied from left to right, we're referring to their **associativity**. You'll see that some operators associate from right to left. Figure 3.19 summarizes these rules of operator precedence. The table will be expanded as additional operators are introduced. Appendix A provides the complete precedence chart.

### Sample Algebraic and C# Expressions

Now let's consider several expressions in light of the rules of operator precedence. Each example lists an algebraic expression and its C# equivalent. The following is an example of an arithmetic mean (average) of five terms:

<i>Algebra:</i>	$m = \frac{a + b + c + d + e}{5}$
<i>C#:</i>	<code>m = ( a + b + c + d + e ) / 5;</code>

The parentheses are required because division has *higher* precedence than addition. The entire quantity ( $a + b + c + d + e$ ) is to be divided by 5. If the parentheses are erroneously omitted, we obtain  $a + b + c + d + e / 5$ , which evaluates as

$$a + b + c + d + \frac{e}{5}$$

The following is an example of the equation of a straight line:

<i>Algebra:</i>	$y = mx + b$
<i>C#:</i>	<code>y = m * x + b;</code>

No parentheses are required. The multiplication operator is applied first, because multiplication has a *higher* precedence than addition. The assignment occurs last, because it has a *lower* precedence than multiplication or addition.

The following example contains remainder (%), multiplication, division, addition and subtraction operations:

<i>Algebra:</i>	$z = pr \% q + w/x - y$
<i>C++:</i>	<code>z = p * r % q + w / x - y;</code>
	<span style="border: 1px solid gray; border-radius: 50%; padding: 2px;">6</span> <span style="border: 1px solid gray; border-radius: 50%; padding: 2px;">1</span> <span style="border: 1px solid gray; border-radius: 50%; padding: 2px;">2</span> <span style="border: 1px solid gray; border-radius: 50%; padding: 2px;">4</span> <span style="border: 1px solid gray; border-radius: 50%; padding: 2px;">3</span> <span style="border: 1px solid gray; border-radius: 50%; padding: 2px;">5</span>

The circled numbers under the statement indicate the order in which C# applies the operators. The multiplication, remainder and division operations are evaluated first in left-to-right order (i.e., they associate from left to right), because they have *higher* precedence than addition and subtraction. The addition and subtraction operations are evaluated next. These operations are also applied from left to right.

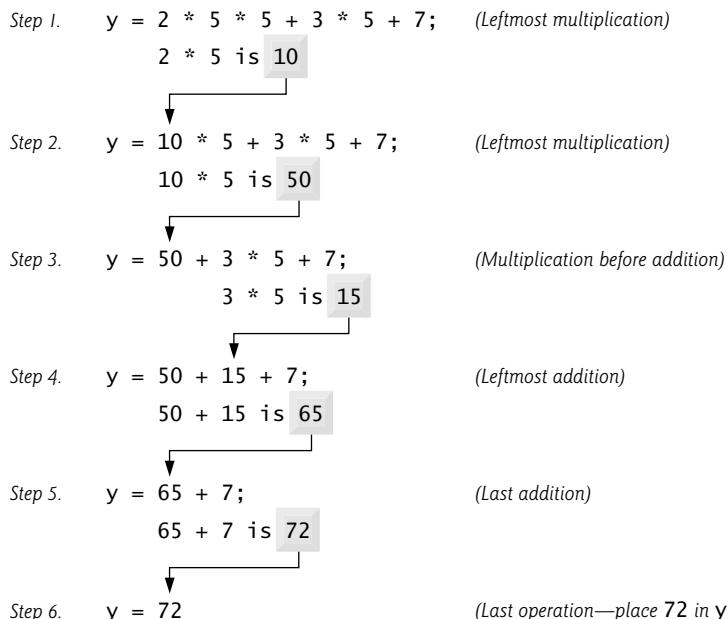
### Evaluation of a Second-Degree Polynomial

To develop a better understanding of the rules of operator precedence, consider the evaluation of a second-degree polynomial ( $y = ax^2 + bx + c$ ):

```
y = a * x * x + b * x + c;
  6   1   2   4   3   5
```

The circled numbers indicate the order in which C# applies the operators. The multiplication operations are evaluated first in left-to-right order (i.e., they associate from left to right), because they have *higher* precedence than addition. The addition operations are evaluated next and are applied from left to right. There's no arithmetic operator for exponentiation in C#, so  $x^2$  is represented as  $x * x$ . Section 6.4 shows an alternative for performing exponentiation in C#.

Suppose that  $a$ ,  $b$ ,  $c$  and  $x$  in the preceding second-degree polynomial are initialized (given values) as follows:  $a = 2$ ,  $b = 3$ ,  $c = 7$  and  $x = 5$ . Figure 3.20 illustrates the order in which the operators are applied.



**Fig. 3.20** | Order in which a second-degree polynomial is evaluated.

### *Redundant Parentheses*

As in algebra, it's acceptable to place unnecessary parentheses in an expression to make the expression clearer. These are called **redundant parentheses**. For example, the preceding assignment statement might be parenthesized to highlight its terms as follows:

```
y = ( a * x * x ) + ( b * x ) + c;
```

## 3.9 Decision Making: Equality and Relational Operators

A **condition** is an expression that can be either **true** or **false**. This section introduces a simple version of C#'s **if statement** that allows an app to make a **decision** based on the value of a condition. For example, the condition “grade is greater than or equal to 60” determines whether a student passed a test. If the condition in an **if** statement is true, the body of the **if** statement executes. If the condition is false, the body does *not* execute. We'll see an example shortly.

Conditions in **if** statements can be formed by using the **equality operators** (`==` and `!=`) and **relational operators** (`>`, `<`, `>=` and `<=`) summarized in Fig. 3.21. The two equality operators (`==` and `!=`) each have the same level of precedence, the relational operators (`>`, `<`, `>=` and `<=`) each have the same level of precedence, and the equality operators have lower precedence than the relational operators. They all associate from left to right.



### Common Programming Error 3.5

*Confusing the equality operator, `==`, with the assignment operator, `=`, can cause a logic error or a syntax error. The equality operator should be read as “is equal to,” and the assignment operator should be read as “gets” or “gets the value of.” To avoid confusion, some programmers read the equality operator as “double equals” or “equals equals.”*

Standard algebraic equality and relational operators	C# equality or relational operator	Sample C# condition	Meaning of C# condition
<i>Relational operators</i>			
<code>&gt;</code>	<code>&gt;</code>	<code>x &gt; y</code>	<code>x</code> is greater than <code>y</code>
<code>&lt;</code>	<code>&lt;</code>	<code>x &lt; y</code>	<code>x</code> is less than <code>y</code>
<code>≥</code>	<code>&gt;=</code>	<code>x &gt;= y</code>	<code>x</code> is greater than or equal to <code>y</code>
<code>≤</code>	<code>&lt;=</code>	<code>x &lt;= y</code>	<code>x</code> is less than or equal to <code>y</code>
<i>Equality operators</i>			
<code>=</code>	<code>==</code>	<code>x == y</code>	<code>x</code> is equal to <code>y</code>
<code>≠</code>	<code>!=</code>	<code>x != y</code>	<code>x</code> is not equal to <code>y</code>

**Fig. 3.21** | Relational and equality operators.

### *Using the if Statement*

Figure 3.22 uses six **if** statements to compare two integers entered by the user. If the condition in any of these **if** statements is true, the assignment statement associated with that **if** statement executes. The app uses class **Console** to prompt for and read two lines of text

from the user, extracts the integers from that text with the `ToInt32` method of class `Convert`, and stores them in variables `number1` and `number2`. Then the app compares the numbers and displays the results of the comparisons that are true.

```
1 // Fig. 3.22: Comparison.cs
2 // Comparing integers using if statements, equality operators
3 // and relational operators.
4 using System;
5
6 public class Comparison
7 {
8     // Main method begins execution of C# app
9     public static void Main( string[] args )
10    {
11        int number1; // declare first number to compare
12        int number2; // declare second number to compare
13
14        // prompt user and read first number
15        Console.WriteLine( "Enter first integer: " );
16        number1 = Convert.ToInt32( Console.ReadLine() );
17
18        // prompt user and read second number
19        Console.WriteLine( "Enter second integer: " );
20        number2 = Convert.ToInt32( Console.ReadLine() );
21
22        if ( number1 == number2 )
23            Console.WriteLine( "{0} == {1}", number1, number2 );
24
25        if ( number1 != number2 )
26            Console.WriteLine( "{0} != {1}", number1, number2 );
27
28        if ( number1 < number2 )
29            Console.WriteLine( "{0} < {1}", number1, number2 );
30
31        if ( number1 > number2 )
32            Console.WriteLine( "{0} > {1}", number1, number2 );
33
34        if ( number1 <= number2 )
35            Console.WriteLine( "{0} <= {1}", number1, number2 );
36
37        if ( number1 >= number2 )
38            Console.WriteLine( "{0} >= {1}", number1, number2 );
39    } // end Main
40 } // end class Comparison
```

```
Enter first integer: 42
Enter second integer: 42
42 == 42
42 <= 42
42 >= 42
```

**Fig. 3.22** | Comparing integers using `if` statements, equality operators and relational operators.  
(Part 1 of 2.)

```
Enter first integer: 1000
Enter second integer: 2000
1000 != 2000
1000 < 2000
1000 <= 2000
```

```
Enter first integer: 2000
Enter second integer: 1000
2000 != 1000
2000 > 1000
2000 >= 1000
```

**Fig. 3.22** | Comparing integers using if statements, equality operators and relational operators.  
(Part 2 of 2.)

### Class Comparison

The declaration of class Comparison begins at line 6

```
public class Comparison
```

The class's Main method (lines 9–39) begins the execution of the app.

### Variable Declarations

Lines 11–12

```
int number1; // declare first number to compare
int number2; // declare second number to compare
```

declare the int variables used to store the values entered by the user.

### Reading the Inputs from the User

Lines 14–16

```
// prompt user and read first number
Console.Write( "Enter first integer: " );
number1 = Convert.ToInt32( Console.ReadLine() );
```

prompt the user to enter the first integer and input the value. The input value is stored in variable number1. Lines 18–20

```
// prompt user and read second number
Console.Write( "Enter second integer: " );
number2 = Convert.ToInt32( Console.ReadLine() );
```

perform the same task, except that the input value is stored in variable number2.

### Comparing Numbers

Lines 22–23

```
if ( number1 == number2 )
    Console.WriteLine( "{0} == {1}", number1, number2 );
```

compare the values of the variables number1 and number2 to determine whether they're equal. An if statement always begins with keyword if, followed by a condition in paren-

theses. An `if` statement expects *one* statement in its body. The indentation of the body statement shown here is not required, but it improves the code's readability by emphasizing that the statement in line 23 is part of the `if` statement that begins in line 22. Line 23 executes only if the numbers stored in variables `number1` and `number2` are equal (i.e., the condition is true). The `if` statements in lines 25–26, 28–29, 31–32, 34–35 and 37–38 compare `number1` and `number2` with the operators `!=`, `<`, `>`, `<=` and `>=`, respectively. If the condition in any of the `if` statements is true, the corresponding body statement executes.



### Common Programming Error 3.6

*Omitting the left and/or right parentheses for the condition in an `if` statement is a syntax error—the parentheses are required.*



### Common Programming Error 3.7

*Reversing the operators `!=`, `>=` and `<=`, as in `=!`, `=>` and `=<`, can result in syntax or logic errors.*



### Common Programming Error 3.8

*It's a syntax error if the operators `==`, `!=`, `>` and `<` contain spaces between their symbols, as in `= =`, `! =`, `> =` and `< =`, respectively.*



### Good Programming Practice 3.11

*Indent an `if` statement's body to make it stand out and to enhance app readability.*

## No Semicolon at the End of the First Line of an `if` Statement

There's no semicolon (`;`) at the end of the first line of each `if` statement. Such a semicolon would result in a logic error at execution time. For example,

```
if ( number1 == number2 ); // logic error
    Console.WriteLine( "{0} == {1}", number1, number2 );
```

would actually be interpreted by C# as

```
if ( number1 == number2 )
    ; // empty statement
    Console.WriteLine( "{0} == {1}", number1, number2 );
```

where the semicolon in the line by itself—called the **empty statement**—is the statement to execute if the condition in the `if` statement is true. When the empty statement executes, no task is performed in the app. The app then continues with the output statement, which always executes, regardless of whether the condition is true or false, because the output statement is not part of the `if` statement.



### Common Programming Error 3.9

*Placing a semicolon immediately after the right parenthesis of the condition in an `if` statement is normally a logic error.*

## Whitespace

Note the use of whitespace in Fig. 3.22. Recall that whitespace characters, such as tabs, newlines and spaces, are normally ignored by the compiler. So statements may be split over

several lines and may be spaced according to your preferences without affecting the meaning of an app. It's incorrect to split identifiers, strings, and multicharacter operators (like `>=`). Ideally, statements should be kept small, but this is not always possible.



### Good Programming Practice 3.12

*Place no more than one statement per line in an app. This format enhances readability.*



### Good Programming Practice 3.13

*A lengthy statement can be spread over several lines. If a single statement must be split across lines, choose breaking points that make sense, such as after a comma in a comma-separated list, or after an operator in a lengthy expression. If a statement is split across two or more lines, indent all subsequent lines until the end of the statement.*

### Precedence and Associativity of the Operators We've Discussed So Far

Figure 3.23 shows the precedence of the operators introduced in this chapter. The operators are shown from top to bottom in decreasing order of precedence. All these operators, with the exception of the assignment operator, `=`, associate from left to right. Addition is left associative, so an expression like `x + y + z` is evaluated as if it had been written as `(x + y) + z`. The assignment operator, `=`, associates from right to left, so an expression like `x = y = 0` is evaluated as if it had been written as `x = (y = 0)`, which, as you'll soon see, first assigns the value 0 to variable `y` then assigns the result of that assignment, 0, to `x`.



### Good Programming Practice 3.14

*Refer to the operator precedence chart (the complete chart is in Appendix A) when writing expressions containing many operators. Confirm that the operations in the expression are performed in the order you expect. If you're uncertain about the order of evaluation in a complex expression, use parentheses to force the order, as you would do in algebraic expressions. Observe that some operators, such as assignment, `=`, associate from right to left rather than left to right.*

Operators	Associativity	Type
<code>*</code> <code>/</code> <code>%</code>	left to right	multiplicative
<code>+</code> <code>-</code>	left to right	additive
<code>&lt;</code> <code>&lt;=</code> <code>&gt;</code> <code>&gt;=</code>	left to right	relational
<code>==</code> <code>!=</code>	left to right	equality
<code>=</code>	right to left	assignment

**Fig. 3.23 |** Precedence and associativity of operations discussed so far.

## 3.10 Wrap-Up

You learned many important features of C# in this chapter. First you learned how to display data on the screen in a **Command Prompt** using the `Console` class's `Write` and `WriteLine` methods. Next, we showed how to use format strings and format items to create

formatted output strings. You learned how to input data from the keyboard using the `Console` class's `ReadLine` method. We discussed how to perform calculations using C#'s arithmetic operators. Finally, you learned to make decisions using the `if` statement and the relational and equality operators. The apps presented here introduced you to basic programming concepts. As you'll see in Chapter 4, C# apps typically contain just a few lines of code in method `Main`—these statements normally create the objects that perform the work of the app. You'll learn how to implement your own classes and use objects of those classes in apps.

---

## Summary

### *Section 3.2 A Simple C# App: Displaying a Line of Text*

- You may insert comments to document apps and improve their readability. The C# compiler ignores comments.
- A comment that begins with `//` is called a single-line comment, because it terminates at the end of the line on which it appears.
- Comments delimited by `/*` and `*/` can be spread over several lines.
- A programming language's syntax specifies rules for creating a proper app in that language.
- A `using` directive helps the compiler locate a class that's used in an app.
- C# provides a rich set of predefined classes that you can reuse rather than “reinventing the wheel.” These classes are grouped into namespaces—named collections of classes.
- Collectively, C#'s predefined namespaces are referred to as the .NET Framework Class Library.
- You may use blank lines and space characters to make apps easier to read. Together, blank lines, space characters and tab characters are known as whitespace. Space characters and tabs are known specifically as whitespace characters. Whitespace is ignored by the compiler.
- Every app in C# consists of at least one class declaration that's defined by the programmer (also known as a user-defined class).
- Keywords are reserved for use by C# and are always spelled with all lowercase letters.
- Keyword `class` introduces a class declaration and is immediately followed by the class name.
- By convention, all class names in C# begin with a capital letter and capitalize the first letter of each word they include (e.g., `SampleClassName`). This known as upper camel casing.
- A C# class name is an identifier—a series of characters consisting of letters, digits, and underscores (`_`) that does not begin with a digit and does not contain spaces.
- C# is case sensitive—that is, uppercase and lowercase letters are distinct.
- The body of every class declaration is delimited by braces, `{` and `}`.
- Method `Main` is the starting point of every C# app and is typically defined as:

```
public static void Main( string[] args )
```

- Methods are able to perform tasks and can return information when they complete their tasks. Keyword `void` indicates that a method will perform a task but will not return any information.
- Statements instruct the computer to perform actions.
- A sequence of characters in double quotation marks is called a string, a character string, a message or a string literal.
- The `Console` class allows C# apps to read and display characters in the console window.

- Method `Console.WriteLine` displays its argument in the console window, followed by a newline character to position the screen cursor to the beginning of the next line.
- Most statements end with a semicolon.

### *Section 3.3 Creating a Simple App in Visual Studio*

- Visual Studio provides many ways to personalize your coding experience. You can modify the editor settings to display line numbers or set code indentation.
- As you type characters, in some contexts Visual Studio highlights the first member that matches all the characters typed, then displays a tool tip containing a description of that member. This IDE feature is called *IntelliSense*.
- When you type a line of code and press *Enter*, the IDE either applies syntax-color highlighting or generates a syntax error.

### *Section 3.4 Modifying Your Simple C# App*

- `Console.Write` displays its argument and positions the screen cursor immediately after the last character displayed.
- C# combines a backslash (\) in a string with the next character in the string to form an escape sequence. The escape sequence \n (newline) positions the cursor on the next line.

### *Section 3.5 Formatting Text with `Console.Write` and `Console.WriteLine`*

- The `Console.Write` and `Console.WriteLine` methods can also display formatted data.
- When a method requires multiple arguments, the arguments are separated with commas (,)—this is known as a comma-separated list.
- Method `Console.Write`'s first argument can be a format string that may consist of fixed text and format items. Fixed text is displayed normally. Each format item is a placeholder for a value.
- Format items are enclosed in curly braces and begin with a number that specifies an argument. The format item {0} is a placeholder for the first additional argument after the format string (because we start counting from 0), {1} is a placeholder for the second, and so on.

### *Section 3.6 Another C# App: Adding Integers*

- Integers are whole numbers, like -22, 7, 0 and 1024.
- A variable declaration statement specifies the name and type of a variable.
- A variable is a location in the computer's memory where a value can be stored for use later in an app. Variables are typically declared with a name and a type before they're used.
- A variable's name enables the app to access the value of the variable in memory. A variable name can be any valid identifier.
- Like other statements, variable declaration statements end with a semicolon (;).
- Type `int` is used to declare variables that will hold integer values. The range of values for an `int` is -2,147,483,648 to +2,147,483,647.
- Types `float`, `double`, and `decimal` specify real numbers, and type `char` specifies character data. Real numbers are numbers that may contain decimal points, such as 3.4, 0.0 and -11.19. Variables of type `char` data represent individual characters, such as an uppercase letter (e.g., A), a digit (e.g., 7), a special character (e.g., \* or %) or an escape sequence (e.g., the newline character, \n).
- Types such as `int`, `float`, `double`, `decimal`, and `char` are often called simple types. Simple-type names are keywords; thus, they must appear in all lowercase letters.
- A prompt directs the user to take a specific action.

- `Console` method `ReadLine` obtains a line of text from the keyboard for use in an app.
- `Convert` method `ToInt32` extracts an integer from a string of characters.
- The assignment operator, `=`, enables the app to give a value to a variable. Operator `=` is called a binary operator because it has two operands. An assignment statement uses an assignment operator to assign a value to a variable.
- Portions of statements that have values are called expressions.

### ***Section 3.7 Memory Concepts***

- Variable names correspond to locations in the computer's memory. Every variable has a name, a type, a size and a value.
- Whenever a value is placed in a memory location, the value replaces the previous value in that location. The previous value is lost.

### ***Section 3.8 Arithmetic***

- Most apps perform arithmetic calculations. The arithmetic operators are `+` (addition), `-` (subtraction), `*` (multiplication), `/` (division) and `%` (remainder).
- If both operands of the division operator (`/`) are integers, the result is an integer.
- The remainder operator, `%`, yields the remainder after division.
- Arithmetic expressions in C# must be written in straight-line form.
- If an expression contains nested parentheses, the innermost set of parentheses is evaluated first.
- C# applies the operators in arithmetic expressions in a precise sequence determined by the rules of operator precedence.
- Associativity determines whether operators are applied from left to right or right to left.
- Redundant parentheses in an expression can make an expression clearer.

### ***Section 3.9 Decision Making: Equality and Relational Operators***

- A condition is an expression that can be either true or false. C#'s `if` statement allows an app to make a decision based on the value of a condition.
- Conditions in `if` statements can be formed by using the equality (`==` and `!=`) and relational (`>`, `<`, `>=` and `<=`) operators.
- An `if` statement always begins with keyword `if`, followed by a condition in parentheses, and expects one statement in its body.
- An empty statement is a statement that does not perform a task.

## **Terminology**

addition operator ( <code>+</code> )	character string
argument	class declaration
arithmetic operators ( <code>*, /, %, +</code> and <code>-</code> )	<code>class</code> keyword
assignment operator ( <code>=</code> )	class name
assignment statement	code walkthrough
associativity of operators	comma (,)
backslash ( <code>\</code> ) escape character	comma-separated list
binary operator	<b>Command Prompt</b>
body of a class declaration	comment
body of a method declaration	compilation error
<code>char</code> simple type	condition

Console class	namespace
console window	nested parentheses
<code>Console.WriteLine</code> method	newline character ( <code>\n</code> )
<code>Console.WriteLine</code> method	operand
contextual keyword	operator precedence
<code>Convert</code> class	<i>Parameter Info</i> window
.cs file-name extension	parentheses ( )
decimal simple type	perform an action
decision	precedence of operators
division operator (/)	prompt
.dll file-name extension	<code>public</code> keyword
double simple type	<code>ReadLine</code> method of class <code>Console</code>
dynamically linked library	redundant parentheses
empty statement ( ; )	relational operators
equality operators	< “is less than”
<code>==</code> “is equal to”	<code>&lt;=</code> “is less than or equal to”
<code>!=</code> “is not equal to”	<code>&gt;</code> “is greater than”
Error List window	<code>&gt;=</code> “is greater than or equal to”
escape character	remainder operator (%)
escape sequence	reserved words
.exe file-name extension	right brace ( } )
executable	rules of operator precedence
expression	semicolon ( ; ) statement terminator
fault tolerant	simple type
<b>File Name</b> property	single-line comment ( // )
fixed text in a format string	standard input/output class ( <code>Console</code> )
<code>float</code> simple type	statement
format item	straight-line form
format string	string
Framework Class Library	subtraction operator ( - )
identifier	syntax color highlighting
<code>if</code> statement	syntax error
int (integer) simple type	<code>ToInt32</code> method of class <code>Convert</code>
integer	upper camel casing
integer division	<code>using</code> directive
<i>Intellisense</i>	variable
left brace ( { )	variable declaration
literal	variable declaration statement
location of a variable	variable name
lower camel casing	variable size
<code>Main</code> method	variable type
member of a class	variable value
method	<code>void</code> keyword
multiplication operator ( * )	whitespace

## Self-Review Exercises

**3.1** Fill in the blanks in each of the following statements:

- a) A(n) \_\_\_\_\_ begins the body of every method, and a(n) \_\_\_\_\_ ends the body of every method.
- b) Most statements end with a(n) \_\_\_\_\_.

- c) The \_\_\_\_\_ statement is used to make decisions.
  - d) \_\_\_\_\_ begins a single-line comment.
  - e) \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_ are called whitespace characters. Newline characters are also considered whitespace characters.
  - f) \_\_\_\_\_ are reserved for use by C#.
  - g) C# apps begin execution at method \_\_\_\_\_.
  - h) Methods \_\_\_\_\_ and \_\_\_\_\_ display information in the console window.
- 3.2** State whether each of the following is *true* or *false*. If *false*, explain why.
- a) Comments cause the computer to display the text after the // on the screen when the app executes.
  - b) C# considers the variables `number` and `NuMbEr` to be identical.
  - c) The remainder operator (%) can be used only with integer operands.
  - d) The arithmetic operators \*, /, %, + and - all have the same level of precedence.
- 3.3** Write statements to accomplish each of the following tasks:
- a) Declare variables `c`, `thisIsAVariable`, `q76354` and `number` to be of type `int`.
  - b) Prompt the user to enter an integer.
  - c) Input an integer and assign the result to `int` variable `value`.
  - d) If the variable `number` is not equal to 7, display "The variable number is not equal to 7".
  - e) Display "This is a C# app" on one line in the console window.
  - f) Display "This is a C# app" on two lines in the console window. The first line should end with C#. Use method `Console.WriteLine`.
  - g) Display "This is a C# app" on two lines in the console window. The first line should end with C#. Use method `Console.WriteLine` and two format items.
- 3.4** Identify and correct the errors in each of the following statements:
- a) 

```
if ( c < 7 );
    Console.WriteLine( "c is less than 7" );
```
  - b) 

```
if ( c => 7 )
    Console.WriteLine( "c is equal to or greater than 7" );
```
- 3.5** Write declarations, statements or comments that accomplish each of the following tasks:
- a) State that an app will calculate the product of three integers.
  - b) Declare the variables `x`, `y`, `z` and `result` to be of type `int`.
  - c) Prompt the user to enter the first integer.
  - d) Read the first integer from the user and store it in the variable `x`.
  - e) Prompt the user to enter the second integer.
  - f) Read the second integer from the user and store it in the variable `y`.
  - g) Prompt the user to enter the third integer.
  - h) Read the third integer from the user and store it in the variable `z`.
  - i) Compute the product of the three integers contained in variables `x`, `y` and `z`, and assign the result to the variable `result`.
  - j) Display the message "Product is", followed by the value of the variable `result`.
- 3.6** Using the statements you wrote in Exercise 3.5, write a complete app that calculates and displays the product of three integers.

## Answers to Self-Review Exercises

- 3.1** a) left brace ({), right brace (}). b) semicolon (;). c) if. d) //. e) Blank lines, space characters, tab characters. f) Keywords. g) Main. h) `Console.WriteLine` and `Console.Write`.

- 3.2**
- a) False. Comments do not cause any action to be performed when the app executes. They're used to document apps and improve their readability.
  - b) False. C# is case sensitive, so these variables are distinct.
  - c) False. The remainder operator also can be used with noninteger operands in C#.
  - d) False. The operators \*, / and % are on the same level of precedence, and the operators + and - are on a lower level of precedence.
- 3.3**
- a) `int c, thisIsAVariable, q76354, number;`  
or  
`int c;`  
`int thisIsAVariable;`  
`int q76354;`  
`int number;`
  - b) `Console.WriteLine( "Enter an integer: " );`
  - c) `value = Convert.ToInt32( Console.ReadLine() );`
  - d) `if ( number != 7 )`  
    `Console.WriteLine( "The variable number is not equal to 7" );`
  - e) `Console.WriteLine( "This is a C# app" );`
  - f) `Console.WriteLine( "This is a C#\napp" );`
  - g) `Console.WriteLine( "{0}\n{1}", "This is a C#", "app" );`
- 3.4**
- a) *Error:* Semicolon after the right parenthesis of the condition (`c < 7`) in the `if` statement.  
*Correction:* Remove the semicolon after the right parenthesis. [Note: With the semicolon, the output statement executes regardless of whether the condition in the `if` is true.]
  - b) *Error:* The relational operator `=>` is incorrect.  
*Correction:* Change `=>` to `>=`.
- 3.5**
- a) `// Calculating the product of three integers`
  - b) `int x, y, z, result;`  
or  
`int x;`  
`int y;`  
`int z;`  
`int result;`
  - c) `Console.Write( "Enter first integer: " );`
  - d) `x = Convert.ToInt32( Console.ReadLine() );`
  - e) `Console.Write( "Enter second integer: " );`
  - f) `y = Convert.ToInt32( Console.ReadLine() );`
  - g) `Console.Write( "Enter third integer: " );`
  - h) `z = Convert.ToInt32( Console.ReadLine() );`
  - i) `result = x * y * z;`
  - j) `Console.WriteLine( "Product is {0}", result );`
- 3.6** The solution to Self-Review Exercise 3.6 is as follows:

```

1 // Exercise 3.6: Product.cs
2 // Calculating the product of three integers.
3 using System;
4
5 public class Product
6 {
7     public static void Main( string[] args )
8     {

```

```

9     int x; // stores first number to be entered by user
10    int y; // stores second number to be entered by user
11    int z; // stores third number to be entered by user
12    int result; // product of numbers
13
14    Console.Write( "Enter first integer: " ); // prompt for input
15    x = Convert.ToInt32( Console.ReadLine() ); // read first integer
16
17    Console.Write( "Enter second integer: " ); // prompt for input
18    y = Convert.ToInt32( Console.ReadLine() ); // read second integer
19
20    Console.Write( "Enter third integer: " ); // prompt for input
21    z = Convert.ToInt32( Console.ReadLine() ); // read third integer
22
23    result = x * y * z; // calculate the product of the numbers
24
25    Console.WriteLine( "Product is {0}", result );
26 } // end Main
27 } // end class Product

```

```

Enter first integer: 10
Enter second integer: 20
Enter third integer: 30
Product is 6000

```

## Exercises

- 3.7** Fill in the blanks in each of the following statements:
- \_\_\_\_\_ are used to document an app and improve its readability.
  - A decision can be made in a C# app with a(n) \_\_\_\_\_.
  - Calculations are normally performed by \_\_\_\_\_ statements.
  - The arithmetic operators with the same precedence as multiplication are \_\_\_\_\_ and \_\_\_\_\_.
  - When parentheses in an arithmetic expression are nested, the \_\_\_\_\_ set of parentheses is evaluated first.
  - A location in the computer's memory that may contain different values at various times throughout the execution of an app is called a(n) \_\_\_\_\_.
- 3.8** Write C# statements that accomplish each of the following tasks:
- Display the message "Enter an integer: ", leaving the cursor on the same line.
  - Assign the product of variables b and c to variable a.
  - State that an app performs a simple payroll calculation (i.e., use text that helps to document an app).
- 3.9** State whether each of the following is *true* or *false*. If *false*, explain why.
- C# operators are evaluated from left to right.
  - The following are all valid variable names: `_under_bar_`, `m928134`, `t5`, `j7`, `her_sales`, `his_account_total`, `a`, `b`, `c`, `z` and `z2`.
  - A valid C# arithmetic expression with no parentheses is evaluated from left to right.
  - The following are all invalid variable names: `3g`, `87`, `67h2`, `h22` and `2h`.
- 3.10** Assuming that `x = 2` and `y = 3`, what does each of the following statements display?
- `Console.WriteLine( "x = {0}", x );`
  - `Console.WriteLine( "Value of {0} + {0} is {1}", x, ( x + x ) );`
  - `Console.Write( "x = " );`
  - `Console.WriteLine( "{0} = {1}", ( x + y ), ( y + x ) );`

**3.11** Which of the following C# statements contain variables whose values are modified?

- a) `p = i + j + k + 7;`
- b) `Console.WriteLine( "variables whose values are modified" );`
- c) `Console.WriteLine( "a = 5" );`
- d) `value = Convert.ToInt32( Console.ReadLine() );`

**3.12** Given that  $y = ax^3 + 7$ , which of the following are correct C# statements for this equation?

- a) `y = a * x * x * x + 7;`
- b) `y = a * x * x * ( x + 7 );`
- c) `y = ( a * x ) * x * ( x + 7 );`
- d) `y = ( a * x ) * x * x + 7;`
- e) `y = a * ( x * x * x ) + 7;`
- f) `y = a * x * ( x * x + 7 );`

**3.13** (*Order of Evaluation*) State the order of evaluation of the operators in each of the following C# statements and show the value of  $x$  after each statement is performed:

- a) `x = 7 + 3 * 6 / 2 - 1;`
- b) `x = 2 % 2 + 2 * 2 - 2 / 2;`
- c) `x = ( 3 * 9 * ( 3 + ( 9 * 3 / ( 3 ) ) ) );`

**3.14** (*Displaying Numbers*) Write an app that displays the numbers 1 to 4 on the same line, with each pair of adjacent numbers separated by one space. Write the app using the following techniques:

- a) Use one `Console.WriteLine` statement.
- b) Use four `Console.WriteLine` statements.
- c) Use one `Console.WriteLine` statement with four format items.

**3.15** (*Arithmetic*) Write an app that asks the user to enter two integers, obtains them from the user and displays their sum, product, difference and quotient (division). Use the techniques shown in Fig. 3.14.

**3.16** (*Comparing Integers*) Write an app that asks the user to enter two integers, obtains them from the user and displays the larger number followed by the words "is larger". If the numbers are equal, display the message "These numbers are equal." Use the techniques shown in Fig. 3.22.

**3.17** (*Arithmetic, Smallest and Largest*) Write an app that inputs three integers from the user and displays the sum, average, product, and smallest and largest of the numbers. Use the techniques from Fig. 3.22. [Note: The average calculation in this exercise should result in an integer representation of the average. So, if the sum of the values is 7, the average should be 2, not 2.3333....]

**3.18** (*Displaying Shapes with Asterisks*) Write an app that displays a box, an oval, an arrow and a diamond using asterisks (\*), as follows:

```
*****      ***      *      *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*****      ***      *      *
```

**3.19** What does the following code display?

```
Console.WriteLine( "*\\n**\\n***\\n****\\n*****" );
```

**3.20** What does the following code display?

```
Console.WriteLine( "*" );
Console.WriteLine( "***" );
Console.WriteLine( "*****" );
Console.WriteLine( "*****" );
Console.WriteLine( "***" );
```

**3.21** What does the following code display?

```
Console.Write( "*" );
Console.Write( "***" );
Console.Write( "*****" );
Console.Write( "*****" );
Console.WriteLine( "***" );
```

**3.22** What does the following code display?

```
Console.Write( "*" );
Console.WriteLine( "***" );
Console.WriteLine( "*****" );
Console.WriteLine( "*****" );
Console.WriteLine( "***" );
```

**3.23** What does the following code display?

```
Console.WriteLine( "{0}\n{1}\n{2}", "*", "***", "*****" );
```

**3.24** (*Odd or Even*) Write an app that reads an integer, then determines and displays whether it's odd or even. [Hint: Use the remainder operator. An even number is a multiple of 2. Any multiple of 2 leaves a remainder of 0 when divided by 2.]

**3.25** (*Multiples*) Write an app that reads two integers, determines whether the first is a multiple of the second and displays the result. [Hint: Use the remainder operator.]

**3.26** (*Diameter, Circumference and Area of a Circle*) Here's a peek ahead. In this chapter, you have learned about integers and the type `int`. C# can also represent floating-point numbers that contain decimal points, such as 3.14159. Write an app that inputs from the user the radius of a circle as an integer and displays the circle's diameter, circumference and area using the floating-point value 3.14159 for  $\pi$ . Use the techniques shown in Fig. 3.14. [Note: You may also use the predefined constant `Math.PI` for the value of  $\pi$ . This constant is more precise than the value 3.14159. Class `Math` is defined in namespace `System`.] Use the following formulas ( $r$  is the radius):

$$\begin{aligned} \text{diameter} &= 2r \\ \text{circumference} &= 2\pi r \\ \text{area} &= \pi r^2 \end{aligned}$$

Don't store each calculation's result in a variable. Rather, specify each calculation as the value to be output in a `Console.WriteLine` statement. The values produced by the circumference and area calculations are floating-point numbers. You'll learn more about floating-point numbers in Chapter 4.

**3.27** (*Integer Equivalent of a Character*) Here's another peek ahead. In this chapter, you have learned about integers and the type `int`. C# can also represent uppercase letters, lowercase letters and a considerable variety of special symbols. Every character has a corresponding integer representation. The set of characters a computer uses and the corresponding integer representations for those characters is called that computer's character set. You can indicate a character value in an app simply by enclosing that character in single quotes, as in '`A`'.

You can determine the integer equivalent of a character by preceding that character with `(int)`, as in

```
(int) 'A'
```

The keyword `int` in parentheses is known as a cast operator, and the entire expression is called a cast expression. (You'll learn about cast operators in Chapter 5.) The following statement outputs a character and its integer equivalent:

```
Console.WriteLine("The character {0} has the value {1}",
    'A', ( int ) 'A' );
```

When the preceding statement executes, it displays the character `A` and the value 65 as part of the string. See Appendix C for a list of characters and their integer equivalents.

Using statements similar to the one shown earlier in this exercise, write an app that displays the integer equivalents of some uppercase letters, lowercase letters, digits and special symbols. Display the integer equivalents of the following: `A B C a b c 0 1 2 $ * + /` and the space character.

**3.28** (*Digits of an Integer*) Write an app that inputs one number consisting of five digits from the user, separates the number into its individual digits and displays the digits separated from one another by three spaces each. For example, if the user types in the number 42339, the app should display

4	2	3	3	9
---	---	---	---	---

Assume that the user enters the correct number of digits. What happens when you execute the app and type a number with more than five digits? What happens when you execute the app and type a number with fewer than five digits? [Hint: It's possible to do this exercise with the techniques you learned in this chapter. You'll need to use both division and remainder operations to "pick off" each digit.]

**3.29** (*Table of Squares and Cubes*) Using only the programming techniques you learned in this chapter, write an app that calculates the squares and cubes of the numbers from 0 to 10 and displays the resulting values in table format, as shown below. All calculations should be done in terms of a variable `x`. [Note: This app does not require any input from the user.]

number	square	cube
0	0	0
1	1	1
2	4	8
3	9	27
4	16	64
5	25	125
6	36	216
7	49	343
8	64	512
9	81	729
10	100	1000

**3.30** (*Counting Negative, Positive and Zero Values*) Write an app that inputs five numbers and determines and displays the number of negative numbers input, the number of positive numbers input and the number of zeros input.

## Making a Difference Exercises

**3.31** (*Body Mass Index Calculator*) We introduced the body mass index (BMI) calculator in Exercise 1.29. The formulas for calculating the BMI are

$$BMI = \frac{weightInPounds \times 703}{heightInInches \times heightInInches}$$

or

$$BMI = \frac{weightInKilograms}{heightInMeters \times heightInMeters}$$

Create a BMI calculator app that reads the user's weight in pounds and height in inches (or, if you prefer, the user's weight in kilograms and height in meters), then calculates and displays the user's body mass index. The app should also display the following information from the Department of Health and Human Services/National Institutes of Health so the user can evaluate his/her BMI:

**BMI VALUES**

Underweight:	less than 18.5
Normal:	between 18.5 and 24.9
Overweight:	between 25 and 29.9
Obese:	30 or greater

**3.32** (*Car-Pool Savings Calculator*) Research several car-pooling websites. Create an app that calculates your daily driving cost, so that you can estimate how much money could be saved by car pooling, which also has other advantages such as reducing carbon emissions and reducing traffic congestion. The app should input the following information and display the user's cost per day of driving to work:

- a) Total miles driven per day.
- b) Cost per gallon of gasoline (in cents).
- c) Average miles per gallon.
- d) Parking fees per day (in cents).
- e) Tolls per day (in cents).

# 4

# Introduction to Classes, Objects, Methods and **strings**

*Nothing can have value without being an object of utility.*

—Karl Marx

*Your public servants serve you right.*

—Adlai E. Stevenson

## Objectives

In this chapter you'll:

- Declare a class and use it to create an object.
- Implement a class's behaviors as methods.
- Implement a class's attributes as instance variables and properties.
- Use **string** objects.
- Call an object's methods to make them perform their tasks.
- Understand the differences between instance variables of a class and local variables of a method.
- Use a constructor to initialize an object's data.



# Outline

- 4.1** Introduction
- 4.2** Classes, Objects, Methods, Properties and Instance Variables
- 4.3** Declaring a Class with a Method and Instantiating an Object of a Class
- 4.4** Declaring a Method with a Parameter
- 4.5** Instance Variables and Properties
- 4.6** UML Class Diagram with a Property
- 4.7** Software Engineering with Properties and `set` and `get` Accessors
- 4.8** Auto-Implemented Properties
- 4.9** Value Types vs. Reference Types
- 4.10** Initializing Objects with Constructors
- 4.11** Floating-Point Numbers and Type `decimal`
- 4.12** Wrap-Up

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 4.1 Introduction

In this chapter, we begin by explaining the concept of classes using a real-world example. Then we present five complete working apps to demonstrate how to create and use your own classes. The first four begin our case study on developing a grade book class that instructors can use to maintain student test scores. The last example introduces the type `decimal` and uses it to declare monetary amounts in the context of a bank account class that maintains a customer’s balance.

## 4.2 Classes, Objects, Methods, Properties and Instance Variables

Let’s begin with a simple analogy to help you understand classes and their contents. Suppose you want to drive a car and make it go faster by pressing down on its accelerator pedal. What must happen before you can do this? Well, before you can drive a car, someone has to design it. A car typically begins as engineering drawings, similar to the blueprints used to design a house. These engineering drawings include the design for an accelerator pedal to make the car go faster. The pedal “hides” the complex mechanisms that actually make the car go faster, just as the brake pedal “hides” the mechanisms that slow the car and the steering wheel “hides” the mechanisms that turn the car. This enables people with little or no knowledge of how engines work to drive a car easily.

Unfortunately, you can’t drive the engineering drawings of a car. Before you can drive a car, it must be built from the engineering drawings that describe it. A completed car will have an actual accelerator pedal to make the car go faster, but even that’s not enough—the car will not accelerate on its own, so the driver must press the accelerator pedal.

### Methods

Now let’s use our car example to introduce the key programming concepts of this section. Performing a task in an app requires a method. **The method describes the mechanisms that actually perform its tasks.** The method hides from its user the complex tasks that it performs, just as the accelerator pedal of a car hides from the driver the complex mechanisms of making the car go faster.

### *Classes*

In C#, we begin by creating an app unit called a **class** to house (among other things) a **method**, just as a car's engineering drawings house (among other things) the design of an **accelerator pedal**. In a class, you provide one or more methods that are designed to perform the class's tasks. For example, a class that represents a bank account might contain one method to deposit money in an account, another to withdraw money from an account and a third to inquire what the current account balance is.

### *Objects*

Just as you cannot drive an engineering drawing of a car, you cannot "drive" a class. Just as someone has to build a car from its engineering drawings before you can actually drive it, you must build an **object** of a class before you can make an app perform the tasks the class describes. That's one reason C# is known as an object-oriented programming language.

### *Method Calls*

When you drive a car, pressing its gas pedal sends a message to the car **to perform a task**—make the car go faster. Similarly, you send **messages** to an object—each message is known as a **method call** and tells the called method of the object to perform its task.

### *Attributes*

Thus far, we've used the car analogy to introduce classes, objects and methods. In addition to a car's capabilities, it also has many **attributes**, such as its color, the number of doors, the amount of gas in its tank, its current speed and its total miles driven (i.e., its odometer reading). Like the car's capabilities, these attributes are represented as part of a car's design in its engineering drawings. As you drive a car, these attributes are always associated with the car. Every car maintains its own attributes. For example, each car knows how much gas is in its own gas tank, but not how much is in the tanks of other cars. Similarly, an object has attributes that are carried with the object as it's used in an app. These attributes are specified as part of the object's class. For example, a bank-account object has a **balance** attribute that represents the amount of money in the account. Each bank-account object knows the balance in the account it represents, but not the balances of the other accounts in the bank. **Attributes are specified by the class's instance variables.**

### **Properties, get Accessors and set Accessors**

Notice that these attributes are not necessarily accessible directly. The car manufacturer does not want drivers to take apart the car's engine to observe the amount of gas in its tank. Instead, the driver can check the fuel gauge on the dashboard. The bank does not want its customers to walk into the vault to count the amount of money in an account. Instead, the customers talk to a bank teller or check personalized online bank accounts. Similarly, you do not need to have access to an object's instance variables in order to use them. You should use the **properties** of an object. Properties contain **get accessors** for reading the values of variables, and **set accessors** for storing values into them.

## **4.3 Declaring a Class with a Method and Instantiating an Object of a Class**

We begin with an example that consists of classes GradeBook (Fig. 4.1) and GradeBookTest (Fig. 4.2). Class GradeBook (declared in file GradeBook.cs) will be used to display a

message on the screen (Fig. 4.2) welcoming the instructor to the grade-book app. Class GradeBookTest (declared in the file GradeBookTest.cs) is a testing class in which the Main method will create and use an object of class GradeBook. By convention, we declare classes GradeBook and GradeBookTest in separate files, such that each file's name matches the name of the class it contains.

To start, select **File > New Project...** to open the **New Project** dialog, then create a **GradeBook Console Application**. Rename the Program.cs file to GradeBook.cs. Delete all the code provided automatically by the IDE and replace it with the code in Fig. 4.1.

---

```
1 // Fig. 4.1: GradeBook.cs
2 // Class declaration with one method.
3 using System;
4
5 public class GradeBook
6 {
7     // display a welcome message to the GradeBook user
8     public void DisplayMessage()
9     {
10         Console.WriteLine( "Welcome to the Grade Book!" );
11     } // end method DisplayMessage
12 } // end class GradeBook
```

---

**Fig. 4.1** | Class declaration with one method.

### **Class GradeBook**

The GradeBook class declaration (Fig. 4.1) contains a **DisplayMessage** method (lines 8–11) that displays a message on the screen. Line 10 of the class displays the message. Recall that a class is like a blueprint—we need to make an object of this class and call its method to get line 10 to execute and display its message—we do this in Fig. 4.2.

The class declaration begins in line 5. The keyword **public** is an **access modifier**. Access modifiers determine the accessibility of an object's properties and methods to other methods in an app. For now, we simply declare every class **public**. Every class declaration contains keyword **class** followed by the class's name. Every class's body is enclosed in a pair of left and right braces (**{** and **}**), as in lines 6 and 12 of class GradeBook.

### **Declaration of Method *DisplayMessage***

In Chapter 3, each class we declared had one method named **Main**. Class GradeBook also has one method—**DisplayMessage** (lines 8–11). Recall that **Main** is a special method that's always called automatically when you execute an app. Most methods do *not* get called automatically. As you'll soon see, you must call method **DisplayMessage** to tell it to perform its task.

The method declaration begins with keyword **public** to indicate that the method is “available to the public”—that is, it can be called from outside the class declaration's body by methods of other classes. Keyword **void**—known as the method's **return type**—indicates that this method will *not* return (i.e., give back) any information to its **calling method** when it completes its task. When a method that specifies a return type other than **void** is called and completes its task, the method returns a result to its calling method. For example, when you go to an automated teller machine (ATM) and request your account

balance, you expect the ATM to give you back a value that represents your balance. If you have a method `Square` that returns the square of its argument, you'd expect the statement

```
int result = Square( 2 );
```

to return 4 from method `Square` and assign 4 to variable `result`. If you have a method `Maximum` that returns the largest of three integer arguments, you'd expect the statement

```
int biggest = Maximum( 27, 114, 51 );
```

to return the value 114 from method `Maximum` and assign the value to variable `biggest`. You've already used methods that return information—for example, in Chapter 3 you used `Console` method `ReadLine` to input a string typed by the user at the keyboard. When `ReadLine` inputs a value, it *returns* that value for use in the app.

### **Method Name**

The name of the method, `DisplayMessage`, follows the return type (line 8). Generally, methods are named as *verbs* or *verb phrases* while classes are named as *nouns*. By convention, method names begin with an uppercase first letter, and all subsequent words in the name begin with an uppercase letter. This naming convention is referred to as upper camel case. The parentheses after the method name indicate that this is a method. An empty set of parentheses, as shown in line 8, indicates that this method does *not* require additional information to perform its task. Line 8 is commonly referred to as the **method header**. Every method's body is delimited by left and right braces, as in lines 9 and 11.

### **Method Body**

The body of a method contains statements that perform the method's task. In this case, the method contains one statement (line 10) that displays the message "Welcome to the Grade Book!", followed by a newline in the console window. After this statement executes, the method has completed its task.

### **Using Class `GradeBook`**

Next, we'd like to use class `GradeBook` in an app. As you learned in Chapter 3, method `Main` begins the execution of every app. Class `GradeBook` cannot begin an app because it does not contain `Main`. This was not a problem in Chapter 3, because every class you declared had a `Main` method. To fix this problem for the `GradeBook`, we must either declare a separate class that contains a `Main` method or place a `Main` method in class `GradeBook`. To help you prepare for the larger apps you'll encounter later in this book and in industry, we use a separate class (`GradeBookTest` in this example) containing method `Main` to test each new class we create in this chapter.

### **Adding a Class to a Visual C# Project**

For each example in this chapter, you'll add a class to your console app. To do this, right click the project name in the **Solution Explorer** and select **Add > New Item...** from the pop-up menu. In the **Add New Item** dialog that appears, select **Code File**, enter the name of your new file (`GradeBookTest.cs`) then click **Add**. A new blank file will be added to your project. Add the code from Fig. 4.2 to this file.

***Class GradeBookTest***

The GradeBookTest class declaration (Fig. 4.2) contains the `Main` method that controls our app's execution. Any class that contains a `Main` method (as shown in line 6) can be used to execute an app. This class declaration begins in line 3 and ends in line 14. The class contains only a `Main` method, which is typical of many classes that simply begin an app's execution.

---

```

1 // Fig. 4.2: GradeBookTest.cs
2 // Create a GradeBook object and call its DisplayMessage method.
3 public class GradeBookTest
4 {
5     // Main method begins program execution
6     public static void Main( string[] args )
7     {
8         // create a GradeBook object and assign it to myGradeBook
9         GradeBook myGradeBook = new GradeBook();
10
11         // call myGradeBook's DisplayMessage method
12         myGradeBook.DisplayMessage();
13     } // end Main
14 } // end class GradeBookTest

```

Welcome to the Grade Book!

**Fig. 4.2** | Create a GradeBook object and call its `DisplayMessage` method.

***Main Method***

Lines 6–13 declare method `Main`. A key part of enabling the method `Main` to begin the app's execution is the `static` keyword (line 6), which indicates that `Main` is a `static` method. A `static` method is special because it can be called without first creating an object of the class (in this case, `GradeBookTest`) in which the method is declared. We explain `static` methods in Chapter 7, Methods: A Deeper Look.

***Creating a GradeBook Object***

In this app, we'd like to call class `GradeBook`'s `DisplayMessage` method to display the welcome message in the console window. Typically, you cannot call a method that belongs to another class until you create an object of that class, as shown in line 9. We begin by declaring variable `myGradeBook`. The variable's type is `GradeBook`—the class we declared in Fig. 4.1. Each new class you create becomes a new *type* in C# that can be used to declare variables and create objects. New class types will be accessible to all classes in the same project. You can declare new class types as needed; this is one reason why C# is known as an **extensible language**.

Variable `myGradeBook` (line 9) is initialized with the result of the **object-creation expression** `new GradeBook()`. The `new` operator creates a new object of the class specified to the right of the keyword (i.e., `GradeBook`). The parentheses to the right of the `GradeBook` are required. As you'll learn in Section 4.10, those parentheses in combination with a class name represent a call to a constructor, which is similar to a method, but is used only

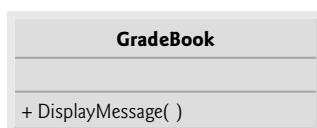
at the time an object is created to initialize the object's data. In that section you'll see that data can be placed in parentheses to specify initial values for the object's data. For now, we simply leave the parentheses empty.

### *Calling the GradeBook Object's DisplayMessage Method*

We can now use `myGradeBook` to call its method `DisplayMessage`. Line 12 calls the method `DisplayMessage` (lines 8–11 of Fig. 4.1) using variable `myGradeBook` followed by a **member access (.) operator**, the method name `DisplayMessage` and an empty set of parentheses. This call causes the `DisplayMessage` method to perform its task. This method call differs from the method calls in Chapter 3 that displayed information in a console window—each of those method calls provided arguments that specified the data to display. At the beginning of line 12 (Fig. 4.2), “`myGradeBook.`” indicates that `Main` should use the `GradeBook` object that was created in line 9. The empty parentheses in line 8 of Fig. 4.1 indicate that method `DisplayMessage` does not require additional information to perform its task. For this reason, the method call (line 12 of Fig. 4.2) specifies an empty set of parentheses after the method name to indicate that no arguments are being passed to method `DisplayMessage`. When method `DisplayMessage` completes its task, method `Main` continues executing at line 13. This is the end of method `Main`, so the app terminates.

### *UML Class Diagram for Class GradeBook*

Figure 4.3 presents a UML class diagram for class `GradeBook` of Fig. 4.1. Recall from Section 1.6 that the UML is a graphical language used by programmers to represent their object-oriented systems in a standardized manner. In the UML, each class is modeled in a class diagram as a rectangle with three compartments. The top compartment contains the name of the class centered horizontally in boldface type. The middle compartment contains the class's attributes, which correspond to instance variables and properties in C#. In Fig. 4.3, the middle compartment is empty because the version of class `GradeBook` in Fig. 4.1 does not have any attributes. The bottom compartment contains the class's operations, which correspond to methods in C#. The UML models operations by listing the operation name followed by a set of parentheses. Class `GradeBook` has one method, `DisplayMessage`, so the bottom compartment of Fig. 4.3 lists one operation with this name. Method `DisplayMessage` does not require additional information to perform its tasks, so there are empty parentheses following `DisplayMessage` in the class diagram, just as they appeared in the method's declaration in line 8 of Fig. 4.1. The plus sign (+) in front of the operation name indicates that `DisplayMessage` is a public operation in the UML (i.e., a `public` method in C#). The plus sign is sometimes called the **public visibility symbol**. We'll often use UML class diagrams to summarize a class's attributes and operations.



**Fig. 4.3** | UML class diagram indicating that class `GradeBook` has a `public` `DisplayMessage` operation.

## 4.4 Declaring a Method with a Parameter

In our car analogy from Section 4.2, we discussed the fact that pressing a car’s gas pedal sends a message to the car to perform a task—make the car go faster. But how fast should the car accelerate? As you know, the farther down you press the pedal, the faster the car accelerates. So the message to the car actually includes both the task to be performed and additional information that helps the car perform the task. This additional information is known as a **parameter**—the value of the parameter helps the car determine how fast to accelerate. Similarly, a method can require one or more parameters that represent additional information it needs to perform its task. A method call supplies values—called arguments—for each of the method’s parameters. For example, the `Console.WriteLine` method requires an argument that specifies the data to be displayed in a console window. Similarly, to make a deposit into a bank account, a `Deposit` method specifies a parameter that represents the deposit amount. When the `Deposit` method is called, an argument value representing the deposit amount is assigned to the method’s parameter. The method then makes a deposit of that amount, by increasing the account’s balance.

Our next example declares class `GradeBook` (Fig. 4.4) with a `DisplayMessage` method that displays the course name as part of the welcome message. (See the sample execution in Fig. 4.5.) The new `DisplayMessage` method requires a parameter that represents the course name to output.

---

```

1 // Fig. 4.4: GradeBook.cs
2 // Class declaration with a method that has a parameter.
3 using System;
4
5 public class GradeBook
6 {
7     // display a welcome message to the GradeBook user
8     public void DisplayMessage( string courseName )
9     {
10         Console.WriteLine( "Welcome to the grade book for\n{0}!", 
11                         courseName );
12     } // end method DisplayMessage
13 } // end class GradeBook

```

---

**Fig. 4.4** | Class declaration with a method that has a parameter.

---

```

1 // Fig. 4.5: GradeBookTest.cs
2 // Create a GradeBook object and pass a string to
3 // its DisplayMessage method.
4 using System;
5
6 public class GradeBookTest
7 {
8     // Main method begins program execution
9     public static void Main( string[] args )
10    {

```

---

**Fig. 4.5** | Create `GradeBook` object and pass a `string` to its `DisplayMessage` method. (Part 1 of 2.)

```

11      // create a GradeBook object and assign it to myGradeBook
12  GradeBook myGradeBook = new GradeBook();
13
14      // prompt for and input course name
15  Console.WriteLine("Please enter the course name:");
16  string nameOfCourse = Console.ReadLine(); // read a line of text
17  Console.WriteLine(); // output a blank line
18
19      // call myGradeBook's DisplayMessage method
20      // and pass nameOfCourse as an argument
21  myGradeBook.DisplayMessage(nameOfCourse);
22 } // end Main
23 } // end class GradeBookTest

```

Please enter the course name:  
**CS101 Introduction to C# Programming**

Welcome to the grade book for  
**CS101 Introduction to C# Programming!**

**Fig. 4.5** | Create GradeBook object and pass a **string** to its **DisplayMessage** method. (Part 2 of 2.)

Before discussing the new features of class **GradeBook**, let's see how the new class is used from the **Main** method of class **GradeBookTest** (Fig. 4.5). Line 12 creates an object of class **GradeBook** and assigns it to variable **myGradeBook**. Line 15 prompts the user to enter a course name. Line 16 reads the name from the user and assigns it to the variable **nameOfCourse**, using **Console** method **ReadLine** to perform the input. The user types the course name and presses *Enter* to submit the course name to the app. Pressing *Enter* inserts a newline character at the end of the characters typed by the user. Method **ReadLine** reads characters typed by the user until the newline character is encountered, then returns a **string** containing the characters up to, but not including, the newline. The newline character is *discarded*.

Line 21 calls **myGradeBook**'s **DisplayMessage** method. The variable **nameOfCourse** in parentheses is the argument that's passed to method **DisplayMessage** so that the method can perform its task. Variable **nameOfCourse**'s value in **Main** becomes the value of method **DisplayMessage**'s parameter **courseName** in line 8 of Fig. 4.4. When you execute this app, notice that method **DisplayMessage** outputs as part of the welcome message the name you type (Fig. 4.5).



### Software Engineering Observation 4.1

Normally, objects are created with **new**. One exception is a **string** literal that's contained in quotes, such as "hello". String literals are **string** objects that are implicitly created by C# the first time they appear in the code.

### More on Arguments and Parameters

When you declare a method, you must specify in the method's declaration whether the method requires data to perform its task. To do so, you place additional information in the method's **parameter list**, which is located in the parentheses that follow the method

name. The parameter list may contain any number of parameters, including none at all. Each parameter is declared as a variable with a type and identifier in the parameter list. Empty parentheses following the method name (as in Fig. 4.1, line 8) indicate that a method does not require any parameters. In Fig. 4.4, `DisplayMessage`'s parameter list (line 8) declares that the method requires one parameter. Each parameter must specify a type and an identifier. In this case, the type `string` and the identifier `courseName` indicate that method `DisplayMessage` requires a `string` to perform its task. At the time the method is called, the argument value in the call is assigned to the corresponding parameter (in this case, `courseName`) in the method header. Then, the method body uses the parameter `courseName` to access the value. Lines 10–11 of Fig. 4.4 display parameter `courseName`'s value, using the `{0}` format item in `WriteLine`'s first argument. The parameter variable's name (Fig. 4.4, line 8) can be the same or different from the argument variable's name (Fig. 4.5, line 21).

A method can specify multiple parameters by separating each parameter from the next with a comma. The number of arguments in a method call must match the number of required parameters in the parameter list of the called method's declaration. Also, the types of the arguments in the method call must be consistent with the types of the corresponding parameters in the method's declaration. (As you'll learn in subsequent chapters, an argument's type and its corresponding parameter's type are *not* always required to be identical.) In our example, the method call passes one argument of type `string` (`nameOfCourse` is declared as a `string` in line 16 of Fig. 4.5), and the method declaration specifies one parameter of type `string` (line 8 in Fig. 4.4). So the type of the argument in the method call exactly matches the type of the parameter in the method header.



### Common Programming Error 4.1

*A compilation error occurs if the number of arguments in a method call does not match the number of required parameters in the method declaration.*

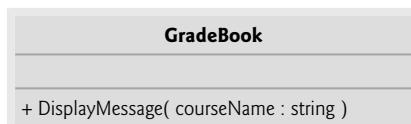


### Common Programming Error 4.2

*A compilation error occurs if the types of the arguments in a method call are not consistent with the types of the corresponding parameters in the method declaration.*

### Updated UML Class Diagram for Class GradeBook

The UML class diagram of Fig. 4.6 models class `GradeBook` of Fig. 4.4. Like Fig. 4.4, this `GradeBook` class contains public operation `DisplayMessage`. However, this version of `DisplayMessage` has a parameter. The UML models a parameter a bit differently from C# by listing the parameter name, followed by a colon and the parameter type in the parentheses following the operation name. The UML has several data types that are similar to



**Fig. 4.6** | UML class diagram indicating that class `GradeBook` has a public `DisplayMessage` operation with a `courseName` parameter of type `string`.

the C# types. For example, UML types `String` and `Integer` correspond to C# types `string` and `int`, respectively. Unfortunately, the UML does not provide types that correspond to every C# type. For this reason, and to avoid confusion between UML types and C# types, *we use only C# types in our UML diagrams*. Class `Gradebook`'s method `DisplayMessage` (Fig. 4.4) has a `string` parameter named `courseName`, so Fig. 4.6 lists the parameter `courseName : string` between the parentheses following `DisplayMessage`.

### **Notes on using Directives**

Notice the `using` directive in Fig. 4.5 (line 4). This indicates to the compiler that the app uses classes in the `System` namespace, like the `Console` class. Why do we need a `using` directive to use class `Console`, but not class `GradeBook`? There's a special relationship between classes that are compiled in the same project, like classes `GradeBook` and `GradeBookTest`. By default, such classes are considered to be in the same namespace. A `using` directive is not required when one class in a namespace uses another in the same namespace—such as when class `GradeBookTest` uses class `GradeBook`. For simplicity, our examples in this chapter do not declare a namespace. Any classes that are not *explicitly* placed in a namespace are *implicitly* placed in the so-called **global namespace**.

Actually, the `using` directive in line 4 is not required if we always refer to class `Console` as `System.Console`, which includes the full namespace and class name. This is known as the class's **fully qualified class name**. For example, line 15 could be written as

```
System.Console.WriteLine( "Please enter the course name:" );
```

Most C# programmers consider using fully qualified names to be cumbersome, and instead prefer to use `using` directives.

## **4.5 Instance Variables and Properties**

In Chapter 3, we declared all of an app's variables in the `Main` method. Variables declared in the body of a method are known as **local variables** and can be used only in that method. When a method terminates, the values of its local variables are lost. Recall from Section 4.2 that an object has attributes that are carried with it as it's used in an app. Such attributes exist before a method is called on an object and after the method completes execution.

Attributes are represented as variables in a class declaration. Such variables are called **fields** and are declared *inside* a class declaration but *outside* the bodies of the class's method declarations. When each object of a class maintains its own copy of an attribute, the field that represents the **attribute** is also known as an **instance variable**—each object (instance) of the class has a separate instance of the variable. In Chapter 10, we discuss another type of field called a **static variable**, where all objects of the same class share one variable.

A class normally contains one or more properties that manipulate the attributes that belong to a particular object of the class. The example in this section demonstrates a `GradeBook` class that contains a `courseName` instance variable to represent a particular `GradeBook` object's course name, and a `CourseName` property to manipulate `courseName`.

### ***GradeBook* Class with an Instance Variable and a Property**

In our next app (Figs. 4.7–4.8), class `GradeBook` (Fig. 4.7) maintains the course name as an instance variable so that it can be used or modified at any time during an app's execution. The class also contains one method—`DisplayMessage` (lines 24–30)—and one

property—`CourseName` (line 11–21). Recall from Chapter 2 that properties are used to manipulate an object’s *attributes*. For example, in that chapter, we used a `Label`’s `Text` property to specify the text to display on the `Label`. In this example, we use a property in code rather than in the **Properties** window of the IDE. To do this, we first declare a property as a member of the `GradeBook` class. As you’ll soon see, the `GradeBook`’s `CourseName` property can be used to store a course name in a `GradeBook` (in instance variable `courseName`) or retrieve the `GradeBook`’s course name (from instance variable `courseName`). Method `DisplayMessage`—which now specifies no parameters—still displays a welcome message that includes the course name. However, the method now uses the `CourseName` property to obtain the course name from instance variable `courseName`.

```

1 // Fig. 4.7: GradeBook.cs
2 // GradeBook class that contains a private instance variable, courseName,
3 // and a public property to get and set its value.
4 using System;
5
6 public class GradeBook
7 {
8     private string courseName; // course name for this GradeBook
9
10    // property to get and set the course name
11    public string CourseName
12    {
13        get
14        {
15            return courseName;
16        } // end get
17        set
18        {
19            courseName = value;
20        } // end set
21    } // end property CourseName
22
23    // display a welcome message to the GradeBook user
24    public void DisplayMessage()
25    {
26        // use property CourseName to get the
27        // name of the course that this GradeBook represents
28        Console.WriteLine( "Welcome to the grade book for\n{0}!",
29            CourseName ); // display property CourseName
30    } // end method DisplayMessage
31 } // end class GradeBook
```

**Fig. 4.7** | `GradeBook` class that contains a **private** instance variable, `courseName`, and a **public** property to **get** and **set** its value.

A typical instructor teaches more than one course, each with its own course name. Line 8 declares `courseName` as a variable of type `string`. Line 8 is a declaration for an instance variable, because the variable is declared in the class’s body (lines 7–31) but outside the bodies of the class’s method (lines 24–30) and property (lines 11–21). Every instance (i.e., object) of class `GradeBook` contains one copy of each instance variable. For

example, if there are two GradeBook objects, each object has its own copy of `courseName`. All the methods and properties of class `GradeBook` can directly manipulate its instance variable `courseName`, but it's considered good practice for methods of a class to use that class's properties to manipulate instance variables (as we do in line 29 of method `DisplayMessage`). The software engineering reasons for this will soon become clear.

### ***Access Modifiers public and private***

Most instance-variable declarations are preceded with the keyword `private` (as in line 8). Like `public`, keyword `private` is an access modifier. **Variables, properties or methods declared with access modifier `private` are accessible only to members (such as properties and methods) of the class in which they're declared.** Thus, variable `courseName` can be used only in property `CourseName` and method `DisplayMessage` of class `GradeBook`.



### **Software Engineering Observation 4.2**

*Precede every field and method declaration with an access modifier. Generally, instance variables should be declared `private` and methods and properties should be declared `public`. If the access modifier is omitted before a member of a class, the member is implicitly declared `private`. We'll see that it's appropriate to declare certain methods `private`, if they will be accessed only by other methods of the class.*



### **Software Engineering Observation 4.3**

*Declaring the instance variables of a class as `private` and the methods and properties of the class as `public` facilitates debugging, because problems with data manipulations are localized to the class's methods and properties, since the `private` instance variables are accessible only to these methods and properties.*

Declaring instance variables with access modifier `private` is known as **information hiding (or encapsulation)**. When an app creates (instantiates) an object of class `GradeBook`, variable `courseName` is encapsulated (hidden) in the object and can be accessed only by members of the object's class.

### ***Setting and Getting the Values of `private` Instance Variables***

How can we allow a program to manipulate a class's `private` instance variables but ensure that they remain in a valid state? We need to provide *controlled* ways for programmers to "get" (i.e., retrieve) the value in an instance variable and "set" (i.e., modify) the value in an instance variable. Although you can define methods like `GetCourseName` and `SetCourseName`, C# properties provide a more elegant solution. Next, we show how to declare and use properties.

### ***GradeBook Class with a Property***

The `GradeBook` class's `CourseName` **property declaration** is located in lines 11–21 of Fig. 4.7. The property begins in line 11 with an access modifier (in this case, `public`), followed by the type that the property represents (`string`) and the property's name (`CourseName`). Properties use the *same* naming conventions as methods and classes.

Properties contain **accessors** that handle the details of returning and modifying data. A property declaration can contain a *get* accessor, a *set* accessor or both. The *get* accessor (lines 13–16) enables a client to read the value of `private` instance variable `courseName`; the *set* accessor (lines 17–20) enables a client to modify `courseName`.

After defining a property, you can use it like a variable in your code. For example, you can assign a value to a property using the = (assignment) operator. This executes the property's set accessor to set the value of the corresponding instance variable. Similarly, referencing the property to use its value (for example, to display it on the screen) executes the code in the property's get accessor to obtain the corresponding *instance variable's* value. We show how to use properties shortly. By convention, we name each property with the capitalized name of the instance variable that it manipulates (e.g., CourseName is the property that represents instance variable `courseName`)—C# is case sensitive, so these are distinct identifiers.

### **get and set Accessors**

Let us look more closely at property `CourseName`'s get and set accessors (Fig. 4.7). The get accessor (lines 13–16) begins with the identifier **get** and its body is delimited by braces. The accessor's body contains a **return statement**, which consists of the keyword **return** followed by an expression. The expression's value is returned to the client code that uses the property. In this example, the value of `courseName` is returned when the property `CourseName` is referenced. For example, in the following statement

```
string theCourseName = gradeBook.CourseName;
```

the expression `gradeBook.CourseName` (where `gradeBook` is an object of class `GradeBook`) executes property `CourseName`'s get accessor, which returns the value of instance variable `courseName`. That value is then stored in variable `theCourseName`. Property `CourseName` can be used *as simply as if it were an instance variable*. The property notation allows the client to think of the property as the underlying data. Again, the client cannot directly manipulate instance variable `courseName` because it's **private**.

The set accessor (lines 17–20) begins with the identifier **set** and its body is delimited by braces. When the property `CourseName` appears in an assignment statement, as in

```
gradeBook.CourseName = "CS100 Introduction to Computers";
```

the text "CS100 Introduction to Computers" is assigned to the set accessor's contextual keyword named **value** and the set accessor executes. Note that **value** is *implicitly declared and initialized in the set accessor*—it's a compilation error to declare a local variable `value` in this body. Line 19 stores the contents of `value` in instance variable `courseName`. A set accessor does not return any data when it completes its task.

The statements inside the property in lines 15 and 19 (Fig. 4.7) each access `courseName` even though it was declared outside the property. We can use instance variable `courseName` in the methods and properties of class `GradeBook`, because `courseName` is an instance variable of the class.

### **Using Property `CourseName` in Method `DisplayMessage`**

Method `DisplayMessage` (lines 24–30 of Fig. 4.7) does not receive any parameters. Lines 28–29 output a welcome message that includes the value of instance variable `courseName`. We do not reference `courseName` directly. Instead, we access property `CourseName` (line 29), which executes the property's get accessor, returning the value of `courseName`.

### **GradeBookTest Class That Demonstrates Class GradeBook**

Class `GradeBookTest` (Fig. 4.8) creates a `GradeBook` object and demonstrates property `CourseName`. Line 11 creates a `GradeBook` object and assigns it to local variable `myGrade-`

Book. Lines 14–15 display the initial course name using the object's `CourseName` property—this executes the property's get accessor, which returns the value of `courseName`.

The first line of the output shows an empty name (marked by single quotes, ''). Unlike local variables, which are not automatically initialized, every field has a **default initial value**—a value provided by C# when you do not specify the initial value. Thus, fields are *not* required to be explicitly initialized before they're used in an app—unless they must be initialized to values *other* than their default values. The default value for an instance variable of type `string` (like `courseName`) is `null`. When you display a `string` variable that contains the value `null`, no text is displayed on the screen.

```

1 // Fig. 4.8: GradeBookTest.cs
2 // Create and manipulate a GradeBook object.
3 using System;
4
5 public class GradeBookTest
6 {
7     // Main method begins program execution
8     public static void Main( string[] args )
9     {
10         // create a GradeBook object and assign it to myGradeBook
11         GradeBook myGradeBook = new GradeBook();
12
13         // display initial value of CourseName
14         Console.WriteLine( "Initial course name is: '{0}'\n",
15             myGradeBook.CourseName );
16
17         // prompt for and read course name
18         Console.WriteLine( "Please enter the course name:" );
19         myGradeBook.CourseName = Console.ReadLine(); // set CourseName
20         Console.WriteLine(); // output a blank line
21
22         // display welcome message after specifying course name
23         myGradeBook.DisplayMessage();
24     } // end Main
25 } // end class GradeBookTest

```

```

Initial course name is: ''

Please enter the course name:
CS101 Introduction to C# Programming

Welcome to the grade book for
CS101 Introduction to C# Programming!

```

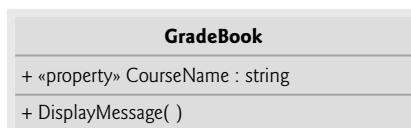
**Fig. 4.8** | Create and manipulate a `GradeBook` object.

Line 18 prompts the user to enter a course name. Line 19 assigns the course name entered by the user to object `myGradeBook`'s `CourseName` property. When a value is assigned to `CourseName`, the value specified (which is returned by `ReadLine` in this case) is assigned to implicit parameter `value` of `CourseName`'s set accessor (lines 17–20, Fig. 4.7). Then parameter `value` is assigned by the set accessor to instance variable `courseName` (line 19 of

Fig. 4.7). Line 20 (Fig. 4.8) displays a blank line, then line 23 calls `myGradeBook`'s `DisplayMessage` method to display the welcome message containing the course name.

## 4.6 UML Class Diagram with a Property

Figure 4.9 contains an updated UML class diagram for the version of class `GradeBook` in Fig. 4.7. We model properties in the UML as attributes—the property (in this case, `CourseName`) is listed as a *public* attribute—as indicated by the plus (+) sign—preceded by the word “property” in guillemets (« and »). Using descriptive words in guillemets (called *stereotypes* in the UML) helps distinguish properties from other attributes and operations. The UML indicates the type of the property by placing a colon and a type after the property name. The *get* and *set* accessors of the property are implied, so they’re not listed in the UML diagram. Class `GradeBook` also contains one *public* method `DisplayMessage`, so the class diagram lists this operation in the third compartment. Recall that the plus (+) sign is the *public visibility symbol*.



**Fig. 4.9** | UML class diagram indicating that class `GradeBook` has a public `CourseName` property of type `string` and one public method.

A class diagram helps you design a class, so it’s not required to show every implementation detail of the class. Since an instance variable that’s manipulated by a property is really an implementation detail of that property, our class diagram does *not* show the `courseName` instance variable. A programmer implementing the `GradeBook` class based on this class diagram would create the instance variable `courseName` as part of the implementation process (as we did in Fig. 4.7).

In some cases, you may find it necessary to model the *private* instance variables of a class. Like properties, instance variables are attributes of a class and are modeled in the *middle* compartment of a class diagram. The UML represents instance variables as attributes by listing the attribute name, followed by a colon and the attribute type. To indicate that an attribute is *private*, a class diagram would list the *private visibility symbol*—a minus sign (−)—before the attribute’s name. For example, the instance variable `courseName` in Fig. 4.7 would be modeled as “`- courseName : string`” to indicate that it’s a *private* attribute of type `string`.

## 4.7 Software Engineering with Properties and `set` and `get` Accessors

Using properties as described earlier in this chapter would seem to *violate* the notion of *private* data. Although providing a property with *get* and *set* accessors may appear to

be the same as making its corresponding instance variable `public`, this is *not* the case. A `public` instance variable can be read or written by any property or method in the program. If an instance variable is `private`, the client code can access the instance variable only *indirectly* through the class's non-private properties or methods. This allows the class to *control* the manner in which the data is set or returned. For example, get and set accessors can translate between the format of the data stored in the `private` instance variable and the format of the data preferred by the client.

### *Validation*

Consider a `Clock` class that represents the time of day as a `private int` instance variable `time`, containing the number of seconds since midnight. Suppose the class provides a `Time` property of type `string` to manipulate this instance variable. Although get accessors typically return data *exactly* as it's stored in an object, they need *not* expose the data in this "raw" format. When a client refers to a `Clock` object's `Time` property, the property's get accessor could use instance variable `time` to determine the number of hours, minutes and seconds since midnight, then return the time as a `string` of the form "`hh:mm:ss`" in which `hh` represents the hour, `mm` the minute and `ss` the second. Similarly, suppose a `Clock` object's `Time` property is assigned a `string` of the form "`hh:mm:ss`". Using the `string` capabilities presented in Chapter 16, and the method `Convert.ToInt32` presented in Section 3.6, the `Time` property's set accessor can convert this `string` to an `int` number of seconds since midnight and store the result in the `Clock` object's `private` instance variable `time`. The `Time` property's set accessor can also provide **data-validation** capabilities that scrutinize attempts to modify the instance variable's value to ensure that the value it receives represents a valid time (e.g., "12:30:45" is valid but "42:85:70" is not). We demonstrate data validation in Section 4.11. So, although a property's accessors enable clients to manipulate `private` data, they carefully control those manipulations, and the object's `private` data remains safely *encapsulated* (i.e., hidden) in the object. This is not possible with `public` instance variables, which can easily be set by clients to *invalid* values.

### *Manipulating Data within a Class Via the Class's Properties*

Properties of a class should also be used by the class's own methods to manipulate the class's `private` instance variables, even though the methods can directly access the `private` instance variables. Accessing an instance variable via a property's accessors—as in the body of method `DisplayMessage` (Fig. 4.7, lines 28–29)—creates a more robust class that's easier to maintain and less likely to malfunction. If we decide to change the representation of instance variable `courseName` in some way, the declaration of method `DisplayMessage` does not require modification—only the bodies of property `CourseName`'s get and set accessors that directly manipulate the instance variable will need to change. For example, suppose we want to represent the course name as two *separate* instance variables—`courseNumber` (e.g., "CS101") and `courseTitle` (e.g., "Introduction to C# Programming"). The `DisplayMessage` method can still use property `CourseName`'s get accessor to obtain the full course name to display as part of the welcome message. In this case, the get accessor would need to build and return a `string` containing the `courseNumber`, followed by the `courseTitle`. Method `DisplayMessage` would continue to display the complete course title "CS101 Introduction to C# Programming," because it's unaffected by the change to the class's instance variables.

## 4.8 Auto-Implemented Properties

In Fig. 4.7, we created a GradeBook class with a private `courseName` instance variable and a public property `CourseName` to enable **client code** to access the `courseName`. When you look at the `CourseName` property's definition (Fig. 4.7, lines 11–21), notice that the `get` accessor simply returns private instance variable `courseName`'s value and the `set` accessor simply assigns a value to the instance variable—no other logic appears in the accessors. For such cases, C# provides **automatically implemented properties** (also known as **auto-implemented properties**). With an auto-implemented property, the C# compiler creates a private instance variable, and the `get` and `set` accessors for returning and modifying the private instance variable. Unlike a user-defined property, an **auto-implemented property**, must have **both a get and a set accessor**. This enables you to implement the property trivially, which is handy when you're first designing a class. If you later decide to include other logic in the `get` or `set` accessors, you can simply modify the property's implementation. To use an auto-implemented property in the `GradeBook` class of Fig. 4.7, you can replace the private instance variable at line 8 and the property at lines 11–21 with the following code:

```
public string CourseName { get; set; }
```

### Code Snippets for Auto-Implemented Properties

The IDE has a feature called **code snippets** that allows you to insert *predefined code templates* into your source code. One such snippet enables you to insert a public auto-implemented property by typing the word “prop” in the code window and pressing the *Tab* key twice. Certain pieces of the inserted code are highlighted for you to easily change the property's type and name. You can press the *Tab* key to move from one highlighted piece of text to the next in the inserted code. By default, the new property's type is `int` and its name is `MyProperty`. To get a list of all available code snippets, type `Ctrl + k, Ctrl + x`. This displays the **Insert Snippet** window in the code editor. You can navigate through the Visual C# snippet folders with the mouse to see the snippets. This feature can also be accessed by *right clicking* in the source code editor and selecting the **Insert Snippet...** menu item.

## 4.9 Value Types vs. Reference Types

Types in C# are divided into two categories—**value types** and **reference types**.

### Value Types

C#'s simple types (like `int` and `double`) are all value types. A variable of a value type simply contains a *value* of that type. For example, Fig. 4.10 shows an `int` variable named `count` that contains the value 7.

---

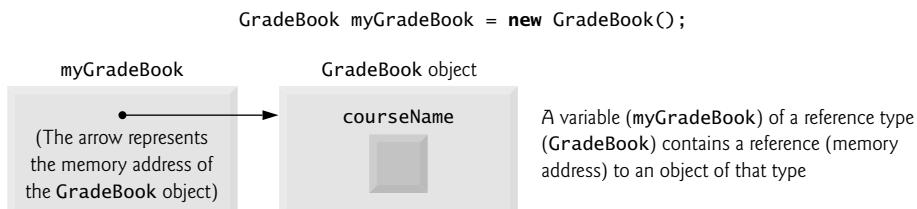
```
int count = 7;
```

count  
7      A variable (count) of a value type (int)  
          contains a value (7) of that type

**Fig. 4.10** | Value-type variable.

### Reference Types

By contrast, a reference-type variable (sometimes called a **reference**) contains the *address* of a location in memory where the data referred to by that variable is stored. Such a variable is said to **refer to an object** in the program. Line 11 of Fig. 4.8 creates a GradeBook object, places it in memory and stores the object's reference in variable myGradeBook of type GradeBook as shown in Fig. 4.11. The GradeBook object is shown with its courseName instance variable.



**Fig. 4.11** | Reference-type variable.

### Reference-Type Instance Variables Initialized to null

Reference-type instance variables (such as myGradeBook in Fig. 4.11) are initialized by default to the value **null**. string is a reference type. For this reason, string variable courseName is shown in Fig. 4.11 with an empty box representing the null-valued variable. A string variable with the value null is *not* an empty string, which is represented by "" or **string.Empty**. The value null represents a reference that does *not* refer to an object. The empty string is a string object with *no* characters in it.

### Using a Variable That Refers to an Object to Send Messages to the Object

A client of an object must use a variable that refers to the object to invoke (i.e., call) the object's methods and access the object's properties. In Fig. 4.8, the statements in Main use variable myGradeBook, which contains the GradeBook object's reference, to send messages to the GradeBook object. These messages are calls to methods (like DisplayMessage) or references to properties (like CourseName) that enable the program to interact with GradeBook objects. For example, the statement (in line 19 of Fig. 4.8)

```
myGradeBook.CourseName = Console.ReadLine(); // set CourseName
```

uses the reference myGradeBook to set the course name by assigning a value to property CourseName. This sends a message to the GradeBook object to invoke the CourseName property's set accessor. The message includes as an argument the value read from the user's input (in this case, "CS101 Introduction to C# Programming") that CourseName's set accessor requires to perform its task. The set accessor uses this information to set the courseName instance variable. In Section 7.16, we discuss value types and reference types in detail.



#### Software Engineering Observation 4.4

A variable's declared type (e.g., int, double or GradeBook) indicates whether the variable is of a value type or a reference type. If a variable's type is not one of the simple types (Appendix B), or an enum or a struct type (which we discuss in Section 7.10 and Chapter 16, respectively), then it's a reference type. For example, Account account1 indicates that account1 is a variable that can refer to an Account object.

## 4.10 Initializing Objects with Constructors

As mentioned in Section 4.5, when a `GradeBook` (Fig. 4.7) object is created, its instance variable `courseName` is initialized to `null` by default. This is also true of the private instance variable that the compiler creates for the auto-implemented `CourseName` property discussed in Section 4.8. What if you want to provide a course name when you create a `GradeBook` object? Each class can provide a **constructor** that can be used to *initialize an object of a class when the object is created*. In fact, C# requires a constructor call for *every* object that's created. The new operator calls the class's constructor to perform the initialization. The constructor call is indicated by the class name, followed by parentheses. For example, line 11 of Fig. 4.8 first uses `new` to create a `GradeBook` object. The empty parentheses after “`new GradeBook()`” indicate a call *without arguments* to the class's constructor. The compiler provides a **public default constructor** with *no* parameters in any class that does not *explicitly* define a constructor, so *every* class has a constructor. The default constructor does *not* modify the default values of the instance variables.

### Custom Initialization with Constructors

When you declare a class, you can provide your own constructor (or several constructors, as you'll learn in Chapter 10) to specify custom initialization for objects of your class. For example, you might want to specify a course name for a `GradeBook` object when the object is created, as in

```
GradeBook myGradeBook =  
    new GradeBook( "CS101 Introduction to C# Programming" );
```

In this case, the argument “`CS101 Introduction to C# Programming`” is passed to the `GradeBook` object's constructor and used to initialize the `CourseName`. Each time you create a *new* `GradeBook` object, you can provide a *different* course name. The preceding statement requires that the class provide a constructor with a `string` parameter. Figure 4.12 contains a modified `GradeBook` class with such a constructor.

---

```
1 // Fig. 4.12: GradeBook.cs  
2 // GradeBook class with a constructor to initialize the course name.  
3 using System;  
4  
5 public class GradeBook  
6 {  
7     // auto-implemented property CourseName implicitly created an  
8     // instance variable for this GradeBook's course name  
9     public string CourseName { get; set; }  
10  
11    // constructor initializes auto-implemented property  
12    // CourseName with string supplied as argument  
13    public GradeBook( string name )  
14    {  
15        CourseName = name; // set CourseName to name  
16    } // end constructor  
17
```

**Fig. 4.12** | `GradeBook` class with a constructor to initialize the course name. (Part I of 2.)

```
18 // display a welcome message to the GradeBook user
19 public void DisplayMessage()
20 {
21     // use auto-implemented property CourseName to get the
22     // name of the course that this GradeBook represents
23     Console.WriteLine( "Welcome to the grade book for\n{0}!",
24         CourseName );
25 } // end method DisplayMessage
26 } // end class GradeBook
```

**Fig. 4.12** | GradeBook class with a constructor to initialize the course name. (Part 2 of 2.)

### Declaring a Constructor

Lines 13–16 declare the constructor for class GradeBook. *A constructor must have the same name as its class.* Like a method, a **constructor specifies in its parameter list the data it requires to perform its task.** When you use new to create an object, you place this data in the parentheses that follow the class name. **Unlike a method, a constructor doesn't specify a return type, not even void.** Line 13 indicates that class GradeBook's constructor has a parameter called name of type string. In line 15, the name passed to the constructor is used to initialize auto-implemented property CourseName via its set accessor.

### Initializing GradeBook Objects with a Custom Constructor

Figure 4.13 demonstrates initializing GradeBook objects using this constructor. Lines 12–13 create and initialize a GradeBook object. The constructor of class GradeBook is called with the argument "CS101 Introduction to C# Programming" to initialize the course name. The *object-creation expression* to the right of = in lines 12–13 returns a reference to the new object, which is assigned to variable gradeBook1. Lines 14–15 repeat this process for another GradeBook object, this time passing the argument "CS102 Data Structures in C#" to initialize the course name for gradeBook2. Lines 18–21 use each object's CourseName property to obtain the course names and show that they were indeed initialized when the objects were created. In Section 4.5, you learned that each instance (i.e., object) of a class contains its own copy of the class's instance variables. The output confirms that each GradeBook maintains its own course name.

---

```
1 // Fig. 4.13: GradeBookTest.cs
2 // GradeBook constructor used to specify the course name at the
3 // time each GradeBook object is created.
4 using System;
5
6 public class GradeBookTest
7 {
8     // Main method begins program execution
9     public static void Main( string[] args )
10    {
```

**Fig. 4.13** | GradeBook constructor used to specify the course name at the time each GradeBook object is created. (Part 1 of 2.)

```

11     // create GradeBook object
12     GradeBook gradeBook1 = new GradeBook( // invokes constructor
13         "CS101 Introduction to C# Programming" );
14     GradeBook gradeBook2 = new GradeBook( // invokes constructor
15         "CS102 Data Structures in C#" );
16
17     // display initial value of courseName for each GradeBook
18     Console.WriteLine( "gradeBook1 course name is: {0}",
19         gradeBook1.CourseName );
20     Console.WriteLine( "gradeBook2 course name is: {0}",
21         gradeBook2.CourseName );
22 } // end Main
23 } // end class GradeBookTest

```

```

gradeBook1 course name is: CS101 Introduction to C# Programming
gradeBook2 course name is: CS102 Data Structures in C#

```

**Fig. 4.13** | GradeBook constructor used to specify the course name at the time each GradeBook object is created. (Part 2 of 2.)

Normally, constructors are declared `public`. If a class does not *explicitly* define a constructor, the class's instance variables are initialized to their default values—0 for numeric types, `false` for type `bool` and `null` for reference types. If you declare any constructors for a class, C# will *not* create a default constructor for that class.

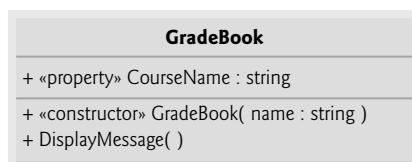


#### Error-Prevention Tip 4.1

*Unless default initialization of your class's instance variables is acceptable, provide a constructor to ensure that your class's instance variables are initialized with meaningful values when each new object of your class is created.*

#### *Adding the Constructor to Class GradeBook's UML Class Diagram*

The UML class diagram of Fig. 4.14 models class `GradeBook` of Fig. 4.12, which has a constructor that has a name parameter of type `string`. Like operations, the UML models constructors in the third compartment of a class in a class diagram. To distinguish a constructor from a class's operations, the UML places the word “constructor” between guillemets (« and ») before the constructor's name. It's customary to list constructors before other operations in the third compartment.



**Fig. 4.14** | UML class diagram indicating that class `GradeBook` has a constructor with a name parameter of type `string`.

## 4.11 Floating-Point Numbers and Type decimal

In our next app, we depart temporarily from our GradeBook case study to declare a class called `Account` that maintains a bank account's balance. Most account balances are not whole numbers (such as 0, -22 and 1024), rather they're numbers that include a decimal point, such as 99.99 or -20.15. For this reason, class `Account` represents the account balance as a real number. C# provides three simple types for storing real numbers—`float`, `double`, and `decimal`. Types `float` and `double` are called **floating-point types**. The primary difference between them and `decimal` is that `decimal` variables store a limited range of real numbers *precisely*, whereas floating-point variables store only *approximations* of real numbers, but across a much greater range of values. Also, `double` variables can store numbers with larger magnitude and finer detail (i.e., more digits to the right of the decimal point—also known as the number's **precision**) than `float` variables. A key use of type `decimal` is representing *monetary amounts*.

### *Real-Number Precision and Storage Requirements*

Variables of type `float` represent **single-precision floating-point numbers** and have *seven* significant digits. Variables of type `double` represent **double-precision floating-point numbers**. These require twice as much storage as `float` variables and provide 15–16 significant digits—approximately double the precision of `float` variables. Variables of type `decimal` require twice as much storage as `double` variables and provide 28–29 significant digits. In some apps, even variables of type `double` and `decimal` will be inadequate—such apps are beyond the scope of this book.

Most programmers represent floating-point numbers with type `double`. In fact, C# treats *all* real numbers you type in an app's source code (such as 7.33 and 0.0975) as `double` values by default. Such values in the source code are known as **floating-point literals**. To type a `decimal` literal, you must type the letter "M" or "m" (which stands for "money") at the end of a real number (for example, 7.33M is a `decimal` literal rather than a `double`). Integer literals are implicitly converted into type `float`, `double` or `decimal` when they're assigned to a variable of one of these types. See Appendix B for the ranges of values for `floats`, `doubles`, `decimals` and all the other simple types.

Although floating-point numbers are not always 100% precise, they have numerous applications. For example, when we speak of a "normal" body temperature of 98.6, we do not need to be precise to a large number of digits. When we read the temperature on a thermometer as 98.6, it may actually be 98.5999473210643. Calling this number simply 98.6 is fine for most applications involving body temperatures. Due to the imprecise nature of floating-point numbers, type `decimal` is preferred over the floating-point types whenever the calculations need to be exact, as with monetary calculations. In cases where approximation is enough, `double` is preferred over type `float` because `double` variables can represent floating-point numbers more accurately. For this reason, we use type `decimal` throughout the book for monetary amounts and type `double` for other real numbers.

Real numbers also arise as a result of division. In conventional arithmetic, for example, when we divide 10 by 3, the result is 3.3333333..., with the sequence of 3s repeating *infinitely*. The computer allocates only a fixed amount of space to hold such a value, so clearly the stored floating-point value can be only an approximation.



### Common Programming Error 4.3

*Using floating-point numbers in a manner that assumes they're represented precisely can lead to logic errors.*

#### **Account Class with an Instance Variable of Type decimal**

Our next app (Figs. 4.15–4.16) contains a simple class named **Account** (Fig. 4.15) that maintains the balance of a bank account. A typical bank services *many* accounts, each with its *own* balance, so line 7 declares an instance variable named **balance** of type **decimal**. Variable **balance** is an *instance variable* because it's declared *in* the body of the class (lines 6–36) but *outside* the class's method and property declarations (lines 10–13, 16–19 and 22–35). Every instance (i.e., object) of class **Account** contains its own copy of **balance**.

```

1 // Fig. 4.15: Account.cs
2 // Account class with a constructor to
3 // initialize instance variable balance.
4
5 public class Account
6 {
7     private decimal balance; // instance variable that stores the balance
8
9     // constructor
10    public Account( decimal initialBalance )
11    {
12        Balance = initialBalance; // set balance using property
13    } // end Account constructor
14
15    // credit (add) an amount to the account
16    public void Credit( decimal amount )
17    {
18        Balance = Balance + amount; // add amount to balance
19    } // end method Credit
20
21    // a property to get and set the account balance
22    public decimal Balance
23    {
24        get
25        {
26            return balance;
27        } // end get
28        set
29        {
30            // validate that value is greater than or equal to 0;
31            // if it is not, balance is left unchanged
32            if ( value >= 0 )
33                balance = value;
34        } // end set
35    } // end property Balance
36 } // end class Account

```

**Fig. 4.15** | Account class with a constructor to initialize instance variable **balance**.

### **Account Class Constructor**

Class Account contains a constructor, a method, and a property. Since it's common for someone opening an account to place money in the account immediately, the constructor (lines 10–13) receives a parameter `initialBalance` of type `decimal` that represents the account's starting balance. Line 12 assigns `initialBalance` to the property `Balance`, invoking `Balance`'s set accessor to initialize the instance variable `balance`.

### **Account Method Credit**

Method `Credit` (lines 16–19) doesn't return data when it completes its task, so its return type is `void`. The method receives one parameter named `amount`—a `decimal` value that's added to the property `Balance`. Line 18 uses both the get and set accessors of `Balance`. The expression `Balance + amount` invokes property `Balance`'s get accessor to obtain the current value of instance variable `balance`, then adds `amount` to it. We then assign the result to instance variable `balance` by invoking the `Balance` property's set accessor (thus replacing the prior `balance` value).

### **Account Property Balance**

Property `Balance` (lines 22–35) provides a get accessor, which allows clients of the class (i.e., other classes that use this class) to obtain the value of a particular `Account` object's `balance`. The property has type `decimal` (line 22). `Balance` also provides an enhanced set accessor.

In Section 4.5, we introduced properties whose set accessors allow clients of a class to modify the value of a private instance variable. In Fig. 4.7, class `GradeBook` defines property `CourseName`'s set accessor to assign the value received in its parameter `value` to instance variable `courseName` (line 19). This `CourseName` property does *not* ensure that `courseName` contains only *valid* data.

The app of Figs. 4.15–4.16 enhances the set accessor of class `Account`'s property `Balance` to perform this validation (also known as **validity checking**). Line 32 (Fig. 4.15) ensures that `value` is nonnegative. If the value is greater than or equal to 0, the amount stored in `value` is assigned to instance variable `balance` in line 33. Otherwise, `balance` is left unchanged.

### **AccountTest Class to Use Class Account**

Class `AccountTest` (Fig. 4.16) creates two `Account` objects (lines 10–11) and initializes them respectively with `50.00M` and `-7.53M` (the decimal literals representing the real numbers 50.00 and -7.53). The `Account` constructor (lines 10–13 of Fig. 4.15) references property `Balance` to initialize `balance`. In previous examples, the benefit of referencing the property in the constructor was not evident. Now, however, the constructor takes advantage of the validation provided by the set accessor of the `Balance` property. The constructor simply assigns a value to `Balance` rather than duplicating the set accessor's validation code. When line 11 of Fig. 4.16 passes an initial balance of `-7.53` to the `Account` constructor, the constructor passes this value to the set accessor of property `Balance`, where the actual initialization occurs. This value is less than 0, so the set accessor does *not* modify `balance`, leaving this instance variable with its default value of 0.

```

1 // Fig. 4.16: AccountTest.cs
2 // Create and manipulate Account objects.
3 using System;
4
5 public class AccountTest
6 {
7     // Main method begins execution of C# app
8     public static void Main( string[] args )
9     {
10         Account account1 = new Account( 50.00M ); // create Account object
11         Account account2 = new Account( -7.53M ); // create Account object
12
13         // display initial balance of each object using a property
14         Console.WriteLine( "account1 balance: {0:C}", 
15             account1.Balance ); // display Balance property
16         Console.WriteLine( "account2 balance: {0:C}\n",
17             account2.Balance ); // display Balance property
18
19         decimal depositAmount; // deposit amount read from user
20
21         // prompt and obtain user input
22         Console.Write( "Enter deposit amount for account1: " );
23         depositAmount = Convert.ToDecimal( Console.ReadLine() );
24         Console.WriteLine( "adding {0:C} to account1 balance\n",
25             depositAmount );
26         account1.Credit( depositAmount ); // add to account1 balance
27
28         // display balances
29         Console.WriteLine( "account1 balance: {0:C}", 
30             account1.Balance );
31         Console.WriteLine( "account2 balance: {0:C}\n",
32             account2.Balance );
33
34         // prompt and obtain user input
35         Console.Write( "Enter deposit amount for account2: " );
36         depositAmount = Convert.ToDecimal( Console.ReadLine() );
37         Console.WriteLine( "adding {0:C} to account2 balance\n",
38             depositAmount );
39         account2.Credit( depositAmount ); // add to account2 balance
40
41         // display balances
42         Console.WriteLine( "account1 balance: {0:C}", account1.Balance );
43         Console.WriteLine( "account2 balance: {0:C}", account2.Balance );
44     } // end Main
45 } // end class AccountTest

```

```

account1 balance: $50.00
account2 balance: $0.00

Enter deposit amount for account1: 49.99
adding $49.99 to account1 balance

```

**Fig. 4.16** | Create and manipulate Account objects. (Part I of 2.)

```

account1 balance: $99.99
account2 balance: $0.00

Enter deposit amount for account2: 123.21
adding $123.21 to account2 balance

account1 balance: $99.99
account2 balance: $123.21

```

**Fig. 4.16** | Create and manipulate Account objects. (Part 2 of 2.)

Lines 14–17 in Fig. 4.16 output the balance in each Account by using the Account's Balance property. When Balance is used for account1 (line 15), the value of account1's balance is returned by the get accessor in line 26 of Fig. 4.15 and displayed by the Console.WriteLine statement (Fig. 4.16, lines 14–15). Similarly, when property Balance is called for account2 from line 17, the value of the account2's balance is returned from line 26 of Fig. 4.15 and displayed by the Console.WriteLine statement (Fig. 4.16, lines 16–17). The balance of account2 is 0 because the constructor ensured that the account could not begin with a negative balance. The value is output by WriteLine with the format item {0:C}, which formats the account balance as a monetary amount. The : after the 0 indicates that the next character represents a **format specifier**, and the C format specifier after the : specifies a monetary amount (C is for currency). The cultural settings on the user's machine determine the format for displaying monetary amounts. For example, in the United States, 50 displays as \$50.00. In Germany, 50 displays as 50,00 €. [Note: Change the Command Prompt's font to Lucida Console for the € symbol to display correctly.] Figure 4.17 lists a few other format specifiers in addition to C.

Format specifier	Description
C or c	Formats the string as currency. Displays an appropriate currency symbol (\$ in the U.S.) next to the number. Separates digits with an appropriate <i>separator character</i> (comma in the U.S.) and sets the number of decimal places to two by default.
D or d	Formats the string as a whole number (integer types only). Displays number as an integer.
N or n	Formats the string with a thousands separator and a default of two decimal places.
E or e	Formats the number using scientific notation with a default of six decimal places.
F or f	Formats the string with a fixed number of decimal places (two by default).
G or g	Formats the number normally with decimal places or using scientific notation, depending on context. If a format item does not contain a format specifier, format G is assumed implicitly.
X or x	Formats the string as hexadecimal.

**Fig. 4.17** | string format specifiers.

Line 19 declares local variable depositAmount to store each deposit amount entered by the user. Unlike the instance variable balance in class Account, the local variable

`depositAmount` in `Main` is *not* initialized to 0 by default. Also, *a local variable can be used only in the method in which it's declared*. However, this variable does not need to be initialized here because its value will be determined by the user's input. *The compiler does not allow a local variable's value to be read until it's initialized.*

Line 22 prompts the user to enter a deposit amount for `account1`. Line 23 obtains the input from the user by calling the `Console` class's `ReadLine` method, then passing the string entered by the user to the `Convert` class's `ToDecimal` method, which returns the `decimal` value in this `string`. Lines 24–25 display the deposit amount. Line 26 calls object `account1`'s `Credit` method and supplies `depositAmount` as the method's argument. When the method is called, the argument's value is assigned to parameter `amount` of method `Credit` (lines 16–19 of Fig. 4.15), then method `Credit` adds that value to the `balance` (line 18 of Fig. 4.15). Lines 29–32 (Fig. 4.16) output the balances of both `Accounts` again to show that *only* `account1`'s balance changed.

Line 35 prompts the user to enter a deposit amount for `account2`. Line 36 obtains the input from the user by calling method `Console.ReadLine`, and passing the return value to the `Convert` class's `ToDecimal` method. Lines 37–38 display the deposit amount. Line 39 calls object `account2`'s `Credit` method and supplies `depositAmount` as the method's argument, then method `Credit` adds that value to the `balance`. Finally, lines 42–43 output the balances of both `Accounts` again to show that *only* `account2`'s balance changed.

### **set and get Accessors with Different Access Modifiers**

By default, the `get` and `set` accessors of a property have the *same* access as the property—for example, for a `public` property, the accessors are `public`. It's possible to declare the `get` and `set` accessors with *different* access modifiers. In this case, one of the accessors must implicitly have the *same* access as the property and the other must be declared with a *more restrictive* access modifier than the property. For example, in a `public` property, the `get` accessor might be `public` and the `set` accessor might be `private`. We demonstrate this feature in Section 10.7.



#### **Error-Prevention Tip 4.2**

*The benefits of data integrity are not automatic simply because instance variables are made private—you must provide appropriate validity checking and report the errors.*

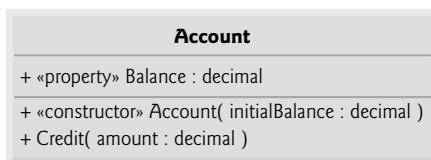


#### **Error-Prevention Tip 4.3**

*set accessors that set the values of private data should verify that the intended new values are proper; if they're not, the set accessors should leave the instance variables unchanged and indicate an error. We demonstrate how to indicate errors in Chapter 10.*

### **UML Class Diagram for Class Account**

The UML class diagram in Fig. 4.18 models class `Account` of Fig. 4.15. The diagram models the `Balance` property as a UML attribute of type `decimal` (because the corresponding C# property had type `decimal`). The diagram models class `Account`'s constructor with a parameter `initialBalance` of type `decimal` in the third compartment of the class. The diagram models operation `Credit` in the third compartment with an `amount` parameter of type `decimal` (because the corresponding method has an `amount` parameter of C# type `decimal`).



**Fig. 4.18** | UML class diagram indicating that class Account has a public Balance property of type decimal, a constructor and a method.

## 4.12 Wrap-Up

In this chapter, you learned the basic object-oriented concepts of classes, objects, methods, instance variables, properties and constructors—these will be used in most substantial C# apps you create. You learned how to declare instance variables of a class to maintain data for each object of the class, how to declare methods that operate on that data, and how to declare properties to obtain and set that data. We demonstrated how to call a method to tell it to perform its task and how to pass information to methods as arguments. We discussed the difference between a local variable of a method and an instance variable of a class and that only instance variables are initialized automatically. We discussed the difference between a value type and a reference type. You learned how to create auto-implemented properties. You also learned how to use a class's constructor to specify the initial values for an object's instance variables. We discussed some of the differences between value types and reference types. You learned about the value types `float`, `double` and `decimal` for storing real numbers.

We showed how the UML can be used to create class diagrams that model the constructors, methods, properties and attributes of classes. You learned the value of declaring instance variables `private` and using `public` properties to manipulate them. For example, we demonstrated how set accessors in properties can be used to validate an object's data and ensure that the object is maintained in a consistent state. In the next chapter we begin our introduction to control statements, which specify the order in which an app's actions are performed. You'll use these in your methods to specify how they should perform their tasks.

---

## Summary

### Section 4.2 Classes, Objects, Methods, Properties and Instance Variables

- Methods perform tasks. Each method describes the mechanisms that actually perform its tasks. The method hides from its user the complex tasks that it performs.
- The app unit that houses a method is called a class. A class may contain one or more methods that are designed to perform the class's tasks.
- A method can perform a task and may return a result.
- An instance of a class is called an object.
- Each message sent to an object is a method call and tells that method to perform its task.
- Each method can specify parameters that represent additional information the method requires to perform its task correctly. A method call supplies arguments for the method's parameters.

- An object has attributes that are carried with the object as it's used in an app. These attributes are specified as part of the object's class. Attributes are specified in classes by fields.
- An object has properties for accessing attributes. Properties contain get accessors for reading attributes and set accessors for storing into them.

### ***Section 4.3 Declaring a Class with a Method and Instantiating an Object of a Class***

- Keyword `public` is an access modifier.
- Every class declaration contains keyword `class` followed immediately by the class's name.
- A method declaration that begins with keyword `public` indicates that the method is "available to the public"—that is, it can be called by other classes declared outside the class declaration.
- Keyword `void` indicates that a method will not return any information when it completes its task.
- By convention, method names begin with an uppercase first letter, and all subsequent words in the name begin with an uppercase first letter. This is called upper camel case.
- Empty parentheses following a method name indicate that the method does not require any parameters to perform its task.
- Every method's body is delimited by left and right braces (`{` and `}`).
- The body of a method contains statements that perform the method's task. After the statements execute, the method has completed its task.
- When you attempt to execute an app, C# looks for a `Main` method to begin execution.
- Typically, you create an object of a class to call the class's methods.
- Object creation expressions begin with the `new` operator and create new objects.
- To call a method of an object, follow the variable name with a member access operator `(.)`, the method name and a set of parentheses containing the method's arguments.
- In the UML, each class is modeled in a class diagram as a rectangle with three compartments. The top compartment contains the name of the class, centered horizontally in boldface. The middle compartment contains the class's attributes, which correspond to fields in C#. The bottom compartment contains the class's operations, which correspond to methods and constructors in C#.
- The UML models operations by listing the operation name, followed by a set of parentheses. A plus sign (+) in front of the operation name indicates that the operation is a public operation in the UML (i.e., a `public` method in C#). The plus sign is called the public visibility symbol.

### ***Section 4.4 Declaring a Method with a Parameter***

- Methods often require additional information to perform their tasks. Such additional information is provided to methods via arguments in method calls.
- `Console` method `ReadLine` reads characters until a newline character is encountered, then returns the characters as a `string`.
- A method that requires data to perform its task must specify this in its declaration by placing additional information in the method's parameter list.
- Each parameter must specify both a type and an identifier.
- At the time a method is called, its arguments are assigned to its parameters. Then the method body uses the parameter variables to access the argument values.
- A method can specify multiple parameters in a comma-separated parameter list.
- The number of arguments in the method call must match the number of required parameters in the method declaration's parameter list. Also, the argument types in the method call must be consistent with the types of the corresponding parameters in the method's declaration.

- The UML models a parameter of an operation by listing the parameter name, followed by a colon and the parameter type between the parentheses following the operation name.
- There's a special relationship between classes that are compiled in the same project. By default, such classes are considered to be in the same namespace. A `using` directive is not required when one class in a namespace uses another in the same namespace.
- A `using` directive is not required if you always refer to a class with its fully qualified class name.

### ***Section 4.5 Instance Variables and Properties***

- Local variables can be used only in the method in which they're declared.
- A class normally contains methods that manipulate the attributes that belong to a particular object of the class. Attributes are represented as instance variables in a class declaration. Such variables are declared inside a class declaration but outside its method's bodies.
- Each object (instance) of a class has a separate copy of each instance variable.
- Most instance-variable declarations are preceded with the `private` access modifier. Variables, properties or methods declared with access modifier `private` are accessible only to members of the class in which they're declared.
- Declaring instance variables with access modifier `private` is known as information hiding.
- Properties contain accessors that handle the details of modifying and returning data.
- Properties provide a controlled way for programmers to "get" (i.e., retrieve) the value in an instance variable and "set" (i.e., modify) the value in an instance variable.
- A property declaration can contain a `get` accessor, a `set` accessor or both. The `get` accessor typically enables a client to read the value of a `private` instance variable. The `set` accessor typically enables a client to modify that instance variable's value.
- After defining a property, you can use it the same way as you use a variable.
- The default value for a field of type `string` is `null`.

### ***Section 4.6 UML Class Diagram with a Property***

- We model properties in the UML as attributes, preceded by the word "property" in guillemets (« and »). Using descriptive words in guillemets (called stereotypes in the UML) helps distinguish properties from other attributes.
- A class diagram helps you design a class, so it's not required to show every implementation detail of the class. Since an instance variable that's manipulated by a property is really an implementation detail of that property, our class diagrams do not show instance variables.
- `private` class members are preceded by the private visibility symbol (-) in the UML.
- The UML represents instance variables and properties as attributes by listing the attribute name, followed by a colon and the attribute type.

### ***Section 4.7 Software Engineering with Properties and set and get Accessors***

- Properties can scrutinize attempts to modify an instance variable's value (known as data validation), thus ensuring that the new value for that instance variable is valid.
- Using properties would seem to violate the notion of `private` data. However, a `set` accessor can validate data to ensure that the value is set properly; `get` and `set` accessors can translate between the format of the data used by the client and the format used in the `private` instance variable.
- A benefit of fields over local variables is that all of a class's methods and properties can use the fields. Another distinction is that a field has a default initial value provided by C# when you do not specify the field's initial value, but a local variable does not.

### Section 4.8 Auto-Implemented Properties

- With an auto-implemented property, the C# compiler automatically creates a `private` instance variable, and the `get` and `set` accessors for returning and modifying the `private` instance variable.
- Visual Studio has a feature called code snippets that allows you to insert predefined code templates into your source code. One such snippet enables you to insert a `public` auto-implemented property by typing the word “`prop`” in the code window and pressing the `Tab` key twice.
- Pieces of the inserted code are highlighted for you to easily change the property’s type and name. Press the `Tab` key to move from one highlighted piece of text to the next in the inserted code.
- To get a list of all available code snippets, type `Ctrl + k, Ctrl + x`. This displays the `Insert Snippet` window in the code editor. This feature can also be accessed by right clicking in the source code editor and selecting the `Insert Snippet...` menu item.

### Section 4.9 Value Types vs. Reference Types

- Types are divided into two categories—value types and reference types.
- A variable of a value type contains data of that type.
- A variable of a reference type (sometimes called a reference) contains the address of a location in memory where an object is stored.
- Reference-type instance variables are initialized by default to the value `null`.

### Section 4.10 Initializing Objects with Constructors

- A constructor can be used to initialize an object of a class when the object is created.
- If no constructor is provided for a class, the compiler provides a `public` default constructor with no parameters that does not modify the instance variables’ default values.
- Like operations, the UML models constructors in the third compartment of a class diagram. To distinguish a constructor from a class’s operations, the UML places the word “constructor” between guillemets (« and ») before the constructor’s name.
- Constructors can specify parameters but cannot specify return types.

### Section 4.11 Floating-Point Numbers and Type `decimal`

- A real number is a number with a decimal point, such as `7.33`, `0.0975` or `1000.12345`. C# provides three simple types for storing real numbers—`float`, `double`, and `decimal`.
- Types `float` and `double` are called floating-point types. The primary difference between them and the `decimal` type is that `decimal` variables store a limited range of real numbers precisely, but floating-point variables store approximations of real numbers across a much greater range.
- Variables of type `float` represent single-precision floating-point numbers and have seven significant digits. Variables of type `double` represent double-precision floating-point numbers. These require twice as much storage as `float` variables and provide 15–16 significant digits—approximately double the precision of `float` variables. Furthermore, variables of type `decimal` require twice as much storage as `double` variables and provide 28–29 significant digits.
- Real number values that appear in source code are of type `double` by default.
- Convert method `.ToDecimal` extracts a `decimal` value from a `string`.
- The `:` in a format item indicates that the next character represents a format specifier.
- The `C` format specifier specifies a monetary amount (`C` is for currency).
- It’s possible to declare the `get` and `set` accessors of a property with different access modifiers. One accessor must implicitly have the same access as the property and the other must be declared with a more restrictive access modifier than the property; `private` is more restrictive than `public`.

## Terminology

access modifier	local variable
attribute (UML)	member access (.) operator
auto-implemented property	message
automatically implemented property	method
C format specifier	method header
calling method	new operator
class	null keyword
class declaration	object (or instance)
class keyword	object-creation expression
client of an object or a class	operation (UML)
code snippet	parameter
compartment in a class diagram (UML)	parameter list
constructor	precision of a floating-point value
create an object	precision of a formatted floating-point number
decimal simple type	“prop” code snippet
default value	property
double-precision floating-point number	private access modifier
double simple type	public access modifier
field	public default constructor
float simple type	public method
floating-point number	ReadLine method of class Console
format specifier	refer to an object
fully qualified class name	reference
get accessor	reference type
global namespace	send a message
guillemets, « and » (UML)	set accessor
information hiding	single-precision floating-point number
instance of a class (object)	ToDecimal method of class Convert
instance variable	UML class diagram
instantiate (or create) an object	UML visibility symbol
invoke a method	void keyword

## Self-Review Exercises

4.1 Fill in the blanks in each of the following:

- a) A house is to a blueprint as a(n) \_\_\_\_\_ is to a class.
- b) Every class declaration contains keyword \_\_\_\_\_ followed immediately by the class’s name.
- c) Operator \_\_\_\_\_ creates an object of the class specified to the right of the keyword.
- d) Each parameter must specify both a(n) \_\_\_\_\_ and a(n) \_\_\_\_\_.
- e) By default, classes that are not explicitly declared in a namespace are implicitly placed in the \_\_\_\_\_.
- f) When each object of a class maintains its own copy of an attribute, the field that represents the attribute is also known as a(n) \_\_\_\_\_.
- g) C# provides three simple types for storing real numbers—\_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.
- h) Variables of type `double` represent \_\_\_\_\_ floating-point numbers.
- i) `Convert` method \_\_\_\_\_ returns a `decimal` value.
- j) Keyword `public` is a(n) \_\_\_\_\_.

- k) Return type \_\_\_\_\_ indicates that a method will not return any information when it completes its task.
- l) Console method \_\_\_\_\_ reads characters until a newline character is encountered, then returns those characters (not including the newline) as a `string`.
- m) A(n) \_\_\_\_\_ is not required if you always refer to a class with its fully qualified class name.
- n) Variables of type `float` represent \_\_\_\_\_ floating-point numbers.
- o) The format specifier \_\_\_\_\_ is used to display values in a monetary format.
- p) Types are either \_\_\_\_\_ types or \_\_\_\_\_ types.
- q) For a(n) \_\_\_\_\_, the compiler automatically generates a private instance variable and `set` and `get` accessors.

**4.2**

State whether each of the following is *true* or *false*. If *false*, explain why.

- a) By convention, method names begin with a lowercase first letter and all subsequent words in the name begin with a capital first letter.
- b) A property's `get` accessor enables a client to modify the value of the instance variable associated with the property.
- c) A `using` directive is not required when one class in a namespace uses another in the same namespace.
- d) Empty parentheses following a method name in a method declaration indicate that the method does not require any parameters to perform its task.
- e) After defining a property, you can use it the same way you use a method, but with empty parentheses, because no arguments are passed to a property.
- f) Variables or methods declared with access modifier `private` are accessible only to members of the class in which they're declared.
- g) Variables declared in the body of a particular method are known as instance variables and can be used in all methods of the class.
- h) A property declaration must contain both a `get` accessor and a `set` accessor.
- i) The body of any method or property is delimited by left and right braces.
- j) Local variables are initialized by default.
- k) Reference-type instance variables are initialized by default to the value `null`.
- l) Any class that contains `public static void Main(string[] args)` can be used to execute an app.
- m) The number of arguments in the method call must match the number of required parameters in the method declaration's parameter list.
- n) Real number values that appear in source code are known as floating-point literals and are of type `float` by default.

**4.3** What is the difference between a local variable and an instance variable?**4.4** Explain the purpose of a method parameter. What is the difference between a parameter and an argument?

## Answers to Self-Review Exercises

**4.1**

- a) object. b) class. c) new. d) type, name. e) global namespace. f) instance variable.
- g) `float`, `double`, `decimal`. h) double-precision. i) `ToDecimal`. j) access modifier. k) `void`.
- l) `ReadLine`. m) `using` directive. n) single-precision. o) C. p) value, reference. q) auto-implemented property.

**4.2**

- a) False. By convention, method names begin with an uppercase first letter and all subsequent words in the name begin with an uppercase first letter. b) False. A property's `get` accessor enables a client to retrieve the value of the instance variable associated with the property. A proper-

ty's `set` accessor enables a client to modify the value of the instance variable associated with the property. c) True. d) True. e) False. After defining a property, you can use it the same way you use a variable. f) True. g) False. Such variables are called local variables and can be used only in the method in which they're declared. h) False. A property declaration can contain a `get` accessor, a `set` accessor or both. i) True. j) False. Instance variables are initialized by default. k) True. l) True. m) True. n) False. Such literals are of type `double` by default.

**4.3** A local variable is declared in the body of a method and can be used only in the method in which it's declared. An instance variable is declared in a class, but not in the body of any of the class's members. Every object (instance) of a class has a separate copy of the class's instance variables. Also, instance variables are accessible to all members of the class. (We'll see an exception to this in Chapter 10.)

**4.4** A parameter represents additional information that a method requires to perform its task. Each parameter required by a method is specified in the method's declaration. An argument is the actual value that's passed to a method parameter when a method is called.

## Exercises

**4.5** What is the purpose of operator `new`? Explain what happens when this keyword is used in an app.

**4.6** What is a default constructor? How are an object's instance variables initialized if a class has only a default constructor?

**4.7** Explain the purpose of an instance variable.

**4.8** Explain how an app could use class `Console` without using a `using` directive.

**4.9** Explain why a class might provide a property for an instance variable.

**4.10** (*GradeBook Modification*) Modify class `GradeBook` (Fig. 4.12) as follows:

- a) Include a second `string` auto-implemented property that represents the name of the course's instructor.
- b) Modify the constructor to specify two parameters—one for the course name and one for the instructor's name.
- c) Modify method `DisplayMessage` such that it first outputs the welcome message and course name, then outputs "This course is presented by: ", followed by the instructor's name.

Use your modified class in a test app that demonstrates the class's new capabilities.

**4.11** (*Account Modification*) Modify class `Account` (Fig. 4.15) to provide a method called `Debit` that withdraws money from an `Account`. Ensure that the debit amount doesn't exceed the balance. If it does, the balance should not be changed and the method should display a message indicating "Debit amount exceeded account balance." Modify class `AccountTest` (Fig. 4.16) to test method `Debit`.

**4.12** (*Invoice Class*) Create a class called `Invoice` that a hardware store might use to represent an invoice for an item sold at the store. An `Invoice` should include four pieces of information as either instance variables or automatic properties—a part number (type `string`), a part description (type `string`), a quantity of the item being purchased (type `int`) and a price per item (decimal). Your class should have a constructor that initializes the four values. Provide a property with a `get` and `set` accessor for any instance variables. For the `Quantity` and `PricePerItem` properties, if the value passed to the `set` accessor is negative, the value of the instance variable should be left unchanged. Also, provide a method named `GetInvoiceAmount` that calculates the invoice amount (i.e., multiplies the quantity by the price per item), then returns the amount as a `decimal` value. Write a test app named `InvoiceTest` that demonstrates class `Invoice`'s capabilities.

**4.13 (*Employee Class*)** Create a class called `Employee` that includes three pieces of information as either instance variables or automatic properties—a first name (type `string`), a last name (type `string`) and a monthly salary (`decimal`). Your class should have a constructor that initializes the three values. Provide a property with a `get` and `set` accessor for any instance variables. If the monthly salary is negative, the `set` accessor should leave the instance variable unchanged. Write a test app named `EmployeeTest` that demonstrates class `Employee`'s capabilities. Create two `Employee` objects and display each object's *yearly* salary. Then give each `Employee` a 10% raise and display each `Employee`'s yearly salary again.

**4.14 (*Date Class*)** Create a class called `Date` that includes three pieces of information as automatic properties—a month (type `int`), a day (type `int`) and a year (type `int`). Your class should have a constructor that initializes the three automatic properties and assumes that the values provided are correct. Provide a method `DisplayDate` that displays the month, day and year separated by forward slashes (/). Write a test app named `DateTest` that demonstrates class `Date`'s capabilities.

## Making a Difference Exercises

**4.15 (*Target-Heart-Rate Calculator*)** While exercising, you can use a heart-rate monitor to see that your heart rate stays within a safe range suggested by your trainers and doctors. According to the American Heart Association (AHA) ([www.heart.org/HEARTORG/GettingHealthy/PhysicalActivity/Target-Heart-Rates\\_UCM\\_434341\\_Article.jsp](http://www.heart.org/HEARTORG/GettingHealthy/PhysicalActivity/Target-Heart-Rates_UCM_434341_Article.jsp)), the formula for calculating your *maximum heart rate* in beats per minute is 220 minus your age in years. Your *target heart rate* is a range that is 50–85% of your maximum heart rate. [Note: These formulas are estimates provided by the AHA. Maximum and target heart rates may vary based on the health, fitness and gender of the individual. Always consult a physician or qualified health care professional before beginning or modifying an exercise program.] Create a class called `HeartRates`. The class attributes should include the person's first name, last name, year of birth and the current year. Your class should have a constructor that receives this data as parameters. For each attribute provide a property with `set` and `get` accessors. The class also should include a property that calculates and returns the person's age (in years), a property that calculates and returns the person's maximum heart rate and properties that calculate and return the person's minimum and maximum target heart rates. Write an app that prompts for the person's information, instantiates an object of class `HeartRates` and displays the information from that object—including the person's first name, last name and year of birth—then calculates and displays the person's age in (years), maximum heart rate and target-heart-rate range.

**4.16 (*Computerization of Health Records*)** A health care issue that has been in the news lately is the computerization of health records. This possibility is being approached cautiously because of sensitive privacy and security concerns, among others. [We address such concerns in later exercises.] Computerizing health records could make it easier for patients to share their health profiles and histories among their various health care professionals. This could improve the quality of health care, help avoid drug conflicts and erroneous drug prescriptions, reduce costs and, in emergencies, could save lives. In this exercise, you'll design a "starter" `HealthProfile` class for a person. The class attributes should include the person's first name, last name, gender, date of birth (consisting of separate attributes for the month, day and year of birth), height (in inches) and weight (in pounds). Your class should have a constructor that receives this data. For each attribute provide a property with `set` and `get` accessors. The class also should include methods that calculate and return the user's age in years, maximum heart rate and target-heart-rate range (see Exercise 4.15), and body mass index (BMI; see Exercise 3.31). Write an app that prompts for the person's information, instantiates an object of class `HealthProfile` for that person and displays the information from that object—including the person's first name, last name, gender, date of birth, height and weight—then calculates and displays the person's age in years, BMI, maximum heart rate and target-heart-rate range. It should also display the "BMI values" chart from Exercise 3.31.

# 5

# Control Statements: Part I

*Let's all move one place on.*

—Lewis Carroll

*The wheel is come full circle.*

—William Shakespeare

*All the evolution we know of  
proceeds from the vague to the  
definite.*

—Charles Sanders Peirce

## Objectives

In this chapter you'll:

- Learn basic problem-solving techniques.
- Develop algorithms through the process of top-down, stepwise refinement.
- Use the `if` and `if...else` selection statements to choose between actions.
- Use the `while` statement to execute statements repeatedly.
- Use counter-controlled repetition and sentinel-controlled repetition.
- Use the increment, decrement and compound assignment operators.



# Outline

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li><b>5.1</b> Introduction</li><li><b>5.2</b> Algorithms</li><li><b>5.3</b> Pseudocode</li><li><b>5.4</b> Control Structures</li><li><b>5.5</b> <code>if</code> Single-Selection Statement</li><li><b>5.6</b> <code>if...else</code> Double-Selection Statement</li><li><b>5.7</b> <code>while</code> Repetition Statement</li><li><b>5.8</b> Formulating Algorithms: Counter-Controlled Repetition</li></ul> | <ul style="list-style-type: none"><li><b>5.9</b> Formulating Algorithms: Sentinel-Controlled Repetition</li><li><b>5.10</b> Formulating Algorithms: Nested Control Statements</li><li><b>5.11</b> Compound Assignment Operators</li><li><b>5.12</b> Increment and Decrement Operators</li><li><b>5.13</b> Simple Types</li><li><b>5.14</b> Wrap-Up</li></ul> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 5.1 Introduction

Before writing a program to solve a problem, we must have a thorough understanding of the problem and a carefully planned approach to solving it. We must also understand the available building blocks and employ proven program-construction techniques. In this chapter and in Chapter 6, Control Statements: Part 2, we discuss these issues as we present the theory and principles of *structured programming*. The concepts presented here are crucial to building effective classes and manipulating objects.

In this chapter, we introduce C#'s `if`, `if...else` and `while` statements, three of the building blocks that allow you to specify the logic required for member functions to perform their tasks. We devote a portion of this chapter (and Chapters 6 and 8) to further developing the `GradeBook` class. In particular, we add a member function to the `GradeBook` class that uses control statements to calculate the average of a set of student grades. Another example demonstrates additional ways to combine control statements. We introduce C#'s assignment, increment and decrement operators. These additional operators abbreviate and simplify many program statements.

## 5.2 Algorithms

Any computing problem can be solved by executing a **series of actions in a specific order**. A **procedure** for solving a problem in terms of

1. the **actions to execute** and
2. the **order in which these actions execute**

is called an **algorithm**. The following example demonstrates that correctly specifying the order in which the actions execute is important.

Consider the “rise-and-shine algorithm” followed by one junior executive for getting out of bed and going to work: (1) get out of bed, (2) take off pajamas, (3) take a shower, (4) get dressed, (5) eat breakfast and (6) carpool to work. This routine prepares the executive for a productive day at the office.

However, suppose that the same steps are performed in a different order: (1) get out of bed, (2) take off pajamas, (3) get dressed, (4) take a shower, (5) eat breakfast, (6) carpool to work. In this case, our junior executive shows up for work soaking wet.

Specifying the order in which statements (actions) execute is called **program control**. This chapter investigates program control using C#'s **control statements**.

## 5.3 Pseudocode

Pseudocode is an informal language that helps you develop algorithms without having to worry about the strict details of C# language syntax. Pseudocode is useful for developing algorithms that will be converted to structured portions of C# apps. **Pseudocode is similar to English—it's not a programming language.**

Pseudocode does *not* execute on computers. Rather, it helps you “think out” an app before attempting to write it in C#. This chapter shows how to use pseudocode to develop C# apps.

You can create pseudocode using any text appeditor. Carefully prepared pseudocode can easily be converted to a corresponding C# app. In many cases, this simply requires replacing pseudocode statements with C# equivalents.

Pseudocode normally describes only **actions**, such as *input*, *output* and *calculations*. We do *not* include variable declarations in our pseudocode, but some programmers do.

## 5.4 Control Structures

Normally, statements execute one after the other in the order in which they're written. This process is called **sequential execution**. Various C# statements enable you to specify that the next statement to execute is *not* necessarily the next one in sequence. This is called **transfer of control**.

During the 1960s, it became clear that the indiscriminate use of transfers of control was the root of much difficulty experienced by software development groups. The blame was pointed at the **goto statement** (used in most programming languages of the time), which allows you to specify a transfer of control to one of a wide range of possible destinations in an app (creating what is often called “spaghetti code”). The notion of so-called **structured programming** became almost synonymous with “*goto elimination*.” We recommend that you avoid C#'s *goto* statement.

Research<sup>1</sup> had demonstrated that apps could be written *without goto statements*. The challenge of the era for programmers was to shift their styles to “*goto-less programming*.” Not until the 1970s did programmers start taking *structured programming* seriously. The results were impressive because *structured apps* were clearer, easier to debug and modify, and more likely to be bug free in the first place.

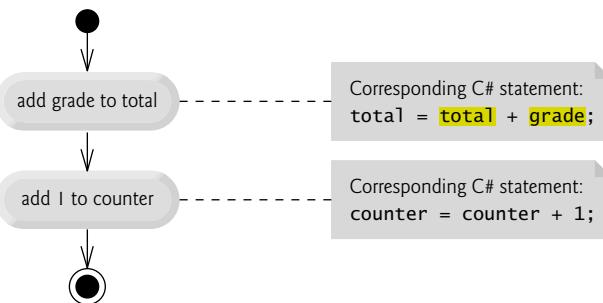
Bohm and Jacopini's work demonstrated that all apps could be written in terms of only three control structures—the **sequence structure**, the **selection structure** and the **repetition structure**. When we introduce C#'s implementations of control structures, we'll refer to them in the terminology of the *C# Language Specification* as “control statements.”

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1. Böhm, C., and G. Jacopini, “Flow Diagrams, Turing Machines, and Languages with Only Two Formation Rules,” *Communications of the ACM*, Vol. 9, No. 5, May 1966, pp. 366–371.

### Sequence Structure in C#

The *sequence structure* is built into C#. Unless directed otherwise, the computer executes C# statements one after the other in the order in which they're written—that is, in sequence. The UML activity diagram in Fig. 5.1 illustrates a typical sequence structure in which two calculations are performed in order. C# lets you have as many actions as you want in a sequence structure.



**Fig. 5.1** | Sequence structure activity diagram.

An activity diagram models the **workflow** (also called the **activity**) of a portion of a software system. Such workflows may include a portion of an algorithm, such as the sequence structure in Fig. 5.1. Activity diagrams are composed of special-purpose symbols, such as **action-state symbols** (rectangles with their left and right sides replaced with arcs curving outward), **diamonds** and **small circles**. These symbols are connected by **transition arrows**, which represent the *flow* of the activity—that is, the *order* in which the actions should occur.

Like pseudocode, activity diagrams help you develop and represent algorithms, although many programmers prefer pseudocode. Activity diagrams clearly show how control structures operate.

Consider the activity diagram for the sequence structure in Fig. 5.1. It contains two **action states** that represent actions to perform. Each action state contains an **action expression**—for example, “add grade to total” or “add 1 to counter”—that specifies an action to perform. Other actions might include calculations or input–output operations. The arrows in the activity diagram represent **transitions**, which indicate the order in which the actions occur. The portion of the app that implements the activities illustrated by the diagram in Fig. 5.1 first adds grade to `total`, then adds 1 to `counter`.

The **solid circle** at the top of the diagram represents the activity's **initial state**—the beginning of the workflow *before* the app performs the modeled actions. The **solid circle surrounded by a hollow circle** that appears at the bottom of the diagram represents the **final state**—the end of the workflow after the app performs its actions.

Figure 5.1 also includes rectangles with the upper-right corners folded over. These are **UML notes** (like comments in C#) that describe the purpose of symbols in the diagram. Figure 5.1 uses UML notes to show the C# code associated with each action state in the activity diagram. A dotted line connects each note with the element that the note describes. Activity diagrams normally do *not* show the C# code that implements the activity. We use notes for this purpose here to illustrate how the diagram relates to C# code.

### *Selection Structures in C#*

C# has three types of selection structures, which from this point forward we shall refer to as **selection statements**. The **if statement** either performs (selects) an action if a condition is *true* or skips the action if the condition is *false*. The **if...else statement** performs an action if a condition is *true* or performs a different action if the condition is *false*. The **switch statement** (Chapter 6) performs one of many different actions, depending on the value of an expression.

The **if** statement is called a **single-selection statement** because it selects or ignores a single action (or, as we'll soon see, a single group of actions). The **if...else** statement is called a **double-selection statement** because it selects between *two* different actions (or groups of actions). The **switch** statement is called a **multiple-selection statement** because it selects among *many* different actions (or groups of actions).

### *Repetition Structures in C#*

C# provides four repetition structures, which from this point forward we shall refer to as **repetition statements** (also called **iteration statements** or **loops**). Repetition statements enable apps to perform statements repeatedly, depending on the value of a **loop-continuation condition**. The repetition statements are the **while**, **do...while**, **for** and **foreach** statements. (Chapter 6 presents the **do...while** and **for** statements. Chapter 8 discusses the **foreach** statement.) The **while**, **for** and **foreach** statements perform the action (or group of actions) in their bodies *zero or more times*—if the loop-continuation condition is initially *false*, the action (or group of actions) will not execute. The **do...while** statement performs the action (or group of actions) in its body one or more times. The words **if**, **else**, **switch**, **while**, **do**, **for** and **foreach** are C# keywords.

### *Summary of Control Statements in C#*

C# has only three kinds of structured control statements: the *sequence statement*, *selection statement* (three types) and *repetition statement* (four types). We combine as many of each type of statement as necessary to make the program flow and work as required. As with the sequence statement in Fig. 5.1, we can model each control statement as an activity diagram. Each diagram contains one initial state and one final state that represent a control statement's entry point and exit point, respectively. **Single-entry/single-exit control statements** make it easy to build apps—the control statements are “attached” to one another by connecting the exit point of one to the entry point of the next. This procedure is similar to the way in which a child stacks building blocks, so we call it **control-statement stacking**. You'll learn that there's only one other way in which control statements may be connected: **control-statement nesting**, in which a control statement appears *inside* another control statement. Thus, algorithms in C# apps are constructed from only three kinds of structured control statements, combined in only two ways. This is the essence of simplicity.

## 5.5 **if** Single-Selection Statement

Apps use selection statements to choose among alternative courses of action. For example, suppose that the passing grade on an exam is 60. **The pseudocode statement**

```
if grade is greater than or equal to 60
    display "Passed"
```

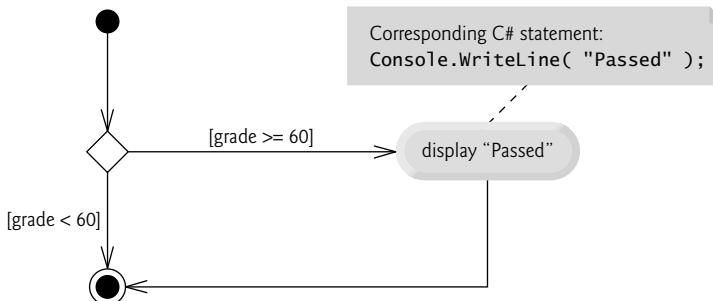
determines whether the *condition* “grade is greater than or equal to 60” is true or false. If the condition is *true*, “Passed” is displayed, and the next pseudocode statement in order is “performed.” (Remember that pseudocode is not a real programming language.) If the condition is *false*, the *display* statement is *ignored*, and the next pseudocode statement in order is performed. The indentation of the second line of this selection statement is optional, but recommended, because it emphasizes the inherent structure.

The preceding pseudocode *if* statement may be written in C# as

```
if ( grade >= 60 )
    Console.WriteLine( "Passed" );
```

The C# code corresponds closely to the pseudocode. This is one of the characteristics of pseudocode that makes it such a useful app-development tool.

Figure 5.2 illustrates the single-selection *if* statement. This activity diagram contains what is perhaps the most important symbol in an activity diagram—the diamond, or **decision symbol**, which indicates that a *decision* is to be made. The workflow will continue along a path determined by *one* of the symbol’s two associated **guard conditions**—one must be *true* and the other *false*. Each transition arrow emerging from a decision symbol has a guard condition (specified in square brackets next to the transition arrow). If a guard condition is *true*, the workflow enters the action state to which the transition arrow points. In Fig. 5.2, if the grade is greater than or equal to 60, the app displays “Passed,” then transitions to the final state of this activity. If the grade is less than 60, the app immediately transitions to the final state without displaying a message.



**Fig. 5.2 |** *if* single-selection statement UML activity diagram.

The *if* statement is a *single-entry/single-exit* control statement. You’ll see that the activity diagrams for the remaining control statements also contain initial states, transition arrows, action states that indicate actions to perform and decision symbols (with associated guard conditions) that indicate decisions to be made, and final states. This is consistent with the **action/decision model of programming** we’ve been emphasizing.

Envision eight bins, each containing only one type of C# control statement. The control statements are all empty. Your task is to assemble an app from as many of each type of control statement as the algorithm demands, combining the control statements in only two possible ways (stacking or nesting), then filling in the action states and decisions with action expressions and guard conditions appropriate for the algorithm. We’ll discuss in detail the variety of ways in which actions and decisions can be written.

## 5.6 if...else Double-Selection Statement

The `if` single-selection statement performs an indicated action *only* when the condition is true; otherwise, the action is skipped. The `if...else` double-selection statement allows you to specify an action to perform when the condition is *true* and a different action when the condition is *false*. For example, the pseudocode statement

```
if grade is greater than or equal to 60
    display "Passed"
else
    display "Failed"
```

displays “Passed” if the grade is greater than or equal to 60, or “Failed” otherwise. In either case, after displaying occurs, the next pseudocode statement in sequence is “performed.”

The preceding `if...else` pseudocode statement can be written in C# as

```
if ( grade >= 60 )
    Console.WriteLine( "Passed" );
else
    Console.WriteLine( "Failed" );
```

The body of the `else` part is also indented. Whatever indentation convention you choose should be applied consistently throughout your apps. It’s difficult to read code that do not obey uniform spacing conventions.



### Good Programming Practice 5.1

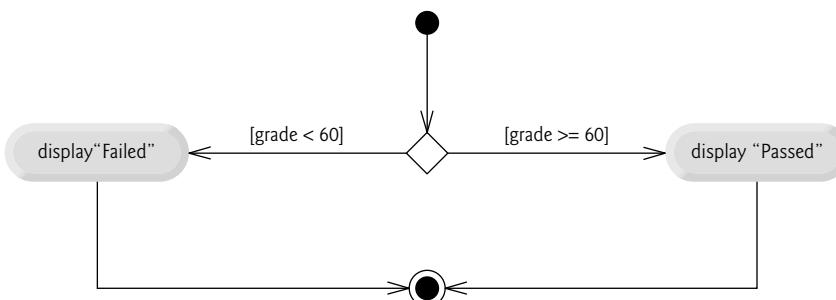
*Indent both body statements of an if...else statement.*



### Good Programming Practice 5.2

*If there are several levels of indentation, each level should be indented the same additional amount of space.*

Figure 5.3 illustrates the flow of control in the `if...else` statement. Imagine again a deep bin containing as many empty `if...else` statements as might be needed to build any C# app. Your job is to assemble these `if...else` statements (by stacking and nesting) with any other control statements required by the algorithm. You fill in the action states and



**Fig. 5.3 |** `if...else` double-selection statement UML activity diagram.

decision symbols with action expressions and guard conditions appropriate for the algorithm you’re developing.

### **Conditional Operator (?:)**

C# provides the **conditional operator (?:)**, which can be used in place of an **if...else** statement like the one diagrammed in Fig. 5.3. This is C#’s only **ternary operator**—this means that it takes three operands. Together, the operands and the ?: symbols form a **conditional expression**. The first operand (to the left of the ?) is a **boolean expression** (i.e., an expression that evaluates to a **bool**-type value—**true** or **false**), the second operand (between the ? and :) is the value of the conditional expression if the boolean expression is **true** and the third operand (to the right of the :) is the value of the conditional expression if the boolean expression is **false**. For example, the statement

```
Console.WriteLine( grade >= 60 ? "Passed" : "Failed" );
```

displays the value of `WriteLine`’s conditional-expression argument. The conditional expression in the preceding statement evaluates to the string “Passed” if the boolean expression `grade >= 60` is **true** and evaluates to the string “Failed” if the boolean expression is **false**. Thus, this statement with the conditional operator performs essentially the same function as the **if...else** statement shown earlier in this section, in which the boolean expression `grade >= 60` was used as the **if...else** statement’s condition. Actually, every control statement’s condition *must* evaluate to the **bool**-type value **true** or **false**. You’ll see that conditional expressions can be used in some situations where **if...else** statements cannot.



### **Good Programming Practice 5.3**

*When a conditional expression is inside a larger expression, it’s good practice to parenthesize the conditional expression for clarity. Adding parentheses may also prevent operator-precedence problems that could cause syntax errors.*

### **Nested if...else Statements**

An app can test multiple cases by placing **if...else** statements *inside* other **if...else** statements to create **nested if...else statements**. For example, the following pseudocode represents a nested **if...else** statement that displays A for exam grades greater than or equal to 90, B for grades in the range 80 to 89, C for grades in the range 70 to 79, D for grades in the range 60 to 69 and F for all other grades:

```
if grade is greater than or equal to 90
    display "A"
else
    if grade is greater than or equal to 80
        display "B"
    else
        if grade is greater than or equal to 70
            display "C"
        else
            if grade is greater than or equal to 60
                display "D"
            else
                display "F"
```

This pseudocode may be written in C# as

```
if ( grade >= 90 )
    Console.WriteLine( "A" );
else
    if ( grade >= 80 )
        Console.WriteLine( "B" );
    else
        if ( grade >= 70 )
            Console.WriteLine( "C" );
        else
            if ( grade >= 60 )
                Console.WriteLine( "D" );
            else
                Console.WriteLine( "F" );
```

If grade is greater than or equal to 90, the first four conditions will be `true`, but only the statement in the `if`-part of the first `if...else` statement will execute. After that statement executes, the `else`-part of the “outermost” `if...else` statement is skipped. Most C# programmers prefer to write the preceding `if...else` statement as

```
if ( grade >= 90 )
    Console.WriteLine( "A" );
else if ( grade >= 80 )
    Console.WriteLine( "B" );
else if ( grade >= 70 )
    Console.WriteLine( "C" );
else if ( grade >= 60 )
    Console.WriteLine( "D" );
else
    Console.WriteLine( "F" );
```

The two forms are identical except for the spacing and indentation, which the compiler ignores. The latter form is popular because it avoids deep indentation of the code to the right—such indentation often leaves little room on a line of code, forcing lines to be split and decreasing the readability of your code.

### *Dangling-else Problem*

The C# compiler always associates an `else` with the *immediately preceding* `if` unless told to do otherwise by the placement of braces (`{` and `}`). This behavior can lead to what is referred to as the **dangling-else problem**. For example,

```
if ( x > 5 )
    if ( y > 5 )
        Console.WriteLine( "x and y are > 5" );
    else
        Console.WriteLine( "x is <= 5" );
```

appears to indicate that if `x` is greater than 5, the nested `if` statement determines whether `y` is also greater than 5. If so, the string “`x and y are > 5`” is output. Otherwise, it appears that if `x` is *not* greater than 5, the `else` part of the `if...else` outputs the string “`x is <= 5`”.

Beware! This nested `if...else` statement does *not* execute as it appears. The compiler actually interprets the statement as

```
if ( x > 5 )
    if ( y > 5 )
        Console.WriteLine( "x and y are > 5" );
    else
        Console.WriteLine( "x is <= 5" );
```

in which the body of the first **if** is a nested **if...else**. The outer **if** statement tests whether **x** is greater than 5. If so, execution continues by testing whether **y** is also greater than 5. If the second condition is **true**, the proper string—"x and y are > 5"—is displayed. However, if the second condition is **false**, the string "x is <= 5" is displayed, even though we know that **x** is greater than 5.

To force the nested **if...else** statement to execute as it was originally intended, we must write it as follows:

```
if ( x > 5 )
{
    if ( y > 5 )
        Console.WriteLine( "x and y are > 5" );
}
else
    Console.WriteLine( "x is <= 5" );
```

The braces (**{}**) indicate to the compiler that the second **if** statement is in the body of the first **if** and that the **else** is associated with the *first if*. Exercises 5.27–5.28 investigate the **dangling-else** problem further.

### Blocks

The **if** statement expects only one statement in its body. To include *several* statements in the body of an **if** (or the body of an **else** for an **if...else** statement), enclose the statements in braces (**{** and **}**). A set of statements contained within a pair of braces is called a **block**. A block can be placed anywhere in an app that a single statement can be placed.

The following example includes a block in the **else**-part of an **if...else** statement:

```
if ( grade >= 60 )
    Console.WriteLine( "Passed" );
else
{
    Console.WriteLine( "Failed" );
    Console.WriteLine( "You must take this course again." );
}
```

In this case, if **grade** is less than 60, the app executes *both* statements in the body of the **else** and displays

```
Failed.
You must take this course again.
```

Note the braces surrounding the two statements in the **else** clause. These braces are important. Without the braces, the statement

```
Console.WriteLine( "You must take this course again." );
```

would be outside the body of the `else`-part of the `if...else` statement and would execute regardless of whether the grade was less than 60.

Syntax errors are caught by the compiler. A **logic error** (e.g., when both braces in a block are left out) has its effect at execution time. A **fatal logic error** causes an app to fail and terminate prematurely. A **nonfatal logic error** allows an app to continue executing, but causes it to produce incorrect results.



### Good Programming Practice 5.4

*Some programmers always use braces in an `if...else` (or other) statement to prevent their accidental omission, especially when adding statements to the `if`-part or the `else`-part at a later time. To avoid omitting one or both of the braces, some programmers type the beginning and ending braces of blocks before typing the individual statements within them.*

Just as a block can be placed anywhere a single statement can be placed, it's also possible to have an *empty statement*. Recall from Section 3.9 that the empty statement is represented by placing a semicolon (;) where a statement would normally be.



### Common Programming Error 5.1

*Placing a semicolon after the condition in an `if` or `if...else` statement leads to a logic error in single-selection `if` statements and a syntax error in double-selection `if...else` statements (when the `if`-part contains an actual body statement).*

## 5.7 while Repetition Statement

A **repetition statement** allows you to specify that an app should repeat an action while some condition remains true. The pseudocode statement

```
while there are more items on my shopping list
    put next item in cart and cross it off my list
```

describes the repetition that occurs during a shopping trip. The condition “there are more items on my shopping list” may be true or false. If it’s true, then the action “Purchase next item and cross it off my list” is performed. This action will be performed *repeatedly* while the condition remains true. The statement(s) contained in the `while` repetition statement constitute the body of the `while` repetition statement, which may be a single statement or a block. Eventually, the condition will become false (when the last item on the shopping list has been purchased and crossed off the list). At this point, the repetition terminates, and the first statement after the repetition statement executes.

As an example of C#’s **while repetition statement**, consider a code segment designed to find the first power of 3 larger than 100. When the following `while` statement finishes executing, `product` contains the result:

```
int product = 3;
while ( product <= 100 )
    product = 3 * product;
```

When this `while` statement begins execution, the value of variable `product` is 3. Each repetition of the `while` statement multiplies `product` by 3, so `product` takes on the subsequent values 9, 27, 81 and 243 successively. When variable `product` becomes 243, the

`while` statement condition—`product <= 100`—becomes `false`. This terminates the repetition, so the final value of `product` is 243. At this point, execution continues with the next statement after the `while` statement.

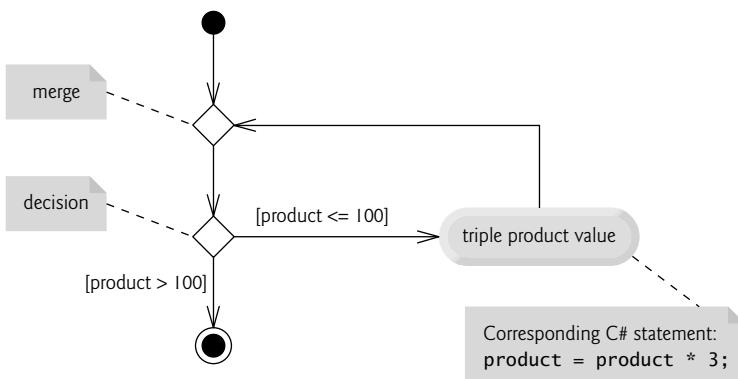


### Common Programming Error 5.2

*Not providing in the body of a `while` statement an action that eventually causes the condition in the `while` to become `false` normally results in a logic error called an **infinite loop**, in which the loop never terminates.*

### `while` Repetition Statement Activity Diagram

The activity diagram in Fig. 5.4 illustrates the flow of control for the preceding `while` statement. This diagram also introduces the UML's **merge symbol**. The UML represents *both* the merge and decision symbols as diamonds. The merge symbol joins two flows of activity into one. In this diagram, the merge symbol joins the transitions from the initial state and the action state, so they both flow into the decision that determines whether the loop should begin (or continue) executing. The decision and merge symbols can be distinguished by the number of “incoming” and “outgoing” transition arrows. A decision symbol has one transition arrow pointing to the diamond and two or more transition arrows pointing out from the diamond to indicate possible transitions from that point. Each transition arrow pointing out of a decision symbol has a guard condition. A merge symbol has *two or more* transition arrows pointing to the diamond and *only one* transition arrow pointing from the diamond, to indicate multiple activity flows merging to continue the activity. None of the transition arrows associated with a merge have guard conditions.



**Fig. 5.4** | `while` repetition statement UML activity diagram.

Figure 5.4 clearly shows the repetition of the `while` statement discussed earlier in this section. The transition arrow emerging from the action state points back to the merge, from which program flow transitions back to the decision that's tested at the beginning of each repetition of the loop. The loop continues to execute until the guard condition `product > 100` becomes true. Then the `while` statement exits (reaches its final state), and control passes to the next statement in sequence in the app.

## 5.8 Formulating Algorithms: Counter-Controlled Repetition

To illustrate how algorithms are developed, we modify the GradeBook class of Chapter 4 to solve two variations of a problem that averages student grades. Consider the following problem statement:

*A class of 10 students took a quiz. The grades (integers in the range 0 to 100) for this quiz are available to you. Determine the class average on the quiz.*

The class average is equal to the sum of the grades divided by the number of students. The algorithm for solving this problem on a computer must input each grade, keep track of the total of all grades input, perform the averaging calculation and display the result.

### Pseudocode Algorithm with Counter-Controlled Repetition

Let's use pseudocode to list the actions to execute and specify the order in which they should execute. We use **counter-controlled repetition** to input the grades one at a time. This technique uses a variable called a **counter** (or **control variable**) to control the number of times a set of statements will execute. Counter-controlled repetition is often called **definite repetition**, because the number of repetitions is known *before* the loop begins executing. In this example, repetition terminates when the counter exceeds 10. This section presents a fully developed pseudocode algorithm (Fig. 5.5) and a version of class GradeBook (Fig. 5.6) that implements the algorithm in a C# method. The section then presents an app (Fig. 5.7) that demonstrates the algorithm in action. In Section 5.9, we demonstrate how to use pseudocode to develop such an algorithm from scratch.



### Software Engineering Observation 5.1

*Experience has shown that the most difficult part of solving a problem on a computer is developing the algorithm for the solution. Once a correct algorithm has been specified, the process of producing a working C# app from it is normally straightforward.*

- 1 set total to zero
- 2 set grade counter to one
- 3
- 4 while grade counter is less than or equal to 10
  - 5 prompt the user to enter the next grade
  - 6 input the next grade
  - 7 add the grade into the total
  - 8 add one to the grade counter
  - 9
- 10 set the class average to the total divided by 10
- 11 display the class average

**Fig. 5.5** | Pseudocode algorithm that uses counter-controlled repetition to solve the class-average problem.

Note the references in the algorithm of Fig. 5.5 to a total and a counter. A **total** is a variable used to accumulate the sum of several values. A **counter** is a variable used to count—in this case, the grade counter indicates which of the 10 grades is about to be

entered by the user. Variables used to store totals are normally initialized to zero before being used in an app.

### ***Implementing Counter-Controlled Repetition in Class GradeBook***

Class GradeBook (Fig. 5.6) contains a constructor (lines 12–15) that assigns a value to the instance variable created by auto-implemented property CourseName in line 9. Lines 18–23 declare method DisplayMessage. Lines 26–52 declare method DetermineClassAverage, which implements the class-averaging algorithm described by the pseudocode in Fig. 5.5.

```
1 // Fig. 5.6: GradeBook.cs
2 // GradeBook class that solves the class-average problem using
3 // counter-controlled repetition.
4 using System;
5
6 public class GradeBook
7 {
8     // auto-implemented property CourseName
9     public string CourseName { get; set; }
10
11    // constructor initializes CourseName property
12    public GradeBook( string name )
13    {
14        CourseName = name; // set CourseName to name
15    } // end constructor
16
17    // display a welcome message to the GradeBook user
18    public void DisplayMessage()
19    {
20        // property CourseName gets the name of the course
21        Console.WriteLine( "Welcome to the grade book for\n{0}!\n",
22                          CourseName );
23    } // end method DisplayMessage
24
25    // determine class average based on 10 grades entered by user
26    public void DetermineClassAverage()
27    {
28        int total; // sum of the grades entered by user
29        int gradeCounter; // number of the grade to be entered next
30        int grade; // grade value entered by the user
31        int average; // average of the grades
32
33        // initialization phase
34        total = 0; // initialize the total
35        gradeCounter = 1; // initialize the loop counter
36
37        // processing phase
38        while ( gradeCounter <= 10 ) // loop 10 times
39        {
40            Console.Write( "Enter grade: " ); // prompt the user
41            grade = Convert.ToInt32( Console.ReadLine() ); // read grade
```

**Fig. 5.6** | GradeBook class that solves the class-average problem using counter-controlled repetition. (Part I of 2.)

---

```

42         total = total + grade; // add the grade to total
43         gradeCounter = gradeCounter + 1; // increment the counter by 1
44     } // end while
45
46     // termination phase
47     average = total / 10; // integer division yields integer result
48
49     // display total and average of grades
50     Console.WriteLine( "\nTotal of all 10 grades is {0}", total );
51     Console.WriteLine( "Class average is {0}", average );
52 } // end method DetermineClassAverage
53 } // end class GradeBook

```

---

**Fig. 5.6** | GradeBook class that solves the class-average problem using counter-controlled repetition. (Part 2 of 2.)

### Method `DetermineClassAverage`

Lines 28–31 declare local variables `total`, `gradeCounter`, `grade` and `average` to be of type `int`. In this example, variable `total` accumulates the sum of the grades entered and `gradeCounter` counts the number of grades entered. Variable `grade` stores the most recent grade value entered (line 41). Variable `average` stores the average grade.

The declarations (in lines 28–31) appear in method `DetermineClassAverage`'s body. Variables declared in a method body are *local* variables and can be used only from the line of their declaration to the closing right brace of the block in which they're declared. A local variable's declaration *must* appear before the variable is used in that method. A local variable cannot be accessed *outside* the block in which it's declared.

In the versions of class `GradeBook` in this chapter, we simply read and process a set of grades. The averaging calculation is performed in method `DetermineClassAverage` using local variables—we do not preserve any information about student grades in instance variables of the class. In later versions of the class (in Chapter 8), we store the grades using an instance variable that refers to a data structure known as an array. This will allow a `GradeBook` object to perform various calculations on the same set of grades without requiring the user to enter the grades multiple times.



### Good Programming Practice 5.5

*Separate declarations from other statements in methods with a blank line for readability.*

We say that a variable is **definitely assigned** when it's guaranteed to be assigned a value before the variable is used. Notice that each local variable declared in lines 28–31 is definitely assigned before it's used in calculations. The assignments (in lines 34–35) initialize `total` to 0 and `gradeCounter` to 1. Variables `grade` and `average` (for the user input and calculated average, respectively) need not be initialized here—their values are assigned as they're input or calculated later in the method.



### Common Programming Error 5.3

*Using the value of a local variable before it's definitely assigned results in a compilation error.  
All local variables must be definitely assigned before their values are used in expressions.*



### Error-Prevention Tip 5.1

*Initialize each counter and total, either in its declaration or in an assignment statement. Totals are normally initialized to 0. Counters are normally initialized to 0 or 1, depending on how they're used (we'll show examples of each).*

Line 38 indicates that the while statement should continue looping (also called **iterating**) as long as the value of gradeCounter is less than or equal to 10. While this condition remains true, the while statement repeatedly executes the statements between the braces that delimit its body (lines 39–44).

Line 40 displays the prompt "Enter grade: " in the console window. Line 41 reads the grade entered by the user and assigns it to variable grade. Then line 42 adds the new grade entered by the user to the total and assigns the result to total, which replaces its previous value.

Line 43 adds 1 to gradeCounter to indicate that the app has processed a grade and is ready to input the next grade from the user. Incrementing gradeCounter eventually causes gradeCounter to exceed 10. At that point the while loop terminates, because its condition (line 38) becomes false.

When the loop terminates, line 47 performs the averaging calculation and assigns its result to the variable average. Line 50 uses Console's WriteLine method to display the text "Total of all 10 grades is " followed by variable total's value. Line 51 then displays the text "Class average is " followed by variable average's value. Method DetermineClassAverage returns control to the calling method (i.e., Main in GradeBookTest of Fig. 5.7) after reaching line 52.

#### Class GradeBookTest

Class GradeBookTest (Fig. 5.7) creates an object of class GradeBook (Fig. 5.6) and demonstrates its capabilities. Lines 9–10 of Fig. 5.7 create a new GradeBook object and assign it to variable myGradeBook. The string in line 10 is passed to the GradeBook constructor (lines 12–15 of Fig. 5.6). Line 12 (Fig. 5.7) calls myGradeBook's DisplayMessage method to display a welcome message to the user. Line 13 then calls myGradeBook's DetermineClassAverage method to allow the user to enter 10 grades, for which the method then calculates and displays the average—the method performs the algorithm shown in Fig. 5.5.

---

```

1 // Fig. 5.7: GradeBookTest.cs
2 // Create GradeBook object and invoke its DetermineClassAverage method.
3 public class GradeBookTest
4 {
5     public static void Main( string[] args )
6     {
7         // create GradeBook object myGradeBook and
8         // pass course name to constructor
9         GradeBook myGradeBook = new GradeBook(
10             "CS101 Introduction to C# Programming" );
11
12     myGradeBook.DisplayMessage(); // display welcome message

```

---

**Fig. 5.7** | Create GradeBook object and invoke its DetermineClassAverage method. (Part 1 of 2.)

```

13     myGradeBook.DetermineClassAverage(); // find average of 10 grades
14 } // end Main
15 } // end class GradeBookTest

```

Welcome to the grade book for  
CS101 Introduction to C# Programming!

Enter grade: 88  
 Enter grade: 79  
 Enter grade: 95  
 Enter grade: 100  
 Enter grade: 48  
 Enter grade: 88  
 Enter grade: 92  
 Enter grade: 83  
 Enter grade: 90  
 Enter grade: 85

Total of all 10 grades is 848  
 Class average is 84

**Fig. 5.7** | Create GradeBook object and invoke its `DetermineClassAverage` method. (Part 2 of 2.)

#### *Notes on Integer Division and Truncation*

The averaging calculation performed by method `DetermineClassAverage` in response to the method call at line 13 in Fig. 5.7 produces an integer result. The app's output indicates that the sum of the grade values in the sample execution is 848, which, when divided by 10, should yield the floating-point number 84.8. However, the result of the calculation `total / 10` (line 47 of Fig. 5.6) is the integer 84, because `total` and 10 are *both* integers. Dividing two integers results in **integer division**—any fractional part of the calculation is lost (i.e., truncated, not rounded). We'll see how to obtain a floating-point result from the averaging calculation in the next section.



#### **Common Programming Error 5.4**

*Assuming that integer division rounds (rather than truncates) can lead to incorrect results. For example,  $7 \div 4$ , which yields 1.75 in conventional arithmetic, truncates to 1 in integer arithmetic, rather than rounding to 2.*

## 5.9 Formulating Algorithms: Sentinel-Controlled Repetition

Let us generalize Section 5.8's class-average problem. Consider the following problem:

*Develop a class-averaging app that processes grades for an arbitrary number of students each time it's run.*

In the previous class-average example, the problem statement specified the number of students, so the number of grades (10) was known in advance. In this example, no indication is given of how many grades the user will enter during the app's execution. The app must

process an *arbitrary* number of grades. How can it determine when to *stop* the input of grades? How will it know *when* to calculate and display the class average?

One way to solve this problem is to use a special value called a **sentinel value** (also called a **signal value**, a **dummy value** or a **flag value**) to indicate “end of data entry.” This is called **sentinel-controlled repetition**. The user enters grades until all *legitimate* grades have been entered. The user then types the sentinel value to indicate that no more grades will be entered. Sentinel-controlled repetition is often called **indefinite repetition** because the number of repetitions is *not* known by the app before the loop begins executing.

Clearly, a sentinel value must be chosen that *cannot* be confused with an acceptable input value. Grades on a quiz are nonnegative integers, so  $-1$  is an acceptable sentinel value for this problem. Thus, a run of the class-average app might process a stream of inputs such as 95, 96, 75, 74, 89 and  $-1$ . The app would then compute and display the class average for the grades 95, 96, 75, 74 and 89. Since  $-1$  is the sentinel value, it should not enter into the averaging calculation.



### Common Programming Error 5.5

*Choosing a sentinel value that's also a legitimate data value is a logic error.*

## *Developing the Pseudocode Algorithm with Top-Down, Stepwise Refinement: The Top and First Refinement*

We approach the class-average app with a technique called **top-down, stepwise refinement**, which is essential to the development of well-structured apps. We begin with a pseudocode representation of the **top**—a single statement that conveys the overall function of the app:

*determine the class average for the quiz*

The top is, in effect, a *complete* representation of an app. Unfortunately, the top rarely conveys sufficient detail from which to write a C# app. So we now begin the refinement process. We divide the top into a series of smaller tasks and list these in the order in which they'll be performed. This results in the following **first refinement**:

*initialize variables  
input, sum and count the quiz grades  
calculate and display the class average*

This refinement uses only the sequence structure—the steps listed should execute in order, one after the other.



### Software Engineering Observation 5.2

*Each refinement, as well as the top itself, is a complete specification of the algorithm—only the level of detail varies.*



### Software Engineering Observation 5.3

*Many apps can be divided logically into three phases: an initialization phase that initializes the variables; a processing phase that inputs data values and adjusts variables (e.g., counters and totals) accordingly; and a termination phase that calculates and outputs the final results.*

### *Proceeding to the Second Refinement*

The preceding *Software Engineering Observation* is often all you need for the first refinement in the top-down process. To proceed to the next level, the **second refinement**, we specify individual variables. In this example, we need a running total of the numbers, a count of how many numbers have been processed, a variable to receive the value of each grade as it's input by the user and a variable to hold the calculated average. The pseudocode statement

*initialize variables*

can be refined as follows:

*initialize total to zero*

*initialize counter to zero*

Only the variables *total* and *counter* need to be initialized before they're used. The variables *average* and *grade* (for the calculated average and the user input, respectively) need *not* be initialized, because their values will be replaced as they're calculated or input.

The pseudocode statement

*input, sum and count the quiz grades*

requires a repetition statement that successively inputs each grade. We do not know in advance how many grades are to be processed, so we'll use sentinel-controlled repetition. The user enters grades one at a time. *After* entering the last grade, the user enters the sentinel value. The app tests for the sentinel value after each grade is input and terminates the loop when the user enters the sentinel value. The second refinement of the preceding pseudocode statement is then

*prompt the user to enter the first grade*  
*input the first grade (possibly the sentinel)*  
*while the user has not yet entered the sentinel*  
*add this grade into the running total*  
*add one to the grade counter*  
*prompt the user to enter the next grade*  
*input the next grade (possibly the sentinel)*

In pseudocode, we do not use braces around the statements that form the body of the *while* structure. We simply indent the statements under the *while* to show that they belong to the *while*. Again, pseudocode is only an informal app-development aid.

The pseudocode statement

*calculate and display the class average*

can be refined as follows:

*if the counter is not equal to zero*  
*set the average to the total divided by the counter*  
*display the average*  
*else*  
*display "No grades were entered"*

We're careful here to test for the possibility of *division by zero*—a logic error that, if undetected, would cause the app to fail. The complete second refinement of the pseudocode for the class-average problem is shown in Fig. 5.8.



### Error-Prevention Tip 5.2

*When performing division by an expression whose value could be zero, explicitly test for this possibility and handle it appropriately in your app (e.g., by displaying an error message) rather than allowing the error to occur.*

```
1 initialize total to zero
2 initialize counter to zero
3
4 prompt the user to enter the first grade
5 input the first grade (possibly the sentinel)
6
7 while the user has not yet entered the sentinel
8     add this grade into the running total
9     add one to the grade counter
10    prompt the user to enter the next grade
11    input the next grade (possibly the sentinel)
12
13 if the counter is not equal to zero
14     set the average to the total divided by the counter
15     display the average
16 else
17     display "No grades were entered"
```

**Fig. 5.8** | Class-average problem pseudocode algorithm with sentinel-controlled repetition.

In Fig. 5.5 and Fig. 5.8, we included some completely blank lines and indentation in the pseudocode to make it more readable. The blank lines separate the pseudocode algorithms into their various phases and set off control statements, and the indentation emphasizes the bodies of the control statements.

The pseudocode algorithm in Fig. 5.8 solves the more general class-averaging problem. This algorithm was developed after only *two* refinements. Sometimes more refinements are necessary.



### Software Engineering Observation 5.4

*Terminate the top-down, stepwise refinement process when you've specified the pseudocode algorithm in sufficient detail for you to convert the pseudocode to C#. Normally, implementing the C# app is then straightforward.*



### Software Engineering Observation 5.5

*Some experienced programmers write apps without ever using app-development tools like pseudocode. They feel that their ultimate goal is to solve the problem on a computer and that writing pseudocode merely delays the production of final outputs. Although this method may work for simple and familiar problems, it can lead to serious errors and delays in large, complex projects.*

***Implementing Sentinel-Controlled Repetition in Class GradeBook***

Figure 5.9 shows the C# class `GradeBook` containing method `DetermineClassAverage` that implements the pseudocode algorithm of Fig. 5.8. Although each grade is an integer, the averaging calculation is likely to produce a number with a decimal point—in other words, a real number or floating-point number. The type `int` cannot represent such a number, so this class uses type `double` to do so.

---

```

1 // Fig. 5.9: GradeBook.cs
2 // GradeBook class that solves the class-average problem using
3 // sentinel-controlled repetition.
4 using System;
5
6 public class GradeBook
7 {
8     // auto-implemented property CourseName
9     public string CourseName { get; set; }
10
11    // constructor initializes the CourseName property
12    public GradeBook( string name )
13    {
14        CourseName = name; // set CourseName to name
15    } // end constructor
16
17    // display a welcome message to the GradeBook user
18    public void DisplayMessage()
19    {
20        Console.WriteLine( "Welcome to the grade book for\n{0}!\n",
21                          CourseName );
22    } // end method DisplayMessage
23
24    // determine the average of an arbitrary number of grades
25    public void DetermineClassAverage()
26    {
27        int total; // sum of grades
28        int gradeCounter; // number of grades entered
29        int grade; // grade value
30        double average; // number with decimal point for average
31
32        // initialization phase
33        total = 0; // initialize total
34        gradeCounter = 0; // initialize loop counter
35
36        // processing phase
37        // prompt for and read a grade from the user
38        Console.Write( "Enter grade or -1 to quit: " );
39        grade = Convert.ToInt32( Console.ReadLine() );
40
41        // loop until sentinel value is read from the user
42        while ( grade != -1 )
43        {

```

**Fig. 5.9** | `GradeBook` class that solves the class-average problem using sentinel-controlled repetition. (Part I of 2.)

---

```
44     total = total + grade; // add grade to total
45     gradeCounter = gradeCounter + 1; // increment counter
46
47     // prompt for and read the next grade from the user
48     Console.WriteLine( "Enter grade or -1 to quit: " );
49     grade = Convert.ToInt32( Console.ReadLine() );
50 } // end while
51
52 // termination phase
53 // if the user entered at least one grade...
54 if ( gradeCounter != 0 )
55 {
56     // calculate the average of all the grades entered
57     average = ( double ) total / gradeCounter;
58
59     // display the total and average (with two digits of precision)
60     Console.WriteLine( "\nTotal of the {0} grades entered is {1}",
61                         gradeCounter, total );
62     Console.WriteLine( "Class average is {0:F}", average );
63 } // end if
64 else // no grades were entered, so output error message
65     Console.WriteLine( "No grades were entered" );
66 } // end method DetermineClassAverage
67 } // end class GradeBook
```

**Fig. 5.9** | GradeBook class that solves the class-average problem using sentinel-controlled repetition. (Part 2 of 2.)

In this example, we see that control statements may be *stacked* on top of one another (in sequence) just as a child stacks building blocks. The `while` statement (lines 42–50) is followed in sequence by an `if...else` statement (lines 54–65). Much of the code in this app is identical to the code in Fig. 5.6, so we concentrate on the new features and issues.

Line 30 declares `double` variable `average`. This variable allows us to store the calculated class average as a floating-point number. Line 34 initializes `gradeCounter` to 0, because no grades have been entered yet. Remember that this app uses sentinel-controlled repetition to input the grades from the user. To keep an accurate record of the number of grades entered, the app increments `gradeCounter` only when the user inputs a valid grade value.

#### *Program Logic for Sentinel-Controlled Repetition vs. Counter-Controlled Repetition*

Compare the program logic for sentinel-controlled repetition in this app with that for counter-controlled repetition in Fig. 5.6. In counter-controlled repetition, each repetition of the `while` statement (e.g., lines 38–44 of Fig. 5.6) reads a value from the user, for the specified number of repetitions. In sentinel-controlled repetition, the app reads the first value (lines 38–39 of Fig. 5.9) before reaching the `while`. This value determines whether the app's flow of control should enter the body of the `while`. If the condition of the `while` is *false*, the user entered the sentinel value, so the body of the `while` does *not* execute (because no grades were entered). If, on the other hand, the condition is *true*, the body begins execution, and the loop adds the grade value to the `total` (line 44) and adds 1 to `gradeCounter` (line 45). Then lines 48–49 in the loop's body input the next value from the user.

Next, program control reaches the closing right brace of the body at line 50, so execution continues with the test of the `while`'s condition (line 42).

The condition uses the most recent `grade` input by the user to determine whether the loop's body should execute again. The value of variable `grade` is always input from the user immediately before the app tests the `while` condition. This allows the app to determine whether the value just input is the sentinel value *before* the app processes that value (i.e., adds it to the `total`). If the sentinel value is input, the loop terminates; the app does *not* add `-1` to the `total`.



### Good Programming Practice 5.6

*In a sentinel-controlled loop, the prompts requesting data entry should explicitly remind the user of the sentinel value.*

Notice the `while` statement's block in Fig. 5.9 (lines 43–50). Without the braces, the loop would consider its body to be *only* the first statement, which adds the `grade` to the `total`. The last three statements in the block would fall outside the loop's body, causing the computer to interpret the code incorrectly as follows:

```
while ( grade != -1 )
    total = total + grade; // add grade to total
    gradeCounter = gradeCounter + 1; // increment counter

    // prompt for input and read next grade from user
    Console.WriteLine("Enter grade or -1 to quit: ");
    grade = Convert.ToInt32(Console.ReadLine());
```

The preceding code would cause an *infinite loop* if the user did not enter the sentinel `-1` at line 39 (before the `while` statement).



### Error-Prevention Tip 5.3

*Omitting the braces that delimit a block can lead to logic errors, such as infinite loops. To prevent this problem, some programmers enclose the body of every control statement in braces even if the body contains only a single statement.*

After the loop terminates, the `if...else` statement at lines 54–65 executes. The condition at line 54 determines whether any grades were input. If none were input, the `else` part (lines 64–65) of the `if...else` statement executes and displays the message "No grades were entered", and the method returns control to the calling method.

### *Explicitly and Implicitly Converting Between Simple Types*

If at least one grade was entered, line 57 calculates the average of the grades. Recall from Fig. 5.6 that integer division yields an integer result. Even though variable `average` is declared as a `double` (line 30), the calculation

```
average = total / gradeCounter;
```

loses the division's fractional part before the result is assigned to `average`. This occurs because `total` and `gradeCounter` are *both* integers, and integer division yields an integer result. To perform a floating-point calculation with integer values, we must *temporarily* treat these values as floating-point numbers for use in the calculation. C# provides the **unary cast operator** to accomplish this task. Line 57 uses the **(double)** cast operator—which has higher precedence than the arithmetic operators—to create a *temporary* floating-point copy of

its operand `total` (which appears to the right of the operator). Using a cast operator in this manner is called **explicit conversion**. The value stored in `total` is still an integer.

The calculation now consists of a floating-point value (the temporary `double` version of `total`) divided by the integer `gradeCounter`. C# knows how to evaluate only arithmetic expressions in which the operands' types are *identical*. To ensure that the operands are of the same type, C# performs an operation called **promotion** (or **implicit conversion**) on selected operands. For example, in an expression containing values of the types `int` and `double`, the `int` values are promoted to `double` values for use in the expression. In this example, the value of `gradeCounter` is promoted to type `double`, then floating-point division is performed and the result of the calculation is assigned to `average`. As long as the `(double)` cast operator is applied to *any* variable in the calculation, the calculation will yield a `double` result.



### Common Programming Error 5.6

A cast operator can be used to convert between simple numeric types, such as `int` and `double`, and between related reference types (as we discuss in Chapter 12, OOP: Polymorphism, Interfaces and Operator Overloading). Casting to the wrong type may cause compilation or runtime errors.

Cast operators are available for all simple types. We'll discuss cast operators for reference types in Chapter 12. The cast operator is formed by placing parentheses around the name of a type. This operator is a **unary operator** (i.e., an operator that takes only one operand). In Chapter 3, we studied the binary arithmetic operators. C# also supports unary versions of the plus (+) and minus (-) operators, so you can write expressions like `+5` or `-7`. Cast operators associate from right to left and have the same precedence as other unary operators, such as unary + and unary -. This precedence is one level higher than that of the **multiplicative operators** `*`, `/` and `%`. (See the operator precedence chart in Appendix A.) We indicate the cast operator with the notation `(type)` in our precedence charts, to indicate that any type name can be used to form a cast operator.

Line 62 outputs the class average. In this example, we decided that we'd like to display the class average *rounded to the nearest hundredth* and output the average with exactly two digits to the right of the decimal point. The format specifier `F` in `WriteLine`'s format item (line 62) indicates that variable `average`'s value should be displayed as a real number. By default, numbers output with `F` have two digits to the right of the decimal point. The number of decimal places to the right of the decimal point is also known as the number's **precision**. Any floating-point value output with `F` will be rounded to the hundredths position—for example, `123.457` will be rounded to `123.46`, and `27.333` will be rounded to `27.33`. In this app, the three grades entered during the sample execution of class `GradeBookTest` (Fig. 5.10) total 263, which yields the average `87.66666....`. The format item rounds the average to the hundredths position, and the average is displayed as `87.67`.

---

```
1 // Fig. 5.10: GradeBookTest.cs
2 // Create GradeBook object and invoke its DetermineClassAverage method.
3 public class GradeBookTest
4 {
```

**Fig. 5.10** | Create `GradeBook` object and invoke `DetermineClassAverage` method. (Part 1 of 2.)

```

5  public static void Main( string[] args )
6  {
7      // create GradeBook object myGradeBook and
8      // pass course name to constructor
9      GradeBook myGradeBook = new GradeBook(
10         "CS101 Introduction to C# Programming" );
11
12     myGradeBook.DisplayMessage(); // display welcome message
13     myGradeBook.DetermineClassAverage(); // find average of grades
14 } // end Main
15 } // end class GradeBookTest

```

```

Welcome to the grade book for
CS101 Introduction to C# Programming!

Enter grade or -1 to quit: 96
Enter grade or -1 to quit: 88
Enter grade or -1 to quit: 79
Enter grade or -1 to quit: -1

Total of the 3 grades entered is 263
Class average is 87.67

```

**Fig. 5.10** | Create GradeBook object and invoke DetermineClassAverage method. (Part 2 of 2.)

## 5.10 Formulating Algorithms: Nested Control Statements

For the next example, we once again formulate an algorithm by using pseudocode and top-down, stepwise refinement, and write a corresponding C# app. We've seen that control statements can be *stacked* on top of one another (in sequence). In this case study, we examine the only other structured way control statements can be connected, namely, by *nesting* one control statement within another.

Consider the following problem statement:

*A college offers a course that prepares students for the state licensing exam for real estate brokers. Last year, 10 of the students who completed this course took the exam. The college wants to know how well its students did on the exam. You've been asked to write an app to summarize the results. You've been given a list of these 10 students. Next to each name is written a 1 if the student passed the exam or a 2 if the student failed.*

*Your app should analyze the results of the exam as follows:*

1. *Input each test result (i.e., a 1 or a 2). Display the message “Enter result” on the screen each time the app requests another test result.*
2. *Count the number of test results of each type.*
3. *Display a summary of the test results indicating the number of students who passed and the number who failed.*
4. *If more than eight students passed the exam, display the message “Bonus to instructor!”*

After reading the problem statement, we make the following observations:

1. The app must process test results for 10 students. A *counter-controlled loop* can be used because the number of test results is known in advance.

2. Each test result has a numeric value—either a 1 or a 2. Each time the app reads a test result, the app must determine whether the number is a 1 or a 2. We test for a 1 in our algorithm. If the number is not a 1, we assume that it's a 2. (Exercise 5.24 considers the consequences of this assumption.)
3. Two counters are used to keep track of the exam results—one to count the number of students who passed the exam and one to count the number of students who failed the exam.
4. After the app has processed all the results, it must determine whether more than eight students passed the exam.

Let us proceed with top-down, stepwise refinement. We begin with a pseudocode representation of the top:

*analyze exam results and decide whether the instructor should receive a bonus*

Once again, the top is a *complete* representation of the app, but several refinements are likely to be needed before the pseudocode can evolve naturally into a C# app.

Our first refinement is

*initialize variables  
input the 10 exam results, and count passes and failures  
display a summary of the exam results and decide if the instructor should receive a bonus*

Here, too, even though we have a complete representation of the entire app, further refinement is necessary. We now specify individual variables. Counters are needed to record the passes and failures, a counter will be used to control the looping process and a variable is needed to store the user input. The variable in which the user input will be stored is not initialized at the start of the algorithm, because its value is read from the user during each repetition of the loop.

The pseudocode statement

*initialize variables*

can be refined as follows:

*initialize passes to zero  
initialize failures to zero  
initialize student counter to one*

Notice that only the counters are initialized at the start of the algorithm.

The pseudocode statement

*input the 10 exam results, and count passes and failures*

requires a loop that successively inputs the result of each exam. We know in advance that there are precisely 10 exam results, so counter-controlled looping is appropriate. Inside the loop (i.e., **nested** within the loop), a double-selection statement will determine whether each exam result is a pass or a failure and will increment the appropriate counter. The refinement of the preceding pseudocode statement is then

```

while student counter is less than or equal to 10
    prompt the user to enter the next exam result
    input the next exam result

    if the student passed
        add one to passes
    else
        add one to failures

    add one to student counter

```

We use blank lines to isolate the *if...else* control statement, which improves readability.

The pseudocode statement

```

display a summary of the exam results and decide if the instructor should
receive a bonus

```

can be refined as follows:

```

display the number of passes
display the number of failures

if more than eight students passed
    display "Bonus to instructor!"

```

### ***Complete Second Refinement of Pseudocode and Conversion to Class Analysis***

The complete second refinement of the pseudocode appears in Fig. 5.11. Notice that blank lines are also used to set off the *while* statement for readability. This pseudocode is now sufficiently refined for conversion to C#. The program that implements the pseudocode algorithm and sample outputs are shown in Fig. 5.12.

---

```

1  initialize passes to zero
2  initialize failures to zero
3  initialize student counter to one
4
5  while student counter is less than or equal to 10
6      prompt the user to enter the next exam result
7      input the next exam result

8
9      if the student passed
10         add one to passes
11     else
12         add one to failures
13
14     add one to student counter
15

```

---

**Fig. 5.11** | Pseudocode for the examination-results problem. (Part I of 2.)

---

```
16   display the number of passes
17   display the number of failures
18
19   if more than eight students passed
20       display "Bonus to instructor!"
```

---

**Fig. 5.11** | Pseudocode for the examination-results problem. (Part 2 of 2.)

This example contains only *one* class, with method `Main` performing all the class's work. In this chapter and in Chapter 4, you've seen examples consisting of *two* classes—one class containing methods that perform useful tasks and one containing method `Main`, which creates an object of the other class and calls its methods. Occasionally, when it makes no sense to try to create a reusable class, we'll use a mechanical example contained entirely within the `Main` method of a single class.

Lines 10–13 of Fig. 5.12 declare the variables that method `Main` uses to process the examination results. Several of these declarations use C#'s ability to incorporate variable initialization into declarations (`passes` is assigned 0, `failures` is assigned 0 and `studentCounter` is assigned 1).

---

```
1 // Fig. 5.12: Analysis.cs
2 // Analysis of examination results, using nested control statements.
3 using System;
4
5 public class Analysis
6 {
7     public static void Main( string[] args )
8     {
9         // initialize variables in declarations
10        int passes = 0; // number of passes
11        int failures = 0; // number of failures
12        int studentCounter = 1; // student counter
13        int result; // one exam result from user
14
15        // process 10 students using counter-controlled repetition
16        while ( studentCounter <= 10 )
17        {
18            // prompt user for input and obtain a value from the user
19            Console.Write( "Enter result (1 = pass, 2 = fail): " );
20            result = Convert.ToInt32( Console.ReadLine() );
21
22            // if...else nested in while
23            if ( result == 1 ) // if result 1,
24                passes = passes + 1; // increment passes
25            else // else result is not 1, so
26                failures = failures + 1; // increment failures
27
28            // increment studentCounter so loop eventually terminates
29            studentCounter = studentCounter + 1;
30        } // end while
```

---

**Fig. 5.12** | Analysis of examination results, using nested control statements. (Part 1 of 2.)

```

31
32     // termination phase; prepare and display results
33     Console.WriteLine( "Passed: {0}\nFailed: {1}", passes, failures );
34
35     // determine whether more than 8 students passed
36     if ( passes > 8 )
37         Console.WriteLine( "Bonus to instructor!" );
38 } // end Main
39 } // end class Analysis

```

```

Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 2
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Passed: 9
Failed: 1
Bonus to instructor!

```

```

Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 2
Enter result (1 = pass, 2 = fail): 2
Enter result (1 = pass, 2 = fail): 2
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 1
Enter result (1 = pass, 2 = fail): 2
Enter result (1 = pass, 2 = fail): 2
Passed: 5
Failed: 5

```

**Fig. 5.12** | Analysis of examination results, using nested control statements. (Part 2 of 2.)

The `while` statement (lines 16–30) loops 10 times. During each repetition, the loop inputs and processes one exam result. Notice that the `if...else` statement (lines 23–26) for processing each result is *nested* in the `while` statement. If the result is 1, the `if...else` statement increments `passes`; otherwise, it *assumes* the result is 2 and increments `failures`. Line 29 increments `studentCounter` before the loop condition is tested again at line 16. After 10 values have been input, the loop terminates and line 33 displays the number of `passes` and the number of `failures`. Lines 36–37 determine whether more than eight students passed the exam and, if so, outputs the message "Bonus to instructor!".

Figure 5.12 shows the input and output from two sample executions of the app. During the first sample execution, the condition at line 36 is `true`—more than eight students passed the exam, so the app outputs a message indicating that the instructor should receive a bonus.

**Error-Prevention Tip 5.4**

*Initializing local variables when they're declared helps you avoid compilation errors that might arise from attempts to use uninitialized data. While C# does not require that local-variable initializations be incorporated into declarations, it does require that local variables be initialized before their values are used in an expression.*

## 5.11 Compound Assignment Operators

C# provides several **compound assignment operators** for abbreviating assignment expressions. Any statement of the form

```
variable = variable operator expression;
```

where *operator* is one of the binary operators +, -, \*, / or % (or others we discuss later in the text) can be written in the form

```
variable operator= expression;
```

For example, you can abbreviate the statement

```
c = c + 3;
```

with the **addition compound assignment operator**, `+=`, as

```
c += 3;
```

The `+=` operator adds the value of the expression on the **right** of the operator to the value of the variable on the **left** of the operator and stores the result in the variable on the **left** of the operator. Thus, the assignment expression `c += 3` adds 3 to `c`. Figure 5.13 shows the arithmetic compound assignment operators, sample expressions using the operators and explanations of what the operators do.

Assignment operator	Sample expression	Explanation	Assigns
<i>Assume: int c = 3, d = 5, e = 4, f = 6, g = 12;</i>			
<code>+=</code>	<code>c += 7</code>	<code>c = c + 7</code>	10 to <code>c</code>
<code>-=</code>	<code>d -= 4</code>	<code>d = d - 4</code>	1 to <code>d</code>
<code>*=</code>	<code>e *= 5</code>	<code>e = e * 5</code>	20 to <code>e</code>
<code>/=</code>	<code>f /= 3</code>	<code>f = f / 3</code>	2 to <code>f</code>
<code>%=</code>	<code>g %= 9</code>	<code>g = g % 9</code>	3 to <code>g</code>

**Fig. 5.13** | Arithmetic compound assignment operators.

## 5.12 Increment and Decrement Operators

C# provides two unary operators for adding 1 to or subtracting 1 from the value of a numeric variable. These are the unary **increment operator**, `++`, and the unary **decrement operator**, `--`, respectively, which are summarized in Fig. 5.14. An app can increment by 1 the

value of a variable called `c` using the increment operator, `++`, rather than the expression `c = c + 1` or `c += 1`. An increment or decrement operator that's prefixed to (placed *before*) a variable is referred to as the **prefix increment operator** or **prefix decrement operator**, respectively. An increment or decrement operator that's postfixified to (placed *after*) a variable is referred to as the **postfix increment operator** or **postfix decrement operator**, respectively.

Operator	Called	Sample expression	Explanation
<code>++</code>	prefix increment	<code>++a</code>	Increments <code>a</code> by 1 and uses the new value of <code>a</code> in the expression in which <code>a</code> resides.
<code>++</code>	postfix increment	<code>a++</code>	Increments <code>a</code> by 1, but uses the original value of <code>a</code> in the expression in which <code>a</code> resides.
<code>--</code>	prefix decrement	<code>--b</code>	Decrements <code>b</code> by 1 and uses the new value of <code>b</code> in the expression in which <code>b</code> resides.
<code>--</code>	postfix decrement	<code>b--</code>	Decrements <code>b</code> by 1 but uses the original value of <code>b</code> in the expression in which <code>b</code> resides.

**Fig. 5.14** | Increment and decrement operators.

Incrementing (or decrementing) a variable with an *increment* (or *decrement*) operator causes it to be incremented (or decremented) by 1. For a *prefix increment* (or *decrement*) operator, the variable's *new* value is used in the expression in which the variable appears. For a *postfix increment* (or *decrement*) operator, the variable's *original* value is used in the expression in which the variable appears.



### Good Programming Practice 5.7

*Unlike binary operators, the unary increment and decrement operators should (by convention) be placed next to their operands, with no intervening spaces.*

Figure 5.15 demonstrates the difference between the prefix increment and postfix increment versions of the `++` increment operator. The decrement operator (`--`) works similarly. In this example, we simply want to show the mechanics of the `++` operator, so we use only one class declaration containing method `Main`.

---

```

1 // Fig. 5.15: Increment.cs
2 // Prefix increment and postfix increment operators.
3 using System;
4
5 public class Increment
6 {
7     public static void Main( string[] args )
8     {
9         int c;
10    }
```

**Fig. 5.15** | Prefix increment and postfix increment operators. (Part 1 of 2.)

```

11     // demonstrate postfix increment operator
12     c = 5; // assign 5 to c
13     Console.WriteLine( c ); // display 5
14     Console.WriteLine( c++ ); // increment c and display 5
15     Console.WriteLine( c ); // display 6
16
17     Console.WriteLine(); // skip a line
18
19     // demonstrate prefix increment operator
20     c = 5; // assign 5 to c
21     Console.WriteLine( c ); // display 5
22     Console.WriteLine( ++c ); // increment c and display 6
23     Console.WriteLine( c ); // display 6 again
24 } // end Main
25 } // end class Increment

```

```

5
5
6

5
6
6

```

**Fig. 5.15** | Prefix increment and postfix increment operators. (Part 2 of 2.)

Line 12 initializes the variable *c* to 5, and line 13 outputs *c*'s initial value. Line 14 outputs the value of the expression *c*++. This expression performs the postfix increment operation on the variable *c*, so even though *c*'s value is incremented, *c*'s *original* value (5) is output. Thus, line 14 outputs *c*'s initial value (5) again. Line 15 outputs *c*'s new value (6) to prove that the variable's value was indeed incremented in line 14.

Line 20 resets *c*'s value to 5, and line 21 outputs *c*'s value. Line 22 outputs the value of the expression *++c*. This expression performs the prefix increment operation on *c*, so its value is incremented and the *new* value (6) is output. Line 23 outputs *c*'s value again to show that the value of *c* is still 6 after line 22 executes.

The arithmetic compound assignment operators and the increment and decrement operators can be used to simplify statements. For example, the three assignment statements in Fig. 5.12 (lines 24, 26 and 29)

```

passes = passes + 1;
failures = failures + 1;
studentCounter = studentCounter + 1;

```

can be written more concisely with compound assignment operators as

```

passes += 1;
failures += 1;
studentCounter += 1;

```

and even more concisely with prefix increment operators as

```

++passes;
++failures;
++studentCounter;

```

or with postfix increment operators as

```
passes++;
failures++;
studentCounter++;
```

When incrementing or decrementing a variable in a statement by itself, the prefix increment and postfix increment forms have the *same* result, and the prefix decrement and postfix decrement forms have the *same* result. It's only when a variable appears in the context of a larger expression that the prefix increment and postfix increment have *different* results (and similarly for the prefix decrement and postfix decrement).



### Common Programming Error 5.7

*Attempting to use the increment or decrement operator on an expression other than one to which a value can be assigned is a syntax error. For example, writing `++(x + 1)` is a syntax error, because `(x + 1)` is not an expression to which a value can be assigned.*

### Precedence and Associativity of the Operators We've Discussed So Far

Figure 5.16 shows the precedence and associativity of the operators we've introduced to this point. The operators are shown from top to bottom in decreasing order of precedence. The second column describes the associativity of the operators at each level of precedence. The conditional operator (`?:`); the unary operators prefix increment (`++`), prefix decrement (`--`), plus (`+`) and minus (`-`); the cast operators; and the assignment operators `=`, `+=`, `-=`, `*=`, `/=` and `%=` associate from right to left. All the other operators in the operator precedence chart in Fig. 5.16 associate from left to right. The third column names the groups of operators.

Operators	Associativity	Type
<code>.</code> <code>new</code> <code>++(postfix)</code> <code>--(postfix)</code>	left to right	highest precedence
<code>++</code> <code>--</code> <code>+</code> <code>-</code> <code>(type)</code>	right to left	unary prefix
<code>*</code> <code>/</code> <code>%</code>	left to right	multiplicative
<code>+</code> <code>-</code>	left to right	additive
<code>&lt;</code> <code>&lt;=</code> <code>&gt;</code> <code>&gt;=</code>	left to right	relational
<code>==</code> <code>!=</code>	left to right	equality
<code>?:</code>	right to left	conditional
<code>=</code> <code>+=</code> <code>-=</code> <code>*=</code> <code>/=</code> <code>%=</code>	right to left	assignment

**Fig. 5.16** | Precedence and associativity of the operators discussed so far.

## 5.13 Simple Types

The table in Appendix B lists the 13 **simple types** in C#. Like its predecessor languages C and C++, C# requires *all* variables to have a type. For this reason, C# is referred to as a **strongly typed language**.

In C and C++, you frequently have to write separate versions of apps to support different computer platforms, because the simple types are *not* guaranteed to be identical

from computer to computer. For example, an `int` value on one machine might be represented by 16 bits (2 bytes) of storage, while an `int` value on another machine might be represented by 32 bits (4 bytes) of storage. In C#, `int` values are always 32 bits (4 bytes). In fact, *all* C# numeric types have fixed sizes, as is shown in Appendix B.

Each type in Appendix B is listed with its size in bits (there are eight bits to a byte) and its range of values. Because the designers of C# want it to be maximally portable, they use internationally recognized standards for both character formats (Unicode; for more information, see Appendix F, Unicode®) and floating-point numbers (IEEE 754; for more information, visit [grouper.ieee.org/groups/754/](http://grouper.ieee.org/groups/754/)).

Recall from Section 4.5 that variables of *simple types* declared *outside* of a method as fields of a class are automatically assigned default values unless explicitly initialized. Instance variables of types `char`, `byte`, `sbyte`, `short`, `ushort`, `int`, `uint`, `long`, `ulong`, `float`, `double`, and `decimal` are all given the value 0 by default. Instance variables of type `bool` are given the value `false` by default. Similarly, reference-type instance variables are initialized by default to the value `null`.

## 5.14 Wrap-Up

This chapter presented basic problem-solving techniques that you'll use in building classes and developing methods for these classes. We demonstrated how to construct an algorithm (i.e., an approach to solving a problem), then how to refine the algorithm through several phases of pseudocode development, resulting in C# code that can be executed as part of a method. The chapter showed how to use top-down, stepwise refinement to plan out the specific actions that a method must perform and the order in which the method must perform these actions.

Only three types of control structures—sequence, selection and repetition—are needed to develop any algorithm. Specifically, we demonstrated the `if` single-selection statement, the `if...else` double-selection statement and the `while` repetition statement. These are some of the building blocks used to construct solutions to many problems. We used control-statement stacking to compute the total and the average of a set of student grades with counter- and sentinel-controlled repetition, and we used control-statement nesting to analyze and make decisions based on a set of exam results. We introduced C#'s compound assignment, unary cast, conditional (`? :`), increment and decrement operators. Finally, we discussed the simple types. In Chapter 6, we continue our discussion of control statements, introducing the `for`, `do...while` and `switch` statements.

---

## Summary

### Section 5.2 Algorithms

- An algorithm is a procedure for solving a problem in terms of the actions to execute and the order in which these actions execute.
- Specifying the order in which statements (actions) execute in an app is called program control.

***Section 5.3 Pseudocode***

- Pseudocode is an informal language that helps you develop algorithms without having to worry about the strict details of C# language syntax.
- Carefully prepared pseudocode can easily be converted to a corresponding C# app.

***Section 5.4 Control Structures***

- There are three types of control structures—sequence, selection and repetition.
- The sequence structure is built into C#. Unless directed otherwise, the computer executes C# statements one after the other in the order in which they're written.
- Activity diagrams are part of the UML. An activity diagram models the workflow of a portion of a software system.
- Activity diagrams are composed of special-purpose symbols, such as action-state symbols, diamonds and small circles. These symbols are connected by transition arrows, which represent the flow of the activity.
- Like pseudocode, activity diagrams help you develop and represent algorithms. Activity diagrams clearly show how control structures operate.
- Action-state symbols (rectangles with their left and right sides replaced with arcs curving outward) represent actions to perform.
- The arrows in an activity diagram represent transitions, which indicate the order in which the actions represented by the action states occur.
- The solid circle in an activity diagram represents the activity's initial state. The solid circle surrounded by a hollow circle represents the final state.
- Rectangles with the upper-right corners folded over are UML notes (like comments in C#)—explanatory remarks that describe the purpose of symbols in the diagram.
- C# has three types of selection statements: the `if` statement, the `if...else` statement and the `switch` statement.
- The `if` statement is called a single-selection statement because it selects or ignores a single action.
- The `if...else` statement is called a double-selection statement because it selects between two different actions (or groups of actions).
- The `switch` statement is called a multiple-selection statement because it selects among many different actions (or groups of actions).
- C# provides four repetition statements: the `while`, `do...while`, `for` and `foreach` statements.
- The `while`, `for` and `foreach` statements perform the actions in their bodies zero or more times.
- The `do...while` statement performs the actions in its body one or more times.
- Control statements may be connected in two ways: control-statement stacking and control-statement nesting.

***Section 5.5 if Single-Selection Statement***

- The `if` single-selection statement performs an indicated action (or group of actions) only when the condition is true; otherwise, the action is skipped.
- In an activity diagram, the diamond symbol indicates that a decision is to be made. The workflow will continue along a path determined by the symbol's associated guard conditions.
- When modelled by a UML activity diagram, all control statements contain initial states, transition arrows, action states and decision symbols.

**Section 5.6 *if...else* Double-Selection Statement**

- The *if...else* double-selection statement allows you to specify an action (or group of actions) to perform when the condition is true and a different action (or group of actions) when the condition is false.
- C# provides the conditional operator (?:), which can be used in place of an *if...else* statement. The conditional expression evaluates to the second operand if the first operand evaluates to *true*, and evaluates to the third operand if the first operand evaluates to *false*.
- To include several statements in the body of an *if* (or the body of an *else* for an *if...else* statement), enclose the statements in braces ({ and }).
- A set of statements contained within a pair of braces is called a block. A block can be placed anywhere in an app that a single statement can be placed.

**Section 5.7 *while* Repetition Statement**

- A repetition statement allows you to specify that an app should repeat an action while some condition remains true.
- The format for the *while* repetition statement is

```
while ( condition )
    statement
```

**Section 5.8 Formulating Algorithms: Counter-Controlled Repetition**

- Counter-controlled repetition is a technique that uses a variable called a counter to control the number of times a set of statements will execute.
- A variable is said to be definitely assigned when the variable is guaranteed to be assigned a value in every possible flow of control. Local variables must be definitely assigned before they're used in calculations.
- Dividing two integers results in integer division—any fractional part of the calculation is lost.

**Section 5.9 Formulating Algorithms: Sentinel-Controlled Repetition**

- Sentinel-controlled repetition is a technique that uses a special value called a sentinel value to indicate “end of data entry.”

**Section 5.10 Formulating Algorithms: Nested Control Statements**

- The unary cast operator (`double`) creates a *temporary* floating-point copy of its operand. Using a cast operator in this manner is called explicit conversion.
- To ensure that both operands of a binary operator are of the same type, C# performs promotion on selected operands.
- The format specifier F indicates that a variable's value should be displayed as a real number.

**Section 5.11 Compound Assignment Operators**

- C# provides several compound assignment operators for abbreviating assignment expressions, including `+=`, `-=`, `*=`, `/=` and `%=`.

**Section 5.12 Increment and Decrement Operators**

- C# provides the unary increment operator, `++`, and the unary decrement operator, `--`, for adding 1 to or subtracting 1 from the value of a numeric variable.
- Incrementing (or decrementing) a variable with the prefix increment (or prefix decrement) operator increments (or decrements) the variable by 1 and uses the new variable value in the expression in which the variable appears. Incrementing (or decrementing) a variable with the postfix

increment (or postfix decrement) operator increments (or decrements) the variable by 1 but uses the original variable value in the expression in which the variable appears.

### **Section 5.13 Simple Types**

- C# is a strongly typed language—it requires all variables to have a type.
- Variables of simple types declared outside a method as fields of a class are automatically assigned default values. Instance variables of types `char`, `byte`, `sbyte`, `short`, `ushort`, `int`, `uint`, `long`, `ulong`, `float`, `double`, and `decimal` are all given the value 0 by default. Instance variables of type `bool` are given the value `false` by default. Reference-type instance variables are initialized by default to the value `null`.

## **Terminology**

-- operator	dummy value
? : operator	explicit conversion
++ operator	<code>false</code>
action	fatal logic error
action/decision model of programming	final state (in the UML)
action expression (in the UML)	flag value
action state (in the UML)	goto statement
action-state symbol (in the UML)	guard condition (in the UML)
activity (in the UML)	if statement
activity diagram (in the UML)	if...else statement
addition compound assignment operator (+=)	implicit conversion
algorithm	increment operator (++)
arithmetic compound assignment operators: +=, -=, *=, /= and %	indefinite repetition
block	infinite loop
body of a loop	initial state (in the UML)
<code>bool</code> simple type	integer division
boolean expression	instantiate an object
cast operator, ( <i>type</i> )	iteration statement
compound assignment operator	logic error
conditional expression	loop
conditional operator (?:)	loop-continuation condition
control statement	merge symbol (in the UML)
control-statement nesting	multiple-selection statement
control-statement stacking	multiplicative operators
control structure	nested control statements
control variable	nested if...else statements
counter	nonfatal logic error
counter-controlled repetition	note (in the UML)
dangling-else problem	order in which actions should execute
decision	postfix decrement operator
decision symbol (in the UML)	postfix increment operator
decrement operator (--)	prefix decrement operator
definite assignment	prefix increment operator
definite repetition	procedure
diamond (in the UML)	program control
dotted line	promotion
double-selection statement	pseudocode
	refinement

repetition	strongly typed language
repetition statement	structured programming
selection statement	syntax error
sentinel-controlled repetition	ternary operator
sentinel value	top-down stepwise refinement
sequence structure	total
sequential execution	transfer of control
signal value	transition (in the UML)
simple types	transition arrow (in the UML)
single-entry/single-exit control structures	true
single-selection statement	truncate
small circle (in the UML)	unary cast operator
solid circle (in the UML)	unary operator
solid circle surrounded by a hollow circle (in the UML)	while statement
stacked control statements	workflow

## Self-Review Exercises

- 5.1** Fill in the blanks in each of the following statements:
- All apps can be written in terms of three types of control structures: \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.
  - The \_\_\_\_\_ statement is used to execute one action when a condition is true and another when that condition is false.
  - Repeating a set of instructions a specific number of times is called \_\_\_\_\_ repetition.
  - When it's not known in advance how many times a set of statements will be repeated, a(n) \_\_\_\_\_ value can be used to terminate the repetition.
  - The \_\_\_\_\_ structure is built into C#—by default, statements execute in the order they appear.
  - Instance variables of type `int` are given the value \_\_\_\_\_ by default.
  - C# is a(n) \_\_\_\_\_ language—it requires all variables to have a type.
  - If the increment operator is \_\_\_\_\_ to a variable, the variable is incremented by 1 and its new value is used in the expression.
- 5.2** State whether each of the following is *true* or *false*. If *false*, explain why.
- An algorithm is a procedure for solving a problem in terms of the actions to execute and the order in which these actions execute.
  - A set of statements contained within a pair of parentheses is called a block.
  - A selection statement specifies that an action is to be repeated while some condition remains true.
  - A nested control statement appears in the body of another control statement.
  - C# provides the arithmetic compound assignment operators `+=`, `-=`, `*=`, `/=` and `%=` for abbreviating assignment expressions.
  - Specifying the order in which statements (actions) execute in an app is called program control.
  - The unary cast operator (`double`) creates a temporary integer copy of its operand.
  - Instance variables of type `bool` are given the value `true` by default.
  - Pseudocode helps you think out an app before attempting to write it in a programming language.
- 5.3** Write four different C# statements that each add 1 to `int` variable `x`.

- 5.4** Write C# statements to accomplish each of the following tasks:
- Assign the sum of *x* and *y* to *z*, and increment *x* by 1 with `++`. Use only one statement and ensure that the original value of *x* is used in the statement.
  - Test whether variable *count* is greater than 10. If it is, display "Count is greater than 10".
  - Decrement the variable *x* by 1, then subtract it from the variable *total*. Use only one statement.
  - Calculate the remainder after *q* is divided by *divisor*, and assign the result to *q*. Write this statement in two different ways.
- 5.5** Write a C# statement to accomplish each of the following tasks:
- Declare variable *sum* to be of type `int`.
  - Declare variable *x* to be of type `int`.
  - Assign 1 to variable *x*.
  - Assign 0 to variable *sum*.
  - Add variable *x* to variable *sum*, and assign the result to variable *sum*.
  - Display "The sum is: ", followed by the value of variable *sum*.
- 5.6** Combine the statements that you wrote in Exercise 5.5 into a C# app that calculates and displays the sum of the integers from 1 to 10. Use a `while` statement to loop through the calculation and increment statements. The loop should terminate when the value of *x* becomes 11.
- 5.7** Determine the values of the variables in the following statement after it executes. Assume that when the statement begins executing, all variables are type `int` and have the value 5.
- ```
product *= x++;
```
- 5.8** Identify and correct the errors in each of the following sets of code:
- ```
while ( c <= 5 )
{
    product *= c;
    ++c;
```
  - ```
if ( gender == 1 )
    Console.WriteLine( "Woman" );
else;
    Console.WriteLine( "Man" );
```
- 5.9** What is wrong with the following `while` statement?
- ```
while ( z >= 0 )
    sum += z;
```

## Answers to Self-Review Exercises

- 5.1** a) sequence, selection, repetition. b) `if...else`. c) counter-controlled (or definite). d) sentinel, signal, flag or dummy. e) sequence. f) 0 (zero). g) strongly typed. h) prefixed.
- 5.2** a) True. b) False. A set of statements contained within a pair of braces (`{` and `}`) is called a block. c) False. A repetition statement specifies that an action is to be repeated while some condition remains true. A selection statement determines whether an action is performed based on the truth or falsity of a condition. d) True. e) True. f) True. g) False. The unary cast operator (`double`) creates a temporary floating-point copy of its operand. h) False. Instance variables of type `bool` are given the value `false` by default. i) True.
- 5.3**
- ```
x = x + 1;
x += 1;
++x;
x++;
```

**5.4**

- `z = x++ + y;`
- `if ( count > 10 )`  
 `Console.WriteLine( "Count is greater than 10" );`
- `total -= --x;`
- `q %= divisor;`  
`q = q % divisor;`

**5.5**

- `int sum;`
- `int x;`
- `x = 1;`
- `sum = 0;`
- `sum += x; or sum = sum + x;`
- `Console.WriteLine( "The sum is: {0}", sum );`

**5.6** The app is as follows:

```

1 // Ex. 5.6: Calculate.cs
2 // Calculate the sum of the integers from 1 to 10
3 using System;
4
5 public class Calculate
6 {
7     public static void Main( string[] args )
8     {
9         int sum;
10        int x;
11
12        x = 1; // initialize x to 1 for counting
13        sum = 0; // initialize sum to 0 for totaling
14
15        while ( x <= 10 ) // while x is less than or equal to 10
16        {
17            sum += x; // add x to sum
18            ++x; // increment x
19        } // end while
20
21        Console.WriteLine( "The sum is: {0}", sum );
22    } // end Main
23 } // end class Calculate

```

The sum is: 55

**5.7** `product = 25, x = 6`

**5.8**

- Error:* The closing right brace of the `while` statement's body is missing.  
*Correction:* Add a closing right brace after the statement `++c;`.
- Error:* The semicolon after `else` results in a logic error. The second output statement will always execute.  
*Correction:* Remove the semicolon after `else`.

**5.9** The value of the variable `z` is never changed in the `while` statement. Therefore, an infinite loop occurs if the loop-continuation condition (`z >= 0`) is initially true. To prevent an infinite loop, `z` must be decremented so that it eventually becomes less than 0.

## Exercises

**5.10** Compare and contrast the `if` single-selection statement and the `while` repetition statement. How are these two statements similar? How are they different?

**5.11** (*Integer Division*) Explain what happens when a C# app attempts to divide one integer by another. What happens to the fractional part of the calculation? How can you avoid that outcome?

**5.12** (*Combining Control Statements*) Describe the two ways in which control statements can be combined.

**5.13** (*Choosing Repetition Statements*) What type of repetition would be appropriate for calculating the sum of the first 100 positive integers? What type of repetition would be appropriate for calculating the sum of an arbitrary number of positive integers? Briefly describe how each of these tasks could be performed.

**5.14** (*Prefix vs. Postfix Increment Operators*) What is the difference between the prefix increment operator and the postfix increment operator?

**5.15** (*Find the Error*) Identify and correct the errors in each of the following pieces of code. [Note: There may be more than one error in each piece of code.]

- a) `if ( age >= 65 );  
 Console.WriteLine( "Age greater than or equal to 65" );  
else  
 Console.WriteLine( "Age is less than 65" );`
- b) `int x = 1, total;  
while ( x <= 10 )  
{  
 total += x;  
 ++x;  
}  
while ( x <= 100 )  
 total += x;  
 ++x;`
- c) `while ( y > 0 )  
{  
 Console.WriteLine( y );  
 ++y;`

**5.16** (*What Does This Program Do?*) What does the following app display?

```

1 // Ex. 5.16: Mystery.cs
2 using System;
3
4 public class Mystery
{
6     public static void Main( string[] args )
7     {
8         int y;
9         int x = 1;
10        int total = 0;
11
12        while ( x <= 10 )
13        {
14            y = x * x;

```

---

```

15         Console.WriteLine( y );
16         total += y;
17         ++x;
18     } // end while
19
20     Console.WriteLine( "Total is {0}", total );
21 } // end Main
22 } // end class Mystery

```

---

*For Exercises 5.17–5.20, perform each of the following steps:*

- Read the problem statement.
- Formulate the algorithm using pseudocode and top-down, stepwise refinement.
- Write a C# app.
- Test, debug and execute the C# app.
- Process three complete sets of data.

**5.17 (Gas Mileage)** Drivers are concerned with the mileage their automobiles get. One driver has kept track of several tankfuls of gasoline by recording the miles driven and gallons used for each tankful. Develop a C# app that will input the miles driven and gallons used (both as integers) for each tankful. The app should calculate and display the miles per gallon obtained for each tankful and display the combined miles per gallon obtained for all tankfuls up to this point. All averaging calculations should produce floating-point results. Display the results rounded to the nearest hundredth. Use the `Console` class's `ReadLine` method and sentinel-controlled repetition to obtain the data from the user.

**5.18 (Credit Limit Calculator)** Develop a C# app that will determine whether any of several department-store customers has exceeded the credit limit on a charge account. For each customer, the following facts are available:

- account number
- balance at the beginning of the month
- total of all items charged by the customer this month
- total of all credits applied to the customer's account this month
- allowed credit limit.

The app should input all these facts as integers, calculate the new balance ( $= \text{beginning balance} + \text{charges} - \text{credits}$ ), display the new balance and determine whether the new balance exceeds the customer's credit limit. For those customers whose credit limit is exceeded, the app should display the message "*Credit limit exceeded*". Use sentinel-controlled repetition to obtain the data for each account.

**5.19 (Sales Commission Calculator)** A large company pays its salespeople on a commission basis. The salespeople receive \$200 per week plus 9% of their gross sales for that week. For example, a salesperson who sells \$5,000 worth of merchandise in a week receives \$200 plus 9% of \$5,000, or a total of \$650. You've been supplied with a list of the items sold by each salesperson. The values of these items are as follows:

| Item | Value  |
|------|--------|
| 1    | 239.99 |
| 2    | 129.75 |
| 3    | 99.95  |
| 4    | 350.89 |

Develop a C# app that inputs one salesperson's items sold for the last week, then calculates and displays that salesperson's earnings. There's no limit to the number of items that can be sold by a salesperson.

**5.20** (*Salary Calculator*) Develop a C# app that will determine the gross pay for each of three employees. The company pays straight time for the first 40 hours worked by each employee and time-and-a-half for all hours worked in excess of 40 hours. You’re given a list of the three employees of the company, the number of hours each employee worked last week and the hourly rate of each employee. Your app should input this information for each employee, then should determine and display the employee’s gross pay. Use the `Console` class’s `ReadLine` method to input the data.

**5.21** (*Find the Largest Number*) The process of finding the maximum value (i.e., the largest of a group of values) is used frequently in computer applications. For example, an app that determines the winner of a sales contest would input the number of units sold by each salesperson. The salesperson who sells the most units wins the contest. Write pseudocode, then a C# app that inputs a series of 10 integers, then determines and displays the largest integer. Your app should use at least the following three variables:

- counter: A counter to count to 10 (i.e., to keep track of how many numbers have been input and to determine when all 10 numbers have been processed).
- number: The integer most recently input by the user.
- largest: The largest number found so far.

**5.22** (*Tabular Output*) Write a C# app that uses looping to display the following table of values:

| N | 10*N | 100*N | 1000*N |
|---|------|-------|--------|
| 1 | 10   | 100   | 1000   |
| 2 | 20   | 200   | 2000   |
| 3 | 30   | 300   | 3000   |
| 4 | 40   | 400   | 4000   |
| 5 | 50   | 500   | 5000   |

**5.23** (*Find the Two Largest Numbers*) Using an approach similar to that for Exercise 5.21, find the *two* largest values of the 10 values entered. [Note: You may input each number only once.]

**5.24** (*Validating User Input*) Modify the app in Fig. 5.12 to validate its inputs. For any input, if the value entered is other than 1 or 2, display the message “Invalid input,” then keep looping until the user enters a correct value.

**5.25** (*What Does This Program Do?*) What does the following app display?

---

```

1 // Ex. 5.25: Mystery2.cs
2 using System;
3
4 public class Mystery2
5 {
6     public static void Main( string[] args )
7     {
8         int count = 1;
9
10        while ( count <= 10 )
11        {
12            Console.WriteLine( count % 2 == 1 ? "****" : "+++++++" );
13            ++count;
14        } // end while
15    } // end Main
16 } // end class Mystery2

```

---

**5.26** (*What Does This Program Do?*) What does the following app display?

```

1 // Ex. 5.26: Mystery3.cs
2 using System;
3
4 public class Mystery3
5 {
6     public static void Main( string[] args )
7     {
8         int row = 10;
9         int column;
10
11         while ( row >= 1 )
12         {
13             column = 1;
14
15             while ( column <= 10 )
16             {
17                 Console.WriteLine( row % 2 == 1 ? "<" : ">" );
18                 ++column;
19             } // end while
20
21             --row;
22             Console.WriteLine();
23         } // end while
24     } // end Main
25 } // end class Mystery3

```

**5.27** (*Dangling-else Problem*) Determine the output for each of the given sets of code when *x* is 9 and *y* is 11 and when *x* is 11 and *y* is 9. The compiler ignores the indentation in a C# app. Also, the C# compiler always associates an *else* with the immediately preceding *if* unless told to do otherwise by the placement of braces ({}). On first glance, you may not be sure which *if* an *else* matches—this situation is referred to as the “dangling-*else* problem.” We’ve eliminated the indentation from the following code to make the problem more challenging. [Hint: Apply the indentation conventions you’ve learned.]

a) *if* ( *x* < 10 )  
*if* ( *y* > 10 )  
Console.WriteLine( "\*\*\*\*\*" );  
*else*  
Console.WriteLine( "#####" );  
Console.WriteLine( "\$\$\$\$\$" );

b) *if* ( *x* < 10 )  
{  
*if* ( *y* > 10 )  
Console.WriteLine( "\*\*\*\*\*" );  
}  
*else*  
{  
Console.WriteLine( "#####" );  
Console.WriteLine( "\$\$\$\$\$" );  
}

**5.28** (*Another Dangling-else Problem*) Modify the given code to produce the output shown in each part of the problem. Use proper indentation techniques. Make no changes other than inserting braces and changing the indentation of the code. The compiler ignores indentation in a C# app.

We've eliminated the indentation from the given code to make the problem more challenging. [Note: It's possible that no modification is necessary for some of the parts.]

```
if ( y == 8 )
if ( x == 5 )
Console.WriteLine( "#####" );
else
Console.WriteLine( "#####" );
Console.WriteLine( "$$$$$" );
Console.WriteLine( "&&&&&" );
```

- a) Assuming that  $x = 5$  and  $y = 8$ , the following output is produced:

```
#####  
$$$$$  
&&&&&
```

- b) Assuming that  $x = 5$  and  $y = 8$ , the following output is produced:

```
#####
```

- c) Assuming that  $x = 5$  and  $y = 8$ , the following output is produced:

```
#####  
&&&&&
```

- d) Assuming that  $x = 5$  and  $y = 7$ , the following output is produced.

```
#####  
$$$$$  
&&&&&
```

**5.29 (Square of Asterisks)** Write an app that prompts the user to enter the size of the side of a square, then displays a hollow square of that size made of asterisks. Your app should work for squares of all side lengths between 1 and 20. If the user enters a number less than 1 or greater than 20, your app should display a square of size 1 or 20, respectively.

**5.30 (Palindromes)** A palindrome is a sequence of characters that reads the same backward as forward. For example, each of the following five-digit integers is a palindrome: 12321, 55555, 45554 and 11611. Write an app that reads in a five-digit integer and determines whether it's a palindrome. If the number is not five digits long, display an error message and allow the user to enter a new value. [Hint: Use the remainder and division operators to pick off the number's digits one at a time, from right to left.]

**5.31 (Displaying the Decimal Equivalent of a Binary Number)** Write an app that inputs an integer containing only 0s and 1s (i.e., a binary integer) and displays its decimal equivalent. [Hint: Picking the digits off a binary number is similar to picking the digits off a decimal number, which you did in Exercise 5.30. In the decimal number system, the rightmost digit has a positional value of 1 and the next digit to the left has a positional value of 10, then 100, then 1000 and so on. The decimal number 234 can be interpreted as  $4 * 1 + 3 * 10 + 2 * 100$ . In the binary number system, the rightmost digit has a positional value of 1, the next digit to the left has a positional value of 2, then 4, then 8 and so on. The decimal equivalent of binary 1101 is  $1 * 1 + 0 * 2 + 1 * 4 + 1 * 8$ , or  $1 + 0 + 4 + 8$ , or 13.]

**5.32 (Checkerboard Pattern of Asterisks)** Write an app that uses only the output statements

```
Console.WriteLine( "*" );
Console.WriteLine( " " );
Console.WriteLine();
```

to display the checkerboard pattern that follows. A `Console.WriteLine` method call with no arguments outputs a single newline character. [Hint: Repetition statements are required.]

```

* * * * *
* * * * *
* * * * *
* * * * *
* * * * *
* * * * *
* * * * *
* * * * *
* * * * *

```

**5.33** (*Multiples of 2*) Write an app that keeps displaying in the console window the powers of the integer 2—namely, 2, 4, 8, 16, 32, 64 and so on. Loop 40 times. What happens when you run this app?

**5.34** (*What's Wrong with This Code?*) What is wrong with the following statement? Provide the correct statement to add 1 to the sum of *x* and *y*.

```
Console.WriteLine( ++(x + y) );
```

**5.35** (*Sides of a Triangle*) Write an app that reads three nonzero values entered by the user, then determines and displays whether they could represent the sides of a triangle.

**5.36** (*Sides of a Right Triangle*) Write an app that reads three nonzero integers, then determines and displays whether they could represent the sides of a right triangle.

**5.37** (*Factorials*) The factorial of a nonnegative integer *n* is written as *n!* (pronounced “*n* factorial”) and is defined as follows:

$$n! = n \cdot (n - 1) \cdot (n - 2) \cdot \dots \cdot 1 \quad (\text{for values of } n \text{ greater than or equal to 1})$$

and

$$n! = 1 \quad (\text{for } n = 0)$$

For example,  $5! = 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$ , which is 120. Write an app that reads a nonnegative integer and computes and displays its factorial.

**5.38** (*Infinite Series: Mathematical Constant e*) Write an app that estimates the value of the mathematical constant *e* by using the formula

$$e = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \dots$$

The predefined constant `Math.E` (class `Math` is in the `System` namespace) provides a good approximation of *e*. Use the `WriteLine` method to output both your estimated value of *e* and `Math.E` for comparison.

**5.39** (*Infinite Series:  $e^x$* ) Write an app that computes the value of  $e^x$  by using the formula

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

Compare the result of your calculation to the return value of the method call

```
Math.Pow( Math.E, x )
```

[*Note:* The predefined method `Math.Pow` takes two arguments and raises the first argument to the power of the second. We discuss `Math.Pow` in Section 6.4.]

## Making a Difference Exercises

**5.40** (*World Population Growth*) World population has grown considerably over the centuries. Continued growth could eventually challenge the limits of breathable air, drinkable water, arable

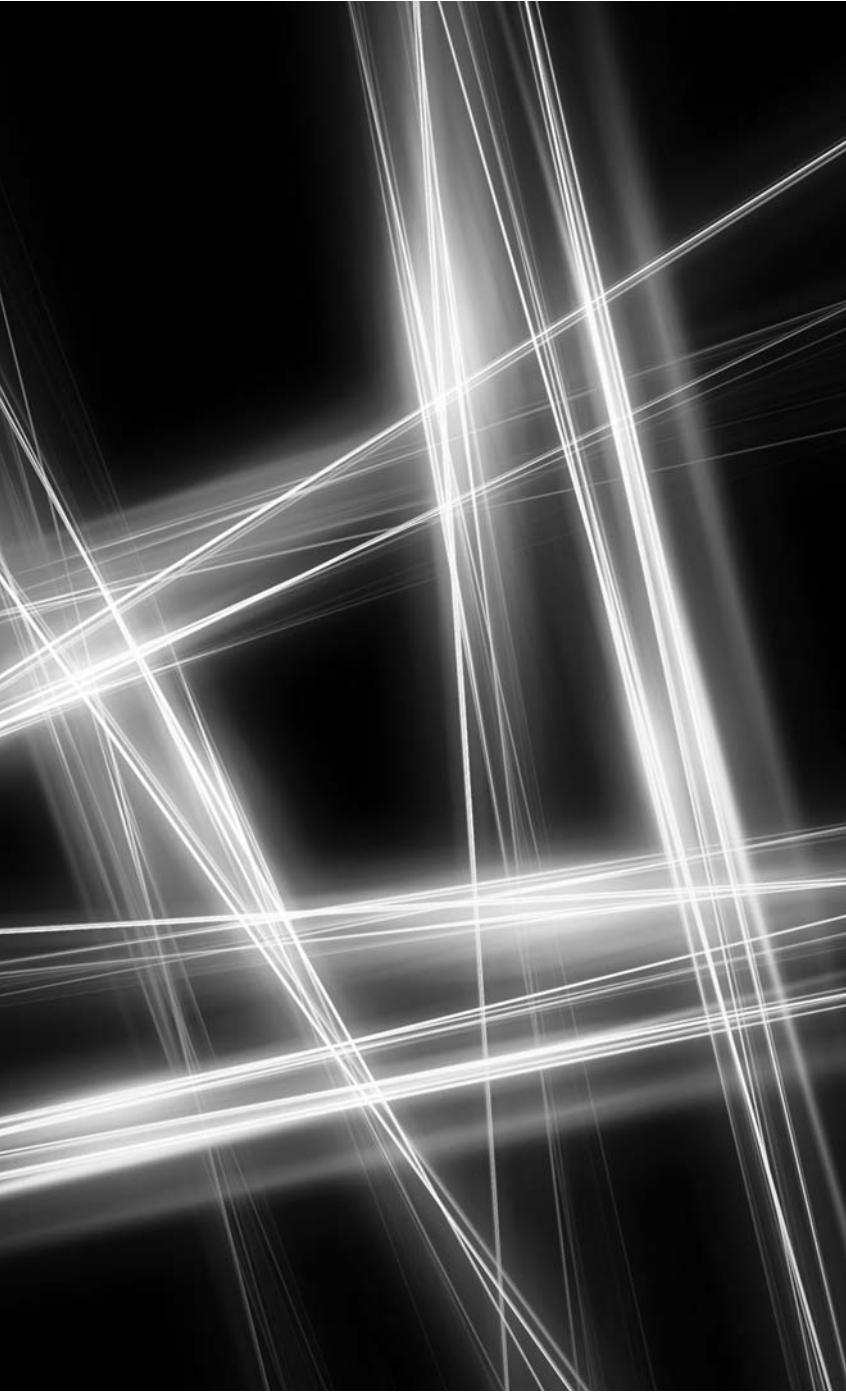
cropland and other limited resources. There's evidence that growth has been slowing in recent years and that world population could peak some time this century, then start to decline.

For this exercise, research world population growth issues online. *Be sure to investigate various viewpoints.* Get estimates for the current world population and its growth rate (the percentage by which it is likely to increase this year). Write a program that calculates world population growth each year for the next 75 years, *using the simplifying assumption that the current growth rate will stay constant.* When displaying the results, the first column should display the year from year 1 to year 75. The second column should display the anticipated world population at the end of that year. The third column should display the numerical increase in the world population that would occur that year. Using your results, determine the year in which the population would be double what it is today, if this year's growth rate were to persist. [Hint: Use `double` variables because `int` variables can store values only up to approximately two billion. Display the `double` values using the format `F0`.]

**5.41** (*Enforcing Privacy with Cryptography*) The explosive growth of Internet communications and data storage on Internet-connected computers has greatly increased privacy concerns. The field of cryptography is concerned with coding data to make it difficult (and hopefully—with the most advanced schemes—impossible) for unauthorized users to read. In this exercise you'll investigate a simple scheme for encrypting and decrypting data. A company that wants to send data over the Internet has asked you to write a program that will encrypt it so that it may be transmitted more securely. All the data is transmitted as four-digit integers. Your app should read a four-digit integer entered by the user and encrypt it as follows: Replace each digit with the result of adding 7 to the digit and getting the remainder after dividing the new value by 10. Then swap the first digit with the third, and swap the second digit with the fourth. Then display the encrypted integer. Write a separate app that inputs an encrypted four-digit integer and decrypts it (by reversing the encryption scheme) to form the original number. Use the format specifier `D4` to display the encrypted value in case the number starts with a 0.

# 6

## Control Statements: Part 2



*Who can control his fate?*

—William Shakespeare

*The used key is always bright.*

—Benjamin Franklin

*Every advantage in the past is judged in the light of the final issue.*

—Demosthenes

### Objectives

In this chapter you'll:

- Learn the essentials of counter-controlled repetition.
- Use the `for` and `do...while` repetition statements.
- Use the `switch` multiple selection statement.
- Use the `break` and `continue` statements to alter the flow of control.
- Use the logical operators to form complex conditional expressions.

- |                                                                                                                                                                                                                                            |                                                                                                                                                                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>6.1</b> Introduction<br><b>6.2</b> Essentials of Counter-Controlled Repetition<br><b>6.3</b> <b>for</b> Repetition Statement<br><b>6.4</b> Examples Using the <b>for</b> Statement<br><b>6.5</b> <b>do...while</b> Repetition Statement | <b>6.6</b> <b>switch</b> Multiple-Selection Statement<br><b>6.7</b> <b>break</b> and <b>continue</b> Statements<br><b>6.8</b> Logical Operators<br><b>6.9</b> Structured-Programming Summary<br><b>6.10</b> Wrap-Up |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 6.1 Introduction

In this chapter, we introduce several of C#'s remaining control statements. (The `foreach` statement is introduced in Chapter 8.) The control statements we study here and in Chapter 5 are helpful in building and manipulating objects.

Through a series of short examples using `while` and `for`, we explore the essentials of counter-controlled repetition. We create a version of class `GradeBook` that uses a `switch` statement to count the number of A, B, C, D and F grade equivalents in a set of numeric grades entered by the user. We introduce the `break` and `continue` program-control statements. We discuss C#'s logical operators, which enable you to use more complex conditional expressions in control statements. Finally, we summarize C#'s control statements and the proven problem-solving techniques presented in this chapter and Chapter 5.

## 6.2 Essentials of Counter-Controlled Repetition

This section uses the **while repetition statement** to formalize the elements required to perform counter-controlled repetition. Counter-controlled repetition requires

1. a **control variable** (or loop counter)
2. the **initial value** of the control variable
3. the **increment** (or **decrement**) by which the control variable is modified each time through the loop (also known as each **iteration of the loop**)
4. the **loop-continuation condition** that determines whether to continue looping.

To see these elements of counter-controlled repetition, consider the app of Fig. 6.1, which uses a loop to display the numbers from 1 through 10.

---

```

1 // Fig. 6.1: WhileCounter.cs
2 // Counter-controlled repetition with the while repetition statement.
3 using System;
4
5 public class WhileCounter
6 {
7     public static void Main( string[] args )
8     {

```

**Fig. 6.1** | Counter-controlled repetition with the `while` repetition statement. (Part 1 of 2.)

```

9      int counter = 1; // declare and initialize control variable
10
11     while ( counter <= 10 ) // loop-continuation condition
12     {
13         Console.WriteLine( "{0} ", counter );
14         ++counter; // increment control variable
15     } // end while
16
17     Console.WriteLine(); // output a newline
18 } // end Main
19 } // end class WhileCounter

```

1 2 3 4 5 6 7 8 9 10

**Fig. 6.1** | Counter-controlled repetition with the `while` repetition statement. (Part 2 of 2.)

In method `Main` (lines 7–18), the elements of counter-controlled repetition are defined in lines 9, 11 and 14. Line 9 declares the control variable (`counter`) as an `int`, reserves space for it in memory and sets its initial value to 1.

Line 13 in the `while` statement displays control variable `counter`'s value during each iteration of the loop. Line 14 increments the control variable by 1 for each iteration of the loop. The loop-continuation condition in the `while` (line 11) tests whether the value of the control variable is less than or equal to 10 (the final value for which the condition is `true`). The app performs the body of this `while` even when the control variable is 10. The loop terminates when the control variable exceeds 10 (i.e., `counter` becomes 11).



### Error-Prevention Tip 6.1

*Because floating-point values may be approximate, controlling loops with floating-point variables may result in imprecise counter values and inaccurate termination tests. Control counting loops with integers.*

The app in Fig. 6.1 can be made more concise by initializing `counter` to 0 in line 9 and incrementing `counter` in the `while` condition with the prefix increment operator as follows:

```

while ( ++counter <= 10 ) // loop-continuation condition
    Console.WriteLine( "{0} ", counter );

```

This code saves a statement (and eliminates the need for braces around the loop's body), because the `while` condition performs the increment before testing the condition. (Recall from Section 5.12 that the precedence of `++` is higher than that of `<=`.) Code written in such a condensed fashion might be more difficult to read, debug, modify and maintain.



### Software Engineering Observation 6.1

*“Keep it simple” is good advice for most of the code you’ll write.*

## 6.3 for Repetition Statement

Section 6.2 presented the essentials of counter-controlled repetition. The `while` statement can be used to implement *any* counter-controlled loop. C# also provides the **for repetition statement**, which specifies the elements of counter-controlled-repetition in a single line of

code. In general, counter-controlled repetition should be implemented with a `for` statement. Figure 6.2 reimplements the app in Fig. 6.1 using the `for` statement.

```

1 // Fig. 6.2: ForCounter.cs
2 // Counter-controlled repetition with the for repetition statement.
3 using System;
4
5 public class ForCounter
6 {
7     public static void Main( string[] args )
8     {
9         // for statement header includes initialization,
10        // loop-continuation condition and increment
11        for ( int counter = 1; counter <= 10; ++counter )
12            Console.WriteLine( "{0} ", counter );
13
14        Console.WriteLine(); // output a newline
15    } // end Main
16 } // end class ForCounter

```

```
1 2 3 4 5 6 7 8 9 10
```

**Fig. 6.2** | Counter-controlled repetition with the `for` repetition statement.

When the `for` statement (lines 11–12) begins executing, control variable `counter` is declared and initialized to 1. (Recall from Section 6.2 that the first two elements of counter-controlled repetition are the *control variable* and its *initial value*.) Next, the app checks the *loop-continuation condition*, `counter <= 10`, which is between the two required semicolons. The initial value of `counter` is 1, so the condition initially is true. Therefore, the body statement (line 12) displays control variable `counter`'s value, which is 1. Next, the app increments `counter` in the expression `++counter`, which appears to the right of the second semicolon. Then the loop-continuation test is performed again to determine whether the app should continue with the next iteration of the loop. At this point, the control-variable value is 2, so the condition is still true—and the app performs the body statement again (i.e., the next iteration of the loop). This process continues until the numbers 1 through 10 have been displayed and the `counter`'s value becomes 11, causing the loop-continuation test to fail and repetition to terminate (after 10 repetitions of the loop body at line 12). Then the app performs the first statement after the `for`—in this case, line 14.

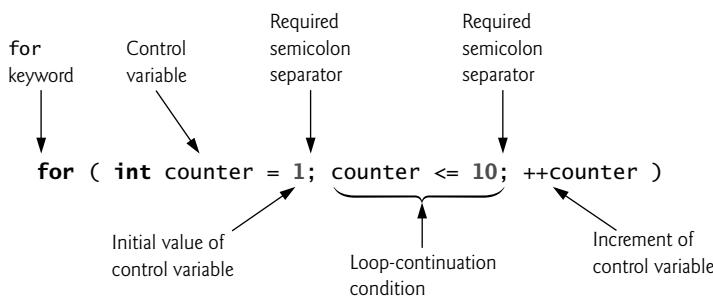
Fig. 6.2 uses (in line 11) the loop-continuation condition `counter <= 10`. If you incorrectly specified `counter < 10` as the condition, the loop would iterate only nine times—a common logic error called an **off-by-one error**.



### Error-Prevention Tip 6.2

Using the *final value* in the condition of a `while` or `for` statement with the `<=` relational operator helps avoid off-by-one errors. For a loop that displays the values 1 to 10, the loop-continuation condition should be `counter <= 10`, rather than `counter < 10` (which causes an off-by-one error) or `counter < 11` (which is correct). Many programmers prefer so-called zero-based counting, in which, to count 10 times, `counter` would be initialized to zero and the loop-continuation test would be `counter < 10`.

Figure 6.3 takes a closer look at the `for` statement in Fig. 6.2. The `for`'s first line (including the keyword `for` and everything in parentheses after `for`)—line 11 in Fig. 6.2—is sometimes called the **for statement header**, or simply the **for header**. The `for` header “does it all”—it specifies each of the items needed for counter-controlled repetition with a control variable. If there's more than one statement in the body of the `for`, braces are required to define the body of the loop.



**Fig. 6.3** | `for` statement header components.

The general format of the `for` statement is

```
for ( initialization; loopContinuationCondition; increment )
    statement
```

where the *initialization* expression names the loop's control variable and provides its initial value, the *loopContinuationCondition* is the condition that determines whether looping should continue and the *increment* modifies the control variable's value (whether an increment or decrement), so that the loop-continuation condition eventually becomes false. The two semicolons in the `for` header are required. We don't include a semicolon after *statement*, because the semicolon is already assumed to be included in the notion of a *statement*.

In most cases, the `for` statement can be represented with an equivalent `while` statement as follows:

```
initialization;
while ( loopContinuationCondition )
{
    statement
    increment;
}
```

In Section 6.7, we discuss a case in which a `for` statement cannot be represented with a `while` statement like the one above.

Typically, `for` statements are used for counter-controlled repetition, and `while` statements are used for sentinel-controlled repetition. However, `while` and `for` can each be used for either repetition type.

If the *initialization* expression in the `for` header declares the control variable (i.e., the control variable's type is specified before the variable name, as in Fig. 6.2), the control variable can be used *only* in that `for` statement—it will not exist outside it. This restricted use of the name of the control variable is known as the variable's **scope**. The scope of a variable defines where it can be used in an app. For example, a local variable can be used only in

the method that declares the variable and *only* from the point of declaration through the end of the block in which the variable has been declared. Scope is discussed in detail in Chapter 7, Methods: A Deeper Look.



### Common Programming Error 6.1

*When a for statement's control variable is declared in the initialization section of the for's header, using the control variable after the for's body is a compilation error.*

All three expressions in a `for` header are *optional*. If the `loopContinuationCondition` is omitted, C# assumes that it's *always true*, thus creating an *infinite loop*. You can omit the `initialization` expression if the app initializes the control variable *before* the loop—in this case, the scope of the control variable will *not* be limited to the loop. You can omit the `increment` expression if the app calculates the increment with statements in the loop's body or if no increment is needed. The increment expression in a `for` acts as if it were a stand-alone statement at the end of the `for`'s body. Therefore, the expressions

```
counter = counter + 1
counter += 1
++counter
counter++
```

are equivalent increment expressions in a `for` statement. Many programmers prefer `counter++` because it's concise and because a `for` loop evaluates its increment expression after its body executes—so the postfix increment form *seems* more natural. In this case, the variable being incremented does not appear in a larger expression, so the prefix and postfix increment operators have the *same* effect.



### Performance Tip 6.1

*There's a slight performance advantage to using the prefix increment operator, but if you choose the postfix increment operator because it seems more natural (as in a for header), optimizing compilers will generate code that uses the more efficient form anyway.*



### Error-Prevention Tip 6.3

*Infinite loops occur when the loop-continuation condition in a repetition statement never becomes false. To prevent this situation in a counter-controlled loop, ensure that the control variable is incremented (or decremented) during each iteration of the loop. In a sentinel-controlled loop, ensure that the sentinel value is eventually input.*

The initialization, loop-continuation condition and increment portions of a `for` statement can contain arithmetic expressions. For example, assume that `x = 2` and `y = 10`; if `x` and `y` are not modified in the body of the loop, then the statement

```
for ( int j = x; j <= 4 * x * y; j += y / x )
```

is equivalent to the statement

```
for ( int j = 2; j <= 80; j += 5 )
```

The increment of a `for` statement may also be *negative*, in which case it's actually a *decrement*, and the loop counts downward.

If the loop-continuation condition is initially `false`, the app does *not* execute the `for` statement's body. Instead, execution proceeds with the statement following the `for`.

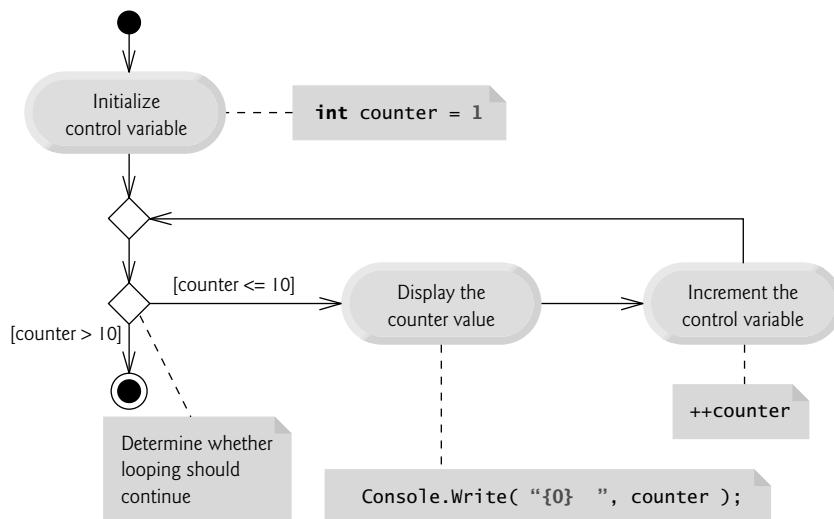
Apps frequently display the control variable value or use it in calculations in the loop body, but this use is not required. The control variable is commonly used to control repetition without being mentioned in the body of the `for`.



### Error-Prevention Tip 6.4

*Although the value of the control variable can be changed in the body of a `for` loop, avoid doing so, because this can lead to subtle errors.*

Figure 6.4 shows the activity diagram of the `for` statement in Fig. 6.2. The diagram makes it clear that initialization occurs *only once* before the loop-continuation test is evaluated the first time, and that incrementing occurs *each* time through the loop after the body statement executes.



**Fig. 6.4** | UML activity diagram for the `for` statement in Fig. 6.2.

## 6.4 Examples Using the for Statement

The following examples show techniques for varying the control variable in a `for` statement. In each case, we write the appropriate `for` header. Note the change in the relational operator for loops that decrement the control variable.

- Vary the control variable from 1 to 100 in increments of 1.

```
for ( int i = 1; i <= 100; ++i )
```

- Vary the control variable from 100 to 1 in decrements of 1.

```
for ( int i = 100; i >= 1; --i )
```

- Vary the control variable from 7 to 77 in increments of 7.

```
for ( int i = 7; i <= 77; i += 7 )
```

- d) Vary the control variable from 20 to 2 in decrements of 2.

```
for ( int i = 20; i >= 2; i -= 2 )
```

- e) Vary the control variable over the sequence 2, 5, 8, 11, 14, 17, 20.

```
for ( int i = 2; i <= 20; i += 3 )
```

- f) Vary the control variable over the sequence 99, 88, 77, 66, 55, 44, 33, 22, 11, 0.

```
for ( int i = 99; i >= 0; i -= 11 )
```



### Common Programming Error 6.2

*Not using the proper relational operator in the loop-continuation condition of a loop that counts downward (e.g., using `i <= 1` instead of `i >= 1` in a loop counting down to 1) is a logic error.*

#### *App: Summing the Even Integers from 2 to 20*

We now consider two sample apps that demonstrate simple uses of `for`. The app in Fig. 6.5 uses a `for` statement to sum the even integers from 2 to 20 and store the result in an `int` variable called `total`.

---

```

1 // Fig. 6.5: Sum.cs
2 // Summing integers with the for statement.
3 using System;
4
5 public class Sum
6 {
7     public static void Main( string[] args )
8     {
9         int total = 0; // initialize total
10
11        // total even integers from 2 through 20
12        for ( int number = 2; number <= 20; number += 2 )
13            total += number;
14
15        Console.WriteLine( "Sum is {0}", total ); // display results
16    } // end Main
17 } // end class Sum

```

```
Sum is 110
```

**Fig. 6.5** | Summing integers with the `for` statement.

The *initialization* and *increment* expressions can be *comma-separated lists* that enable you to use *multiple* initialization expressions or *multiple* increment expressions. For example, you could merge the body of the `for` statement in lines 12–13 of Fig. 6.5 into the increment portion of the `for` header by using a comma as follows:

```
for ( int number = 2; number <= 20; total += number, number += 2 )
    ; // empty statement
```

We prefer *not* complicating `for` headers in this manner.

***App: Compound-Interest Calculations***

The next app uses the **for** statement to compute compound interest. Consider the following problem:

*A person invests \$1,000 in a savings account yielding 5% interest, compounded yearly. Assuming that all the interest is left on deposit, calculate and display the amount of money in the account at the end of each year for 10 years. Use the following formula to determine the amounts:*

$$a = p (1 + r)^n$$

where

*p* is the original amount invested (i.e., the principal)

*r* is the annual interest rate (e.g., use 0.05 for 5%)

*n* is the number of years

*a* is the amount on deposit at the *n*th year.

This problem involves a loop that performs the indicated calculation for each of the 10 years the money remains on deposit. The solution is the app shown in Fig. 6.6. Lines 9–11 in method **Main** declare decimal variables **amount** and **principal**, and double variable **rate**. Lines 10–11 also initialize **principal** to 1000 (i.e., \$1000.00) and **rate** to 0.05. C# treats real-number constants like 0.05 as type **double**. Similarly, C# treats whole-number constants like 7 and 1000 as type **int**. When **principal** is initialized to 1000, the value 1000 of type **int** is *promoted* to a **decimal** type *implicitly*—no cast is required.

---

```

1 // Fig. 6.6: Interest.cs
2 // Compound-interest calculations with for.
3 using System;
4
5 public class Interest
6 {
7     public static void Main( string[] args )
8     {
9         decimal amount; // amount on deposit at end of each year
10        decimal principal = 1000; // initial amount before interest
11        double rate = 0.05; // interest rate
12
13        // display headers
14        Console.WriteLine( "Year{0,20}", "Amount on deposit" );
15
16        // calculate amount on deposit for each of ten years
17        for ( int year = 1; year <= 10; ++year )
18        {
19            // calculate new amount for specified year
20            amount = principal *
21                ( ( decimal ) Math.Pow( 1.0 + rate, year ) );
22
23            // display the year and the amount
24            Console.WriteLine( "{0,4}{1,20:C}", year, amount );
25        } // end for
26    } // end Main
27 } // end class Interest

```

---

**Fig. 6.6** | Compound-interest calculations with **for**. (Part I of 2.)

| Year | Amount on deposit |
|------|-------------------|
| 1    | \$1,050.00        |
| 2    | \$1,102.50        |
| 3    | \$1,157.63        |
| 4    | \$1,215.51        |
| 5    | \$1,276.28        |
| 6    | \$1,340.10        |
| 7    | \$1,407.10        |
| 8    | \$1,477.46        |
| 9    | \$1,551.33        |
| 10   | \$1,628.89        |

**Fig. 6.6** | Compound-interest calculations with `for`. (Part 2 of 2.)

Line 14 outputs the headers for the app’s two columns of output. The first column displays the year, and the second displays the amount on deposit at the end of that year. We use the format item `{0,20}` to output the string "Amount on deposit". The integer 20 after the comma indicates that the value output should be displayed with a field width of 20—that is, `WriteLine` displays the value with at least 20 character positions. If the value to be output is *less than* 20 character positions wide (17 characters in this example), the value is **right justified** in the field by default (in this case the value is preceded by three blanks). If the year value to be output were *more* than four character positions wide, the field width would be *extended to the right* to accommodate the entire value—this would push the amount field to the right, upsetting the neat columns of our tabular output. To indicate that output should be **left justified**, simply use a *negative* field width.

The `for` statement (lines 17–25) executes its body 10 times, varying control variable `year` from 1 to 10 in increments of 1. This loop terminates when control variable `year` becomes 11. (`year` corresponds to  $n$  in the problem statement.)

Classes provide methods that perform common tasks on objects. In fact, most methods must be called on a specific object. For example, to output a greeting in Fig. 4.2, we called method `DisplayMessage` on the `myGradeBook` object. Many classes also provide methods that perform common tasks and cannot be called on objects—they *must* be called using a class name. Such methods are called **static methods**. For example, C# does not include an exponentiation operator, so the designers of C#'s `Math` class defined `static` method `Pow` for raising a value to a power. You can call a `static` method by specifying the class name followed by the member access (.) operator and the method name, as in

```
ClassName.MethodName( arguments )
```

Console methods `Write` and `WriteLine` are `static` methods. In Chapter 7, you’ll learn how to implement `static` methods in your own classes.

We use `static` method `Pow` of class `Math` to perform the compound interest calculation in Fig. 6.6. `Math.Pow(x, y)` calculates the value of  $x$  raised to the  $y$ th power. The method receives two `double` arguments and returns a `double` value. Lines 20–21 perform the calculation  $a = p(1 + r)^n$ , where  $a$  is the amount,  $p$  is the principal,  $r$  is the rate and  $n$  is the year. Notice that, in this calculation, we need to multiply a `decimal` value (`principal`) by a `double` value (the return value of `Math.Pow`). C# will not implicitly convert `double` to a `decimal` type, or vice versa, because of the *possible loss of information* in either conversion, so line 21 contains a (`decimal`) cast operator that explicitly converts the `double` return value of `Math.Pow` to a `decimal`.

After each calculation, line 24 outputs the year and the amount on deposit at the end of that year. The year is output in a field width of four characters (as specified by {0,4}). The amount is output as a currency value with the format item {1,20:C}. The number 20 in the format item indicates that the value should be output *right justified* with a field width of 20 characters. The format specifier C indicates that the number should be formatted as currency.

Notice that we declared the variables `amount` and `principal` to be of type `decimal` rather than `double`. Recall that we introduced type `decimal` for monetary calculations in Section 4.11. We also use `decimal` in Fig. 6.6 for this purpose. You may be curious as to why we do this. We're dealing with fractional parts of dollars and thus need a type that allows decimal points in its values. Unfortunately, floating-point numbers of type `double` (or `float`) can cause trouble in monetary calculations. Two `double` dollar amounts stored in the machine could be 14.234 (which would normally be rounded to 14.23 for display purposes) and 18.673 (which would normally be rounded to 18.67 for display purposes). When these amounts are added, they produce the internal sum 32.907, which would normally be rounded to 32.91 for display purposes. Thus, your output could appear as

```
14.23
+
18.67
-----
32.91
```

but a person adding the individual numbers as displayed would expect the sum to be 32.90. You've been warned! For people who work with programming languages that do not support a type for precise monetary calculations, Exercise 6.18 explores the use of integers to perform such calculations.



### Error-Prevention Tip 6.5

*Do not use variables of type `double` (or `float`) to perform precise monetary calculations; use type `decimal` instead. The imprecision of floating-point numbers can cause errors that will result in incorrect monetary values.*

The body of the `for` statement contains the calculation `1.0 + rate`, which appears as an argument to the `Math.Pow` method. In fact, this calculation produces the same result each time through the loop, so repeating the calculation in every iteration of the loop is wasteful.



### Performance Tip 6.2

*In loops, avoid calculations for which the result never changes—such calculations should typically be placed before the loop. Optimizing compilers will typically place such calculations outside loops in the compiled code.*

## 6.5 do...while Repetition Statement

The `do...while` repetition statement is similar to the `while` statement. In the `while`, the app tests the loop-continuation condition at the beginning of the loop, *before* executing the loop's body. If the condition is false, the body *never* executes. The `do...while` statement tests the loop-continuation condition *after* executing the loop's body; therefore, the body always executes *at least once*. When a `do...while` statement terminates, execution

continues with the next statement in sequence. Figure 6.7 uses a do...while (lines 11–15) to output the numbers 1–10.

```

1 // Fig. 6.7: DoWhileTest.cs
2 // do...while repetition statement.
3 using System;
4
5 public class DoWhileTest
6 {
7     public static void Main( string[] args )
8     {
9         int counter = 1; // initialize counter
10
11         do
12         {
13             Console.WriteLine( "{0} ", counter );
14             ++counter;
15         } while ( counter <= 10 ); // end do...while
16
17         Console.WriteLine(); // outputs a newline
18     } // end Main
19 } // end class DoWhileTest

```

```
1 2 3 4 5 6 7 8 9 10
```

**Fig. 6.7** | do...while repetition statement.

Line 9 declares and initializes control variable `counter`. Upon entering the do...while statement, line 13 outputs `counter`'s value, and line 14 increments `counter`. Then the app evaluates the loop-continuation test at the *bottom* of the loop (line 15). If the condition is true, the loop continues from the first body statement (line 13). If the condition is false, the loop terminates, and the app continues with the next statement after the loop.

Figure 6.8 contains the UML activity diagram for the do...while statement. This diagram makes it clear that the loop-continuation condition is not evaluated until *after* the loop performs the action state *at least once*. Compare this activity diagram with that of the `while` statement (Fig. 5.4). It's not necessary to use braces in the do...while repetition statement if there's only one statement in the body. However, most programmers include the braces to avoid confusion between the `while` and do...while statements. For example,

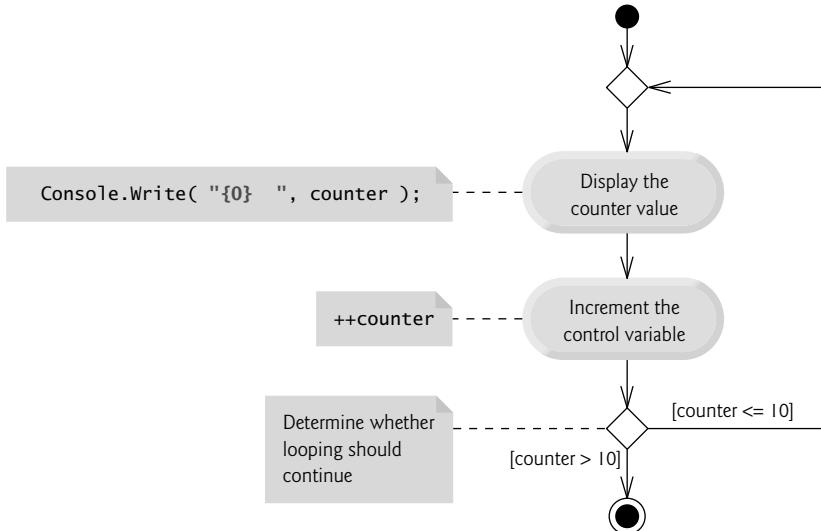
```
while ( condition )
```

is normally the first line of a `while` statement. A do...while statement with no braces around a single-statement body appears as:

```
do
    statement
    while ( condition );
```

which can be confusing. A reader may misinterpret the last line—`while( condition );`—as a `while` statement containing an empty statement (the semicolon by itself). To avoid confusion, a do...while statement with one body statement can be written as follows:

```
do
{
    statement
} while ( condition );
```



**Fig. 6.8** | do...while repetition statement UML activity diagram.

## 6.6 switch Multiple-Selection Statement

We discussed the `if` single-selection statement and the `if...else` double-selection statement in Chapter 5. C# provides the `switch` multiple-selection statement to perform different actions based on the possible values of an expression. Each action is associated with the value of a **constant integral expression** or a **constant string expression** that the variable or expression on which the `switch` is based may assume. A constant integral expression is any expression involving character and integer constants that evaluates to an integer value—i.e., values of type `sbyte`, `byte`, `short`, `ushort`, `int`, `uint`, `long`, `ulong` and `char`, or a constant from an `enum` type (`enum` is discussed in Section 7.10). A constant string expression is any expression composed of `string` literals that always results in the same `string`.

### **GradeBook Class with switch Statement to Count A, B, C, D and F Grades.**

Figure 6.9 contains an enhanced version of the `GradeBook` class introduced in Chapter 4 and further developed in Chapter 5. This version of the class not only calculates the average of a set of numeric grades entered by the user, but uses a `switch` statement to determine whether each grade is the equivalent of an A, B, C, D or F, then increments the appropriate grade counter. The class also displays a summary of the number of students who received each grade. Figure 6.10 shows sample input and output of the `GradeBookTest` app that uses class `GradeBook` to process a set of grades.

```
1 // Fig. 6.9: GradeBook.cs
2 // GradeBook class that uses a switch statement to count letter grades.
3 using System;
4
5 public class GradeBook
6 {
7     private int total; // sum of grades
8     private int gradeCounter; // number of grades entered
9     private int aCount; // count of A grades
10    private int bCount; // count of B grades
11    private int cCount; // count of C grades
12    private int dCount; // count of D grades
13    private int fCount; // count of F grades
14
15    // automatic property CourseName
16    public string CourseName { get; set; }
17
18    // constructor initializes automatic property CourseName;
19    // int instance variables are initialized to 0 by default
20    public GradeBook( string name )
21    {
22        CourseName = name; // set CourseName to name
23    } // end constructor
24
25    // display a welcome message to the GradeBook user
26    public void DisplayMessage()
27    {
28        // CourseName gets the name of the course
29        Console.WriteLine( "Welcome to the grade book for\n{0}!\n",
30                           CourseName );
31    } // end method DisplayMessage
32
33    // input arbitrary number of grades from user
34    public void InputGrades()
35    {
36        int grade; // grade entered by user
37        string input; // text entered by the user
38
39        Console.WriteLine( "{0}\n{1}",
40                           "Enter the integer grades in the range 0-100.",
41                           "Type <Ctrl> z and press Enter to terminate input:" );
42
43        input = Console.ReadLine(); // read user input
44
45        // loop until user enters the end-of-file indicator (<Ctrl> z)
46        while ( input != null )
47        {
48            grade = Convert.ToInt32( input ); // read grade off user input
49            total += grade; // add grade to total
50            ++gradeCounter; // increment number of grades
51        }
```

**Fig. 6.9** | GradeBook class that uses a switch statement to count letter grades. (Part I of 3.)

```
52         // call method to increment appropriate counter
53         IncrementLetterGradeCounter( grade );
54
55         input = Console.ReadLine(); // read user input
56     } // end while
57 } // end method InputGrades
58
59 // add 1 to appropriate counter for specified grade
60 private void IncrementLetterGradeCounter( int grade )
61 {
62     // determine which grade was entered
63     switch ( grade / 10 )
64     {
65         case 9: // grade was in the 90s
66         case 10: // grade was 100
67             ++aCount; // increment aCount
68             break; // necessary to exit switch
69         case 8: // grade was between 80 and 89
70             ++bCount; // increment bCount
71             break; // exit switch
72         case 7: // grade was between 70 and 79
73             ++cCount; // increment cCount
74             break; // exit switch
75         case 6: // grade was between 60 and 69
76             ++dCount; // increment dCount
77             break; // exit switch
78         default: // grade was less than 60
79             ++fCount; // increment fCount
80             break; // exit switch
81     } // end switch
82 } // end method IncrementLetterGradeCounter
83
84 // display a report based on the grades entered by the user
85 public void DisplayGradeReport()
86 {
87     Console.WriteLine( "\nGrade Report:" );
88
89     // if user entered at least one grade...
90     if ( gradeCounter != 0 )
91     {
92         // calculate average of all grades entered
93         double average = ( double ) total / gradeCounter;
94
95         // output summary of results
96         Console.WriteLine( "Total of the {0} grades entered is {1}",
97                           gradeCounter, total );
98         Console.WriteLine( "Class average is {0:F}", average );
99         Console.WriteLine( "{0}A: {1}\nB: {2}\nC: {3}\nD: {4}\nF: {5}",
100                      "Number of students who received each grade:\n",
101                      aCount, // display number of A grades
102                      bCount, // display number of B grades
```

Fig. 6.9 | GradeBook class that uses a `switch` statement to count letter grades. (Part 2 of 3.)

---

```

103         cCount, // display number of C grades
104         dCount, // display number of D grades
105         fCount ); // display number of F grades
106     } // end if
107     else // no grades were entered, so output appropriate message
108         Console.WriteLine( "No grades were entered" );
109     } // end method DisplayGradeReport
110 } // end class GradeBook

```

---

**Fig. 6.9** | GradeBook class that uses a switch statement to count letter grades. (Part 3 of 3.)

### *Instance Variables*

Class GradeBook (Fig. 6.9) declares instance variables total (line 7) and gradeCounter (line 8), which keep track of the sum of the grades entered by the user and the number of grades entered, respectively. Lines 9–13 declare counter variables for each grade category. Class GradeBook maintains total, gradeCounter and the five letter-grade counters as instance variables so that they can be used or modified in any of the class's methods.

### *Property CourseName, Method DisplayMessage and the Constructor*

Like earlier versions of the class, class GradeBook declares automatic property CourseName (line 16) and method DisplayMessage (lines 26–31) to display a welcome message to the user. The class also contains a constructor (lines 20–23) that initializes the course name. The constructor sets only the course name—the remaining seven instance variables are ints and are initialized to 0 by default.

### *Methods InputGrades and DisplayGradeReport*

Class GradeBook contains three additional methods—InputGrades, IncrementLetterGradeCounter and DisplayGradeReport. Method InputGrades (lines 34–57) reads an arbitrary number of integer grades from the user using sentinel-controlled repetition and updates instance variables total and gradeCounter. Method InputGrades calls method IncrementLetterGradeCounter (lines 60–82) to update the appropriate letter-grade counter for each grade entered. Class GradeBook also contains method DisplayGradeReport (lines 85–109), which outputs a report containing the total of all grades entered, the average of the grades and the number of students who received each letter grade. Let's examine these methods in more detail.

Lines 36–37 in method InputGrades declare variables grade and input, which will first store the user's input as a string (in the variable input), then convert it to an int to store in the variable grade. Lines 39–41 prompt the user to enter integer grades and to type *Ctrl + z*, then press *Enter* to terminate the input. The notation *Ctrl + z* means to simultaneously press both the *Ctrl* key and the *z* key when typing in a **Command Prompt**. *Ctrl + z* is the Windows key sequence for typing the **end-of-file indicator**. This is one way to inform an app that there's no more data to input. If *Ctrl + z* is entered while the app is awaiting input with a ReadLine method, null is returned. (The end-of-file indicator is a system-dependent keystroke combination. On many non-Windows systems, end-of-file is entered by typing *Ctrl + d*.) In Chapter 17, Files and Streams, we'll see how the end-of-file indicator is used when an app reads its input from a file. Windows typically displays

the characters ^Z in a **Command Prompt** when the end-of-file indicator is typed, as shown in the output of Fig. 6.10.

Line 43 uses the `ReadLine` method to get the first line that the user entered and store it in variable `input`. The `while` statement (lines 46–56) processes this user input. The condition at line 46 checks whether the value of `input` is `null`. The `Console` class's `ReadLine` method returns `null` only if the user typed an end-of-file indicator. As long as the end-of-file indicator has not been typed, `input` will not be `null`, and the condition will pass.

Line 48 converts the `string` in `input` to an `int` type. Line 49 adds `grade` to `total`. Line 50 increments `gradeCounter`. The class's `DisplayGradeReport` method uses these variables to compute the average of the grades. Line 53 calls the class's `IncrementLetterGradeCounter` method (declared in lines 60–82) to increment the appropriate letter-grade counter, based on the numeric grade entered.

### **Method IncrementLetterGradeCounter**

Method `IncrementLetterGradeCounter` contains a `switch` statement (lines 63–81) that determines which counter to increment. In this example, we assume that the user enters a valid grade in the range 0–100. A grade in the range 90–100 represents A, 80–89 represents B, 70–79 represents C, 60–69 represents D and 0–59 represents F. The `switch` statement consists of a block that contains a sequence of `case` labels and an optional `default` label. These are used in this example to determine which counter to increment based on the grade.

### **The switch Statement**

When control reaches the `switch` statement, the app evaluates the expression in the parentheses (`grade / 10`) following keyword `switch`—this is called the **switch expression**. The app attempts to match the value of the `switch` expression with one of the `case` labels. The `switch` expression in line 63 performs integer division, which *truncates* the fractional part of the result. Thus, when we divide any value in the range 0–100 by 10, the result is always a value from 0 to 10. We use several of these values in our `case` labels. For example, if the user enters the integer 85, the `switch` expression evaluates to `int` value 8. If a match occurs between the `switch` expression and a `case` (case 8: at line 69), the app executes the statements for that case. For the integer 8, line 70 increments `bCount`, because a grade in the 80s is a B. The **break statement** (line 71) causes program control to proceed with the first statement after the `switch`—in this app, we reach the end of method `IncrementLetterGradeCounter`'s body, so control returns to line 55 in method `InputGrades` (the first line after the call to `IncrementLetterGradeCounter`). This line uses the `ReadLine` method to read the next line entered by the user and assign it to the variable `input`. Line 56 marks the end of the body of the `while` statement that inputs grades (lines 46–56), so control flows to the `while`'s condition (line 46) to determine whether the loop should continue executing based on the value just assigned to the variable `input`.

### **Consecutive case Labels**

The cases in our `switch` explicitly test for the values 10, 9, 8, 7 and 6. Note the `case` labels at lines 65–66 that test for the values 9 and 10 (both of which represent the grade A). Listing `case` labels consecutively in this manner with no statements between them enables the cases to perform the same set of statements—when the `switch` expression evaluates to 9 or 10, the statements in lines 67–68 execute. The `switch` statement does not provide a mechanism for testing ranges of values, so every value to be tested must be listed in a separate `case` label.

Each case can have multiple statements. The `switch` statement differs from other control statements in that it does *not* require braces around multiple statements in each case.

### *No “Fall Through” in the C# `switch` Statement*

In C, C++, and many other programming languages that use the `switch` statement, the `break` statement *is not* required at the end of a case. Without `break` statements, each time a match occurs in the `switch`, the statements for that case and subsequent cases execute until a `break` statement or the end of the `switch` is encountered. This is often referred to as “falling through” to the statements in subsequent cases. This leads to logic errors when you forget the `break` statement. C# is different from other programming languages—after the statements in a case, you’re required to include a statement that terminates the case, such as a `break`, a `return` or a `throw`; otherwise, a compilation error occurs (We discuss the `throw` statement in Chapter 13, Exception Handling: A Deeper Look.)

### *The `default` Case*

If no match occurs between the `switch` expression’s value and a case label, the statements after the `default` label (lines 79–80) execute. We use the `default` label in this example to process all `switch-expression` values that are less than 6—that is, all failing grades. If no match occurs and the `switch` does *not* contain a `default` label, program control simply continues with the first statement (if there’s one) after the `switch` statement.

### *GradeBookTest Class That Demonstrates Class GradeBook*

Class `GradeBookTest` (Fig. 6.10) creates a `GradeBook` object (lines 10–11). Line 13 invokes the object’s `DisplayMessage` method to output a welcome message to the user. Line 14 invokes the object’s `InputGrades` method to read a set of grades from the user and keep track of the sum of all the grades entered and the number of grades. Recall that method `InputGrades` also calls method `IncrementLetterGradeCounter` to keep track of the number of students who received each letter grade. Line 15 invokes method `DisplayGradeReport` of class `GradeBook`, which outputs a report based on the grades entered. Line 90 of class `GradeBook` (Fig. 6.9) determines whether the user entered at least one grade—this avoids dividing by zero. If so, line 93 calculates the average of the grades. Lines 96–105 then output the total of all the grades, the class average and the number of students who received each letter grade. If no grades were entered, line 108 outputs an appropriate message. The output in Fig. 6.10 shows a sample grade report based on 9 grades.

---

```

1 // Fig. 6.10: GradeBookTest.cs
2 // Create GradeBook object, input grades and display grade report.
3
4 public class GradeBookTest
5 {
6     public static void Main( string[] args )
7     {
8         // create GradeBook object myGradeBook and
9         // pass course name to constructor
10        GradeBook myGradeBook = new GradeBook(
11            "CS101 Introduction to C# Programming" );

```

---

**Fig. 6.10** | Create `GradeBook` object, input grades and display grade report. (Part 1 of 2.)

```

12     myGradeBook.DisplayMessage(); // display welcome message
13     myGradeBook.InputGrades(); // read grades from user
14     myGradeBook.DisplayGradeReport(); // display report based on grades
15
16 } // end Main
17 } // end class GradeBookTest

```

Welcome to the grade book for  
CS101 Introduction to C# Programming!

Enter the integer grades in the range 0-100.  
Type <Ctrl> z and press Enter to terminate input:

```

99
92
45
100
57
63
76
14
92
^Z

```

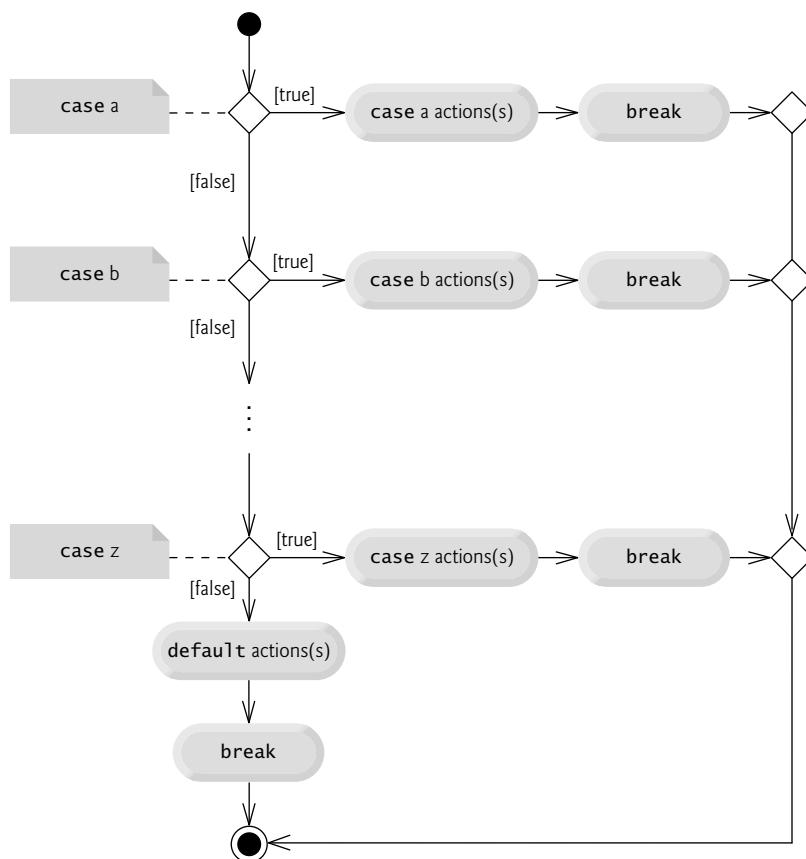
Grade Report:  
Total of the 9 grades entered is 638  
Class average is 70.89  
Number of students who received each grade:  
A: 4  
B: 0  
C: 1  
D: 1  
F: 3

**Fig. 6.10** | Create GradeBook object, input grades and display grade report. (Part 2 of 2.)

Class GradeBookTest (Fig. 6.10) does not directly call GradeBook method IncrementLetterGradeCounter (lines 60–82 of Fig. 6.9). This method is used exclusively by method InputGrades of class GradeBook to update the appropriate letter-grade counter as each new grade is entered by the user. Method IncrementLetterGradeCounter exists solely to support the operations of class GradeBook’s other methods and thus is declared **private**. Members of a class declared with access modifier **private** can be accessed only by members of the class in which the **private** members are declared. When a **private** member is a method, it’s commonly referred to as a **utility method** or **helper method**, because it can be called *only* by other members of that class and is used to support the operation of those other members.

### **switch Statement UML Activity Diagram**

Figure 6.11 shows the UML activity diagram for the general switch statement. Every set of statements after a case label normally ends its execution with a **break** or **return** statement to terminate the **switch** statement after processing the case. Typically, you’ll use **break** statements. Figure 6.11 emphasizes this by including **break** statements in the activity diagram. The diagram makes it clear that the **break** statement at the end of a **case** causes control to exit the **switch** statement immediately.



**Fig. 6.11** | switch multiple-selection statement UML activity diagram with break statements.



### Good Programming Practice 6.1

Although each case and the default label in a switch can occur in any order, place the default label last for clarity.

When using the `switch` statement, remember that the expression after each `case` can be only a *constant integral expression* or a *constant string expression*—that is, any combination of constants that evaluates to a constant value of an integral or string type. An integer constant is simply an integer value (e.g., `-7`, `0` or `221`). In addition, you can use **character constants**—specific characters in single quotes, such as '`A`', '`'7'` or '`$`'—which represent the integer values of characters. (Appendix C shows the integer values of the characters in the ASCII character set, which is a popular subset of the Unicode character set used by C#.) A *string constant* (or *string literal*) is a sequence of characters in double quotes, such as "`Welcome to C# Programming!`". For strings, you can also use `null`.

The expression in each `case` also can be a **constant**—a value which does not change for the entire app. Constants are declared with the keyword `const` (discussed in Chapter 7). C# also has a feature called *enumerations*, which we also present in Chapter 7. Enumeration

constants can also be used in case labels. In Chapter 12, we present a more elegant way to implement switch logic—we use a technique called *polymorphism* to create apps that are often clearer, easier to maintain and easier to extend than apps using switch logic.

## 6.7 break and continue Statements

In addition to selection and repetition statements, C# provides statements `break` and `continue` to alter the flow of control. The preceding section showed how `break` can be used to terminate a `switch` statement's execution. This section discusses how to use `break` to terminate any repetition statement.

### ***break Statement***

The `break` statement, when executed in a `while`, `for`, `do...while`, `switch`, or `foreach`, causes immediate exit from that statement. Execution typically continues with the first statement after the control statement—you'll see that there are other possibilities as you learn about additional statement types in C#. Common uses of the `break` statement are to escape early from a repetition statement or to skip the remainder of a `switch` (as in Fig. 6.9). Figure 6.12 demonstrates a `break` statement exiting a `for`.

---

```

1 // Fig. 6.12: BreakTest.cs
2 // break statement exiting a for statement.
3 using System;
4
5 public class BreakTest
6 {
7     public static void Main( string[] args )
8     {
9         int count; // control variable also used after loop terminates
10
11         for ( count = 1; count <= 10; ++count ) // loop 10 times
12         {
13             if ( count == 5 ) // if count is 5,
14                 break; // terminate loop
15
16             Console.Write( "{0} ", count );
17         } // end for
18
19         Console.WriteLine( "\nBroke out of loop at count = {0}", count );
20     } // end Main
21 } // end class BreakTest

```

```

1 2 3 4
Broke out of loop at count = 5

```

**Fig. 6.12** | `break` statement exiting a `for` statement.

When the `if` nested at line 13 in the `for` statement (lines 11–17) determines that `count` is 5, the `break` statement at line 14 executes. This terminates the `for` statement, and the app proceeds to line 19 (immediately after the `for` statement), which displays a message indicating the value of the control variable when the loop terminated. The loop fully executes its body only four times instead of 10 because of the `break`.

***continue Statement***

The **continue** statement, when executed in a **while**, **for**, **do...while**, or **foreach**, skips the remaining statements in the loop body and proceeds with the next iteration of the loop. In **while** and **do...while** statements, the app evaluates the loop-continuation test *immediately after* the **continue** statement executes. In a **for** statement, the increment expression normally executes next, then the app evaluates the loop-continuation test.

Figure 6.13 uses the **continue** statement in a **for** to skip the statement at line 14 when the nested **if** (line 11) determines that the value of **count** is 5. When the **continue** statement executes, program control continues with the increment of the control variable in the **for** statement (line 9).

```

1 // Fig. 6.13: ContinueTest.cs
2 // continue statement terminating an iteration of a for statement.
3 using System;
4
5 public class ContinueTest
6 {
7     public static void Main( string[] args )
8     {
9         for ( int count = 1; count <= 10; ++count ) // loop 10 times
10        {
11            if ( count == 5 ) // if count is 5,
12                continue; // skip remaining code in loop
13
14            Console.WriteLine( "{0} ", count );
15        } // end for
16
17        Console.WriteLine( "\nUsed continue to skip displaying 5" );
18    } // end Main
19 } // end class ContinueTest

```

```

1 2 3 4 6 7 8 9 10
Used continue to skip displaying 5

```

**Fig. 6.13 |** *continue* statement terminating an iteration of a **for** statement.

In Section 6.3, we stated that the **while** statement can be used in most cases in place of **for**. One exception occurs when the increment expression in the **while** follows a **continue** statement. In this case, the increment does not execute before the app evaluates the repetition-continuation condition, so the **while** does *not* execute in the same manner as the **for**.

**Software Engineering Observation 6.2**

*Some programmers feel that break and continue statements violate structured programming. Since the same effects are achievable with structured programming techniques, these programmers prefer not to use break or continue statements.*

**Software Engineering Observation 6.3**

*There's a tension between achieving quality software engineering and achieving the best-performing software. Often, one of these goals is achieved at the expense of the other. For all but the most performance-intensive situations, apply the following rule: First, make your code simple and correct; then make it fast, but only if necessary.*

## 6.8 Logical Operators

The if, if...else, while, do...while and for statements each require a condition to determine how to continue an app's flow of control. So far, we've studied only **simple conditions**, such as `count <= 10`, `number != sentinelValue` and `total > 1000`. Simple conditions are expressed in terms of the relational operators `>`, `<`, `>=` and `<=`, and the equality operators `==` and `!=`. Each expression tests only one condition. To test *multiple* conditions in the process of making a decision, we performed these tests in separate statements or in nested if or if...else statements. Sometimes, control statements require more complex conditions to determine an app's flow of control.

C# provides **logical operators** to enable you to form more complex conditions by combining simple conditions. The logical operators are `&&` (conditional AND), `||` (conditional OR), `&` (boolean logical AND), `|` (boolean logical inclusive OR), `^` (boolean logical exclusive OR) and `!` (logical negation).

### *Conditional AND (&&) Operator*

Suppose that we wish to ensure at some point in an app that two conditions are *both* true before we choose a certain path of execution. In this case, we can use the **&&** (conditional AND) operator, as follows:

```
if ( gender == 'F' && age >= 65 )
    ++seniorFemales;
```

This if statement contains two simple conditions. The condition `gender == 'F'` determines whether a person is female. The condition `age >= 65` might be evaluated to determine whether a person is a senior citizen. The if statement considers the combined condition

```
gender == 'F' && age >= 65
```

which is true if and only if *both* simple conditions are true. If the combined condition is true, the if statement's body increments `seniorFemales` by 1. If either or both of the simple conditions are false, the app skips the increment. Some programmers find that the preceding combined condition is more readable when redundant parentheses are added, as in:

```
( gender == 'F' ) && ( age >= 65 )
```

The table in Fig. 6.14 summarizes the `&&` operator. The table shows all four possible combinations of false and true values for `expression1` and `expression2`. Such tables are called **truth tables**. C# evaluates all expressions that include relational operators, equality operators or logical operators to `bool` values—which are either `true` or `false`.

| expression1 | expression2 | expression1 && expression2 |
|-------------|-------------|----------------------------|
| false       | false       | false                      |
| false       | true        | false                      |
| true        | false       | false                      |
| true        | true        | true                       |

**Fig. 6.14** | `&&` (conditional AND) operator truth table.

### *Conditional OR (||) Operator*

Now suppose we wish to ensure that *either or both* of two conditions are true before we choose a certain path of execution. In this case, we use the `||` (conditional OR) operator, as in the following app segment:

```
if ( ( semesterAverage >= 90 ) || ( finalExam >= 90 ) )
    Console.WriteLine ( "Student grade is A" );
```

This statement also contains two simple conditions. The condition `semesterAverage >= 90` is evaluated to determine whether the student deserves an A in the course because of a solid performance throughout the semester. The condition `finalExam >= 90` is evaluated to determine whether the student deserves an A in the course because of an outstanding performance on the final exam. The `if` statement then considers the combined condition

```
( semesterAverage >= 90 ) || ( finalExam >= 90 )
```

and awards the student an A if either or both of the simple conditions are true. The only time the message "Student grade is A" is *not* displayed is when *both* of the simple conditions are *false*. Figure 6.15 is a truth table for operator conditional OR (`||`). Operator `&&` has a higher precedence than operator `||`. Both operators associate from left to right.

| expression1 | expression2 | expression1    expression2 |
|-------------|-------------|----------------------------|
| false       | false       | false                      |
| false       | true        | true                       |
| true        | false       | true                       |
| true        | true        | true                       |

**Fig. 6.15** | `||` (conditional OR) operator truth table.

### *Short-Circuit Evaluation of Complex Conditions*

The parts of an expression containing `&&` or `||` operators are evaluated *only* until it's known whether the condition is true or false. Thus, evaluation of the expression

```
( gender == 'F' ) && ( age >= 65 )
```

stops immediately if `gender` is not equal to 'F' (i.e., at that point, it's certain that the entire expression is `false`) and continues *only* if `gender` is equal to 'F' (i.e., the entire expression could still be `true` if the condition `age >= 65` is `true`). This feature of conditional AND and conditional OR expressions is called **short-circuit evaluation**.



### Common Programming Error 6.3

*In expressions using operator `&&`, a condition—which we refer to as the dependent condition—may require another condition to be true for the evaluation of the dependent condition to be meaningful. In this case, the dependent condition should be placed after the other one, or an error might occur. For example, in the expression `(i != 0) && (10 / i == 2)`, the second condition must appear after the first condition, or a divide-by-zero error might occur.*

***Boolean Logical AND (&) and Boolean Logical OR (|) Operators***

The boolean logical AND (`&`) and boolean logical inclusive OR (`|`) operators work identically to the `&&` (conditional AND) and `||` (conditional OR) operators, with one exception—the boolean logical operators *always evaluate both of their operands* (i.e., they do *not* perform short-circuit evaluation). Therefore, the expression

```
( gender == 'F' ) & ( age >= 65 )
```

evaluates `age >= 65` regardless of whether `gender` is equal to `'F'`. This is useful if the right operand of the boolean logical AND or boolean logical inclusive OR operator has a required **side effect**—such as, a modification of a variable’s value. For example, the expression

```
( birthday == true ) | ( ++age >= 65 )
```

guarantees that the condition `++age >= 65` will be evaluated. Thus, the variable `age` is incremented in the preceding expression, *regardless* of whether the overall expression is `true` or `false`.

**Error-Prevention Tip 6.6**

*For clarity, avoid expressions with side effects in conditions. The side effects may appear clever, but they can make it harder to understand code and can lead to subtle logic errors.*

***Boolean Logical Exclusive OR (^)***

A complex condition containing the boolean logical exclusive OR (`^`) operator (also called the **logical XOR operator**) is `true` *if and only if one of its operands is true and the other is false*. If both operands are `true` or both are `false`, the entire condition is `false`. Figure 6.16 is a truth table for the boolean logical exclusive OR operator (`^`). This operator is also guaranteed to evaluate *both* of its operands.

| expression1 | expression2 | expression1 ^ expression2 |
|-------------|-------------|---------------------------|
| false       | false       | false                     |
| false       | true        | true                      |
| true        | false       | true                      |
| true        | true        | false                     |

**Fig. 6.16** | `^` (boolean logical exclusive OR) operator truth table.

***Logical Negation (!) Operator***

The `!` (logical negation or *not*) operator enables you to “reverse” the meaning of a condition. Unlike the logical operators `&&`, `||`, `&`, `|` and `^`, which are *binary* operators that combine two conditions, the logical negation operator is a *unary* operator that has only a single condition as an operand. The logical negation operator is placed before a condition to choose a path of execution if the original condition (without the logical negation operator) is `false`, as in the code segment

```
if ( ! ( grade == sentinelValue ) )
    Console.WriteLine( "The next grade is {0}", grade );
```

which executes the `WriteLine` call *only if* `grade` is not equal to `sentinelValue`. The parentheses around the condition `grade == sentinelValue` are needed because the logical negation operator has a higher precedence than the equality operator.

In most cases, you can avoid using logical negation by expressing the condition differently with an appropriate relational or equality operator. For example, the previous statement may also be written as follows:

```
if ( grade != sentinelValue )
    Console.WriteLine( "The next grade is {0}", grade );
```

This flexibility can help you express a condition in a more convenient manner. Figure 6.17 is a truth table for the logical negation operator.

| expression | !expression |
|------------|-------------|
| false      | true        |
| true       | false       |

**Fig. 6.17 | ! (logical negation) operator truth table.**

### Logical Operators Example

Figure 6.18 demonstrates the logical operators and boolean logical operators by producing their truth tables. The output shows the expression that was evaluated and the `bool` result of that expression. Lines 10–14 produce the truth table for `&&` (conditional AND). Lines 17–21 produce the truth table for `||` (conditional OR). Lines 24–28 produce the truth table for `&` (boolean logical AND). Lines 31–36 produce the truth table for `|` (boolean logical inclusive OR). Lines 39–44 produce the truth table for `^` (boolean logical exclusive OR). Lines 47–49 produce the truth table for `!` (logical negation).

---

```
1 // Fig. 6.18: LogicalOperators.cs
2 // Logical operators.
3 using System;
4
5 public class LogicalOperators
6 {
7     public static void Main( string[] args )
8     {
9         // create truth table for && (conditional AND) operator
10        Console.WriteLine( "{0}\n{1}: {2}\n{3}: {4}\n{5}: {6}\n{7}: {8}\n",
11                      "Conditional AND (&&)", "false && false", ( false && false ),
12                      "false && true", ( false && true ),
13                      "true && false", ( true && false ),
14                      "true && true", ( true && true ) );
15
16        // create truth table for || (conditional OR) operator
17        Console.WriteLine( "{0}\n{1}: {2}\n{3}: {4}\n{5}: {6}\n{7}: {8}\n",
18                      "Conditional OR (||)", "false || false", ( false || false ),
```

---

**Fig. 6.18 |** Logical operators. (Part 1 of 3.)

```

19      "false || true", ( false || true ),
20      "true || false", ( true || false ),
21      "true || true", ( true || true ) );
22
23      // create truth table for & (boolean logical AND) operator
24      Console.WriteLine( "{0}\n{1}: {2}\n{3}: {4}\n{5}: {6}\n{7}: {8}\n",
25          "Boolean logical AND (&)", "false & false", ( false & false ),
26          "false & true", ( false & true ),
27          "true & false", ( true & false ),
28          "true & true", ( true & true ) );
29
30      // create truth table for | (boolean logical inclusive OR) operator
31      Console.WriteLine( "{0}\n{1}: {2}\n{3}: {4}\n{5}: {6}\n{7}: {8}\n",
32          "Boolean logical inclusive OR (|)",
33          "false | false", ( false | false ),
34          "false | true", ( false | true ),
35          "true | false", ( true | false ),
36          "true | true", ( true | true ) );
37
38      // create truth table for ^ (boolean logical exclusive OR) operator
39      Console.WriteLine( "{0}\n{1}: {2}\n{3}: {4}\n{5}: {6}\n{7}: {8}\n",
40          "Boolean logical exclusive OR (^)",
41          "false ^ false", ( false ^ false ),
42          "false ^ true", ( false ^ true ),
43          "true ^ false", ( true ^ false ),
44          "true ^ true", ( true ^ true ) );
45
46      // create truth table for ! (logical negation) operator
47      Console.WriteLine( "{0}\n{1}: {2}\n{3}: {4}",
48          "Logical negation (!)", "!false", ( !false ),
49          "!true", ( !true ) );
50  } // end Main
51 } // end class LogicalOperators

```

Conditional AND (&&  
 false && false: False  
 false && true: False  
 true && false: False  
 true && true: True

Conditional OR (||)  
 false || false: False  
 false || true: True  
 true || false: True  
 true || true: True

Boolean logical AND (&)  
 false & false: False  
 false & true: False  
 true & false: False  
 true & true: True

**Fig. 6.18** | Logical operators. (Part 2 of 3.)

```

Boolean logical inclusive OR (|)
false | false: False
false | true: True
true | false: True
true | true: True

Boolean logical exclusive OR (^)
false ^ false: False
false ^ true: True
true ^ false: True
true ^ true: False

Logical negation (!)
!false: True
!true: False

```

**Fig. 6.18** | Logical operators. (Part 3 of 3.)

Figure 6.19 shows the precedence and associativity of the C# operators introduced so far. The operators are shown from top to bottom in decreasing order of precedence.

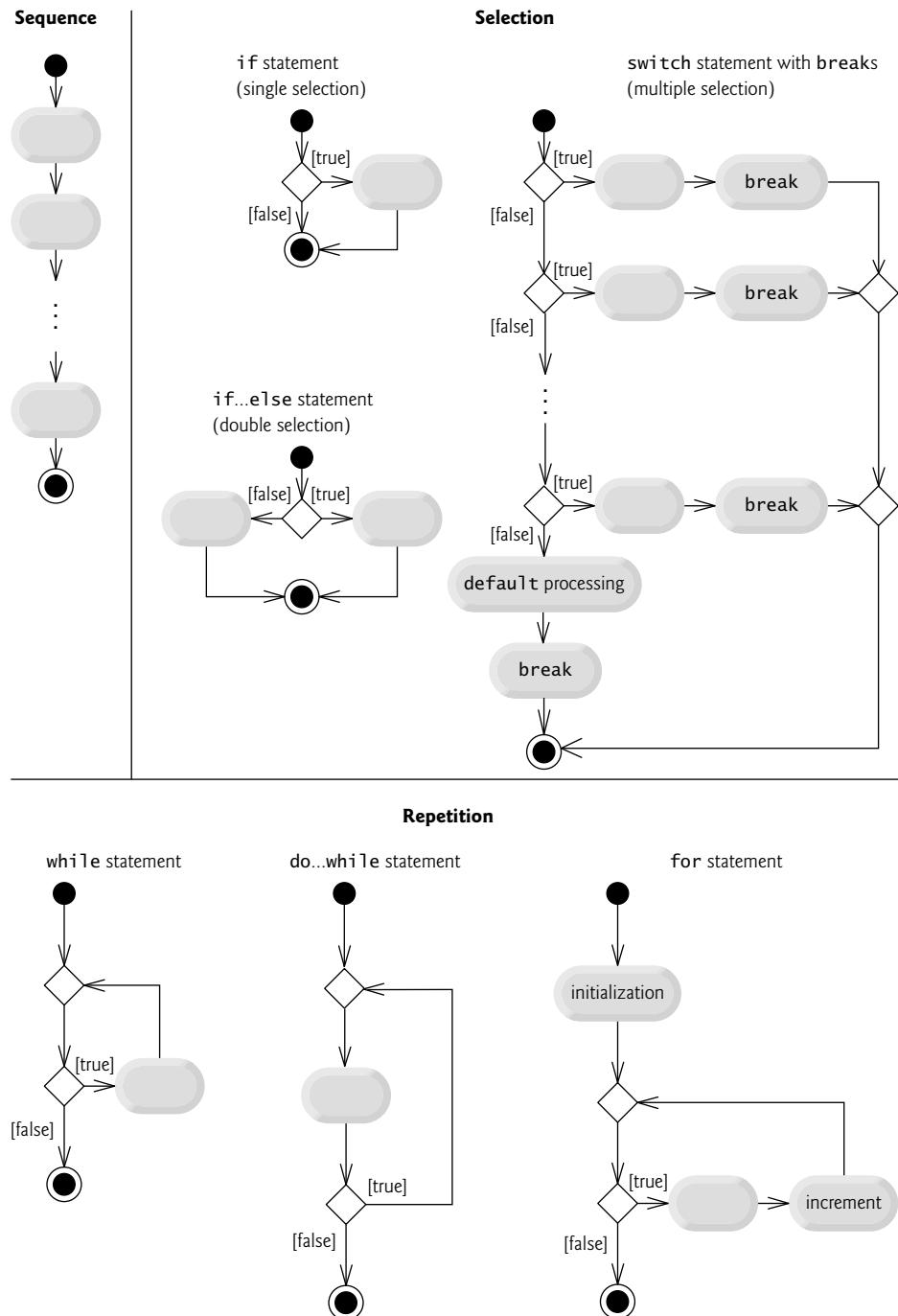
| Operators |                     | Associativity | Type                         |
|-----------|---------------------|---------------|------------------------------|
| .         | new                 | left to right | highest precedence           |
| ++        | --                  | right to left | unary prefix                 |
| *         | /                   | left to right | multiplicative               |
| +         | -                   | left to right | additive                     |
| <         | <=                  | left to right | relational                   |
| ==        | !=                  | left to right | equality                     |
| &         |                     | left to right | boolean logical AND          |
| ^         |                     | left to right | boolean logical exclusive OR |
|           |                     | left to right | boolean logical inclusive OR |
| &&        |                     | left to right | conditional AND              |
|           |                     | left to right | conditional OR               |
| ?:        |                     | right to left | conditional                  |
| =         | + = - = * = / = % = | right to left | assignment                   |

**Fig. 6.19** | Precedence/associativity of the operators discussed so far.

## 6.9 Structured-Programming Summary

Just as architects design buildings by employing the collective wisdom of their profession, so should programmers design apps. Our field is younger than architecture, and our collective wisdom is considerably sparser. We've learned that structured programming produces apps that are easier than unstructured apps to understand, test, debug, modify and even prove correct in a mathematical sense.

Figure 6.20 uses UML activity diagrams to summarize C#'s control statements. The initial and final states indicate the *single entry point* and the *single exit point* of each control statement. Arbitrarily connecting individual symbols in an activity diagram can lead to



**Fig. 6.20** | C#'s sequence, selection and repetition statements.

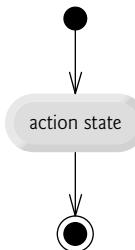
unstructured apps. Therefore, a limited set of control statements can be combined in only two simple ways to build structured apps.

For simplicity, only **single-entry/single-exit control statements** are used—there's *only one* way to enter and *only one* way to exit each control statement. Connecting control statements in sequence to form structured apps is simple. The final state of one control statement is connected to the initial state of the next—that is, the control statements are placed one after another in an app in sequence. We call this *control-statement stacking*. The rules for forming structured apps also allow for control statements to be *nested*.

Figure 6.21 shows the rules for forming structured apps. The rules assume that action states may be used to indicate any action. The rules also assume that we begin with the simplest activity diagram (Fig. 6.22) consisting of only an initial state, an action state, a final state and transition arrows.

| Rules for forming structured apps |                                                                                                                                                                                                                                       |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                                 | Begin with the simplest activity diagram (Fig. 6.22).                                                                                                                                                                                 |
| 2                                 | Any action state can be replaced by two action states in sequence.                                                                                                                                                                    |
| 3                                 | Any action state can be replaced by any control statement (sequence of action states, <i>if</i> , <i>if...else</i> , <i>switch</i> , <i>while</i> , <i>do...while</i> , <i>for</i> or <i>foreach</i> , which we'll see in Chapter 8). |
| 4                                 | Rules 2 and 3 can be applied as often as necessary in any order.                                                                                                                                                                      |

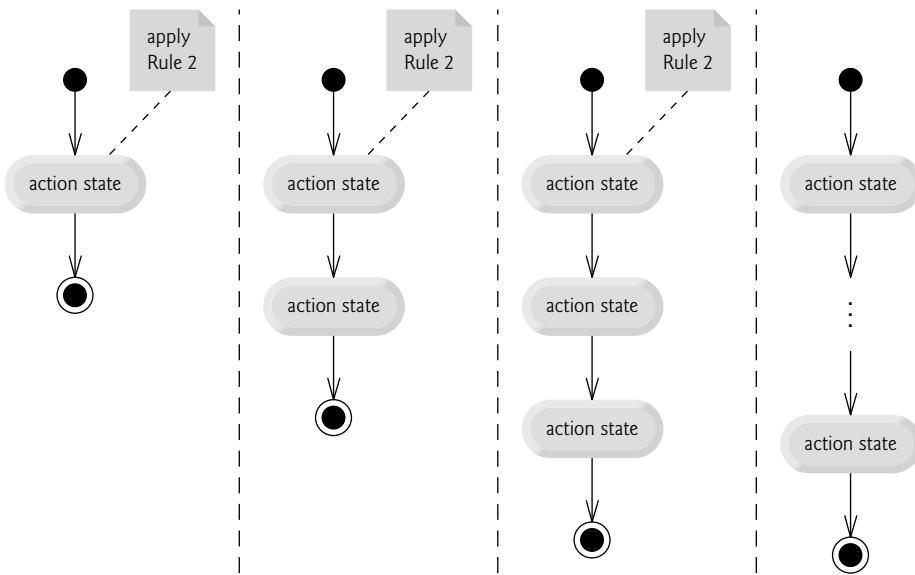
**Fig. 6.21** | Rules for forming structured apps.



**Fig. 6.22** | Simplest activity diagram.

Applying the rules in Fig. 6.21 always results in a properly structured activity diagram with a neat, building-block appearance. For example, repeatedly applying Rule 2 to the simplest activity diagram results in an activity diagram containing many action states in sequence (Fig. 6.23). Rule 2 generates a stack of control statements, so let us call Rule 2 the **stacking rule**. [Note: The vertical dashed lines in Fig. 6.23 are not part of the UML—we use them to separate the four activity diagrams that demonstrate the application of Rule 2 of Fig. 6.21.]

Rule 3 is called the **nesting rule**. Repeatedly applying Rule 3 to the simplest activity diagram results in an activity diagram with neatly **nested control statements**. For example, in Fig. 6.24, the action state in the simplest activity diagram is replaced with a double-selection (*if...else*) statement. Then Rule 3 is applied again to the action states in the



**Fig. 6.23** | Repeatedly applying the stacking rule (Rule 2) of Fig. 6.21 to the simplest activity diagram.

double-selection statement, replacing each of these action states with a double-selection statement. The dashed action-state symbols around each of the double-selection statements represent the action state that was replaced. The dashed arrows and dashed action-state symbols shown in Fig. 6.24 are not part of the UML—they’re used here to illustrate that any action state can be replaced with any control statement.

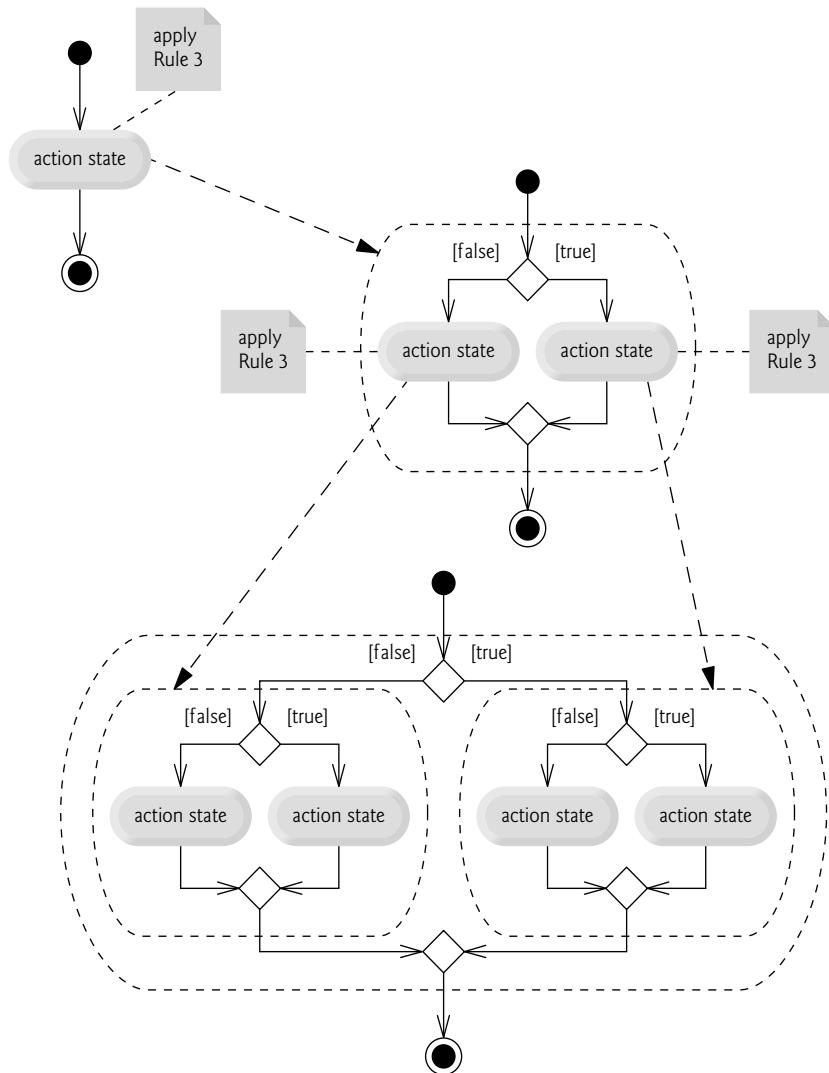
Rule 4 generates larger, more involved and more deeply nested statements. The diagrams that emerge from applying the rules in Fig. 6.21 constitute the set of all possible structured activity diagrams and hence the set of all possible structured apps. The beauty of the structured approach is that we use only eight simple single-entry/single-exit control statements (counting the *foreach* statement, which we introduce in Section 8.6) and assemble them in only two simple ways.

If the rules in Fig. 6.21 are followed, an “unstructured” activity diagram (like the one in Fig. 6.25) cannot be created. If you’re uncertain about whether a particular diagram is structured, apply the rules of Fig. 6.21 *in reverse* to reduce the diagram to the simplest activity diagram. If you *can* reduce it, the original diagram is structured; otherwise, it’s not.

Structured programming promotes simplicity. Research has shown that only three forms of control are needed to implement any algorithm:

- sequence
- selection
- repetition

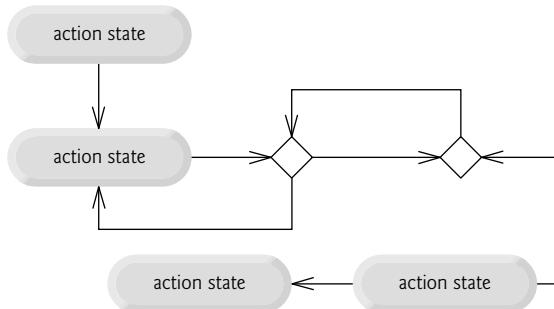
Sequence is trivial. Simply list the statements of the sequence in the order in which they should execute. Selection is implemented in one of three ways:



**Fig. 6.24** | Repeatedly applying Rule 3 of Fig. 6.21 to the simplest activity diagram.

- `if` statement (single selection)
- `if...else` statement (double selection)
- `switch` statement (multiple selection)

In fact, it's straightforward to prove that the simple `if` statement is sufficient to provide any form of selection—everything that can be done with the `if...else` statement and the `switch` statement can be done by combining `if` statements (although perhaps not as clearly and efficiently).



**Fig. 6.25** | “Unstructured” activity diagram.

Repetition is implemented in one of four ways:

- `while` statement
- `do...while`
- `for` statement
- `foreach` statement

It’s straightforward to prove that the `while` statement is sufficient to provide any form of repetition. Everything that can be done with the `do...while`, `for` and `foreach` statements can be done with the `while` statement (although perhaps not as conveniently).

Combining these results illustrates that any form of control ever needed in a C# app can be expressed in terms of

- sequence structure
- `if` statement (selection)
- `while` statement (repetition)

and that these can be combined in only two ways—stacking and nesting. Indeed, structured programming is the essence of simplicity.

## 6.10 Wrap-Up

Chapter 5 discussed the `if`, `if...else` and `while` control statements. In this chapter, we discussed the `for`, `do...while` and `switch` control statements. (We’ll discuss the `foreach` statement in Chapter 8.) You learned that any algorithm can be developed using combinations of sequence (i.e., statements listed in the order in which they should execute), the three selection statements—`if`, `if...else` and `switch`—and the four repetition statements—`while`, `do...while`, `for` and `foreach`. You saw that the `for` and `do...while` statements are simply more convenient ways to express certain types of repetition. Similarly, we showed that the `switch` statement is a convenient notation for multiple selection, rather than using nested `if...else` statements. We discussed how you can combine various control statements by stacking and nesting them. We showed how to use the `break` and `continue` statements to alter the flow of control in repetition statements. You learned about the logical operators, which enable you to use more complex conditional expressions in control statements. In Chapter 7, we examine methods in greater depth.

## Summary

### Section 6.2 Essentials of Counter-Controlled Repetition

- Counter-controlled repetition requires a control variable, the initial value of the control variable, the increment (or decrement) by which the control variable is modified each time through the loop and the loop-continuation condition that determines whether looping should continue.

### Section 6.3 for Repetition Statement

- The for header “does it all”—it specifies each of the items needed for counter-controlled repetition with a control variable. The general format of the for statement is

```
for ( initialization; loopContinuationCondition; increment )  
    statement
```

where the *initialization* expression names the loop’s control variable and provides its initial value, the *loopContinuationCondition* is the condition that determines whether looping should continue and the *increment* modifies the control variable’s value so that the loop-continuation condition eventually becomes false.

- Typically, for statements are used for counter-controlled repetition, and while statements for sentinel-controlled repetition.
- The scope of a variable defines where it can be used in an app. For example, a local variable can be used only in the method that declares the variable and only from the point of declaration through the end of the block in which the variable is declared.
- The increment of a for statement may also be negative, in which case it’s a decrement, and the loop counts downward.
- If the loop-continuation condition is initially false, the for statement’s body doesn’t execute.

### Section 6.4 Examples Using the for Statement

- When a variable of type decimal is initialized to an int value, the value of type int is promoted to a decimal type implicitly—no cast is required.
- In a format item, an integer *n* after a comma indicates that the value output should be displayed with a field width of *n*—that is with at least *n* character positions.
- Values are right justified in a field by default. To indicate that values should be output left justified, simply use a negative field width.
- Methods that must be called using a class name are called static methods.
- C# does not include an exponentiation operator. Instead, `Math.Pow(x, y)` calculates the value of *x* raised to the *y*th power. The method receives two double arguments and returns a double value.
- C# will not implicitly convert a double to a decimal type, or vice versa, because of the possible loss of information in either conversion. To perform this conversion, a cast operator is required.
- Floating-point numbers of type double (or float) can cause trouble in monetary calculations; use type decimal instead.

### Section 6.5 do...while Repetition Statement

- The do...while statement tests the loop-continuation condition *after* executing the loop’s body; therefore, the body always executes at least once.
- The do...while statement has the form:

```
do  
{  
    statement  
} while ( condition );
```

### Section 6.6 **switch** Multiple-Selection Statement

- The **switch** multiple-selection statement performs different actions based on the possible values of an expression.
- Method `Console.ReadLine` returns `null` when the end-of-file key sequence is encountered.
- The **switch** statement consists of a block that contains a sequence of **case** labels and an optional **default** label.
- The expression in parentheses following keyword **switch** is the **switch** expression. The app attempts to match the value of the **switch** expression to a **case** label. If a match occurs, the app executes the statements for that **case**.
- The **switch** statement does not provide a mechanism for testing ranges of values, so every value to be tested must be listed in a separate **case** label.
- After the statements in a **case** execute, you’re required to include a statement that terminates the **case**, such as a **break** or a **return**.
- If no match occurs between the **switch** expression’s value and a **case** label, the statements after the **default** label execute. If no match occurs and the **switch** does not contain a **default** label, program control typically continues with the first statement after the **switch** statement.

### Section 6.7 **break** and **continue** Statements

- The **break** statement causes immediate exit from a **while**, **for**, **do...while**, **switch** or **foreach** statement. Execution typically continues with the first statement after the control statement.
- The **continue** statement, when executed in a **while**, **for**, **do...while** or **foreach**, skips the remaining statements in the loop body and proceeds with the next iteration of the loop. In a **for** statement, the increment is performed before the loop-continuation condition is tested.

### Section 6.8 Logical Operators

- Logical operators enable you to form more complex conditions by combining simple conditions. The logical operators are **&&** (conditional AND), **||** (conditional OR), **&** (boolean logical AND), **|** (boolean logical inclusive OR), **^** (boolean logical exclusive OR) and **!** (logical negation).
- The **&&** (conditional AND) operator ensures that two conditions are *both* true before we choose a certain path of execution.
- The **||** (conditional OR) operator ensures that *either or both* of two conditions are **true** before we choose a certain path of execution.
- The parts of an expression containing **&&** or **||** operators are evaluated only until it’s known whether the condition is **true** or **false**. This feature of conditional AND and conditional OR expressions is called short-circuit evaluation.
- The boolean logical AND (**&**) and boolean logical inclusive OR (**|**) operators work identically to the **&&** (conditional AND) and **||** (conditional OR) operators, but the boolean logical operators always evaluate both of their operands (i.e., they do not perform short-circuit evaluation).
- A complex condition containing the boolean logical exclusive OR (**^**) operator is **true** if and only if one of its operands is **true** and the other is **false**. If both operands are **true** or both are **false**, the entire condition is **false**.
- The **!** (logical negation) operator enables you to “reverse” the meaning of a condition. The logical negation operator is placed before a condition to choose a path of execution if the original condition is **false**. In most cases, you can avoid using logical negation by expressing the condition differently with an appropriate relational or equality operator.

### Section 6.9 Structured-Programming Summary

- Any form of control ever needed in a C# app can be expressed in terms of sequence, the `if` statement (selection) and the `while` statement (repetition). These can be combined in only two ways—stacking and nesting.

## Terminology

|                                                        |                                                  |
|--------------------------------------------------------|--------------------------------------------------|
| <code>!</code> , logical negation operator             | increment a control variable                     |
| <code>&amp;</code> , boolean logical AND operator      | initial value of a control variable              |
| <code>&amp;&amp;</code> , conditional AND operator     | iteration of a loop                              |
| <code> </code> , boolean logical OR operator           | left justified                                   |
| <code>  </code> , conditional OR operator              | logical AND operator ( <code>&amp;&amp;</code> ) |
| <code>^</code> , boolean logical exclusive OR operator | logical negation ( <code>!</code> )              |
| boolean logical AND ( <code>&amp;</code> )             | logical operators                                |
| boolean logical exclusive OR ( <code>^</code> )        | logical OR operator ( <code>  </code> )          |
| boolean logical inclusive OR ( <code> </code> )        | logical XOR operator ( <code>^</code> )          |
| <code>break</code> statement                           | loop-continuation condition                      |
| <code>case</code> label in <code>switch</code>         | multiple-selection statement                     |
| character constant                                     | nested control statements                        |
| conditional AND ( <code>&amp;&amp;</code> )            | nesting rule                                     |
| conditional OR ( <code>  </code> )                     | off-by-one error                                 |
| <code>const</code> keyword                             | repetition statement                             |
| constant                                               | right justified                                  |
| constant integral expression                           | scope of a variable                              |
| constant string expression                             | short-circuit evaluation                         |
| <code>continue</code> statement                        | side effect                                      |
| control variable                                       | simple condition                                 |
| decrement a control variable                           | single-entry/single-exit control statements      |
| <code>default</code> label in <code>switch</code>      | stacked control statements                       |
| <code>do...while</code> repetition statement           | stacking rule                                    |
| end-of-file indicator                                  | <code>static</code> method                       |
| field width                                            | <code>switch</code> expression                   |
| <code>for</code> header                                | <code>switch</code> multiple-selection statement |
| <code>for</code> repetition statement                  | truth table                                      |
| <code>for</code> statement header                      | utility method                                   |
| helper method                                          |                                                  |

## Self-Review Exercises

- 6.1** Fill in the blanks in each of the following statements:
- Typically, \_\_\_\_\_ statements are used for counter-controlled repetition and \_\_\_\_\_ statements are used for sentinel-controlled repetition.
  - The `do...while` statement tests the loop-continuation condition \_\_\_\_\_ executing the loop's body; therefore, the body always executes at least once.
  - The \_\_\_\_\_ statement selects among multiple actions based on the possible values of an integer variable or expression.
  - The \_\_\_\_\_ statement, when executed in a repetition statement, skips the remaining statements in the loop body and proceeds with the next iteration of the loop.
  - The \_\_\_\_\_ operator can be used to ensure that two conditions are *both* true before choosing a certain path of execution.

- f) If the loop-continuation condition in a `for` header is initially \_\_\_\_\_, the `for` statement's body does not execute.
- g) Methods that perform common tasks and cannot be called on objects are called \_\_\_\_\_ methods.
- 6.2** State whether each of the following is *true* or *false*. If *false*, explain why.
- The `default` label is required in the `switch` selection statement.
  - The `break` statement is required in every `case` of a `switch` statement.
  - The expression `(( x > y ) && ( a < b ))` is true if either `(x > y)` is true or `(a < b)` is true.
  - An expression containing the `||` operator is true if either or both of its operands are true.
  - The integer after the comma `(,)` in a format item (e.g., `{0,4}`) indicates the field width of the displayed string.
  - To test for a range of values in a `switch` statement, use a hyphen `(-)` between the start and end values of the range in a `case` label.
  - Listing cases consecutively with no statements between them enables the cases to perform the same set of statements.
- 6.3** Write a C# statement or a set of C# statements to accomplish each of the following tasks:
- Sum the odd integers between 1 and 99, using a `for` statement. Assume that the integer variables `sum` and `count` have been declared.
  - Calculate the value of 2.5 raised to the power of 3, using the `Pow` method.
  - Display the integers from 1 to 20 using a `while` loop and the counter variable `i`. Assume that the variable `i` has been declared, but not initialized. Display only five integers per line. [Hint: Use the calculation `i % 5`. When the value of this expression is 0, display a newline character; otherwise, display a tab character. Use the `Console.WriteLine()` method to output the newline character, and use the `Console.Write('t')` method to output the tab character.]
  - Repeat part (c), using a `for` statement.
- 6.4** Find the error in each of the following code segments and explain how to correct it:
- ```
i = 1;
while ( i <= 10 );
    ++i;
}
```
  - ```
for ( k = 0.1; k != 1.0; k += 0.1 )
    Console.WriteLine( k );
```
  - ```
switch ( n )
{
    case 1:
        Console.WriteLine( "The number is 1" );
    case 2:
        Console.WriteLine( "The number is 2" );
        break;
    default:
        Console.WriteLine( "The number is not 1 or 2" );
        break;
} // end switch
```
  - The following code should display the values 1 to 10:  

```
n = 1;
while ( n < 10 )
    Console.WriteLine( n++ );
```

## Answers to Self-Review Exercises

**6.1** a) for, while. b) after. c) switch. d) continue. e) && (conditional AND) or & (boolean logical AND). f) false. g) static.

**6.2** a) False. The default label is optional. If no default action is needed, then there's no need for a default label. b) False. You could terminate the case with other statements, such as a return. c) False. Both of the relational expressions must be true for this entire expression to be true when using the && operator. d) True. e) True. f) False. The switch statement does not provide a mechanism for testing ranges of values, so you must list every value to test in a separate case label. g) True.

**6.3** a) 

```
sum = 0;
```

```
for ( count = 1; count <= 99; count += 2 )
    sum += count;
```

b) 

```
double result = Math.Pow( 2.5, 3 );
```

c) 

```
i = 1;
```

```
while ( i <= 20 )
{
    Console.Write( i );

    if ( i % 5 == 0 )
        Console.WriteLine();
    else
        Console.Write( '\t' );

    ++i;
} // end while
```

d) 

```
for ( i = 1; i <= 20; ++i )
{
    Console.Write( i );

    if ( i % 5 == 0 )
        Console.WriteLine();
    else
        Console.Write( '\t' );
} // end for
```

**6.4** a) *Error:* The semicolon after the while header causes an infinite loop, and there's a missing left brace for the body of the while statement.

*Correction:* Remove the semicolon and add a { before the loop's body.

b) *Error:* Using a floating-point number to control a for statement may not work, because floating-point numbers are represented only approximately by most computers.

*Correction:* Use an integer, and perform the proper calculation in order to get the values you desire:

```
for ( k = 1; k < 10; ++k )
    Console.WriteLine( ( double ) k / 10 );
```

c) *Error:* case 1 cannot fall through into case 2.

*Correction:* Terminate the case in some way, such as adding a break statement at the end of the statements for the first case.

d) *Error:* The wrong operator is used in the while repetition-continuation condition.

*Correction:* Use <= rather than <, or change 10 to 11.

## Exercises

- 6.5** Describe the four basic elements of counter-controlled repetition.
- 6.6** Compare and contrast the `while` and `for` repetition statements.
- 6.7** Discuss a situation in which it would be more appropriate to use a `do...while` statement than a `while` statement. Explain why.
- 6.8** Compare and contrast the `break` and `continue` statements.
- 6.9** Find and correct the error(s) in each of the following segments of code:
- `For ( i = 100, i >= 1, ++i )`  
`Console.WriteLine( i );`
  - The following code should display whether integer value is odd or even:  

```
switch ( value % 2 )
{
    case 0:
        Console.WriteLine( "Even integer" );
    case 1:
        Console.WriteLine( "Odd integer" );
} // end switch
```
  - The following code should output the odd integers from 19 to 1:  

```
for ( int i = 19; i >= 1; i += 2 )
    Console.WriteLine( i );
```
  - The following code should output the even integers from 2 to 100:  

```
counter = 2;
do
{
    Console.WriteLine( counter );
    counter += 2;
} While ( counter < 100 );
```
- 6.10** (*What Does This Code Do?*) What does the following app do?

---

```

1 // Exercise 6.10 Solution: Printing.cs
2 using System;
3
4 public class Printing
5 {
6     public static void Main( string[] args )
7     {
8         for ( int i = 1; i <= 10; ++i )
9         {
10             for ( int j = 1; j <= 5; ++j )
11                 Console.Write( '@' );
12
13             Console.WriteLine();
14         } // end outer for
15     } // end Main
16 } // end class Printing

```

---

- 6.11** (*Find the Smallest Value*) Write an app that finds the smallest of several integers. Assume that the first value read specifies the number of values to input from the user.
- 6.12** (*Product of Odd Integers*) Write an app that calculates the product of the odd integers from 1 to 7.

**6.13 (Factorials)** Factorials are used frequently in probability problems. The factorial of a positive integer  $n$  (written  $n!$  and pronounced “ $n$  factorial”) is equal to the product of the positive integers from 1 to  $n$ . Write an app that evaluates the factorials of the integers from 1 to 5. Display the results in tabular format. What difficulty might prevent you from calculating the factorial of 20?

**6.14 (Modified Compound Interest Program)** Modify the compound-interest app (Fig. 6.6) to repeat its steps for interest rates of 5, 6, 7, 8, 9 and 10%. Use a `for` loop to vary the rate.

**6.15 (Displaying Triangles)** Write an app that displays the following patterns separately, one below the other. Use `for` loops to generate the patterns. All asterisks (\*) should be displayed by a single statement of the form `Console.WriteLine('*)`; which causes the asterisks to display side by side. A statement of the form `Console.WriteLine()` can be used to move to the next line. A statement of the form `Console.Write(' ')` can be used to display a space for the last two patterns. There should be no other output statements in the app. [Hint: The last two patterns require that each line begin with an appropriate number of blank spaces.]

(a)	(b)	(c)	(d)
*	*****	*****	*
**	*****	*****	**
***	*****	*****	***
****	*****	*****	****
*****	*****	*****	*****
*****	*****	*****	*****
*****	***	***	*****
*****	**	**	*****
*****	*	*	*****

**6.16 (Displaying a Bar Chart)** One interesting application of computers is to display graphs and bar charts. Write an app that reads three numbers between 1 and 30. For each number that’s read, your app should display the same number of adjacent asterisks. For example, if your app reads the number 7, it should display \*\*\*\*\*.

**6.17 (Calculating Sales)** A website sells three products whose retail prices are as follows: product 1, \$2.98; product 2, \$4.50; and product 3, \$9.98. Write an app that reads a series of pairs of numbers as follows:

- a) product number
- b) quantity sold

Your app should use a `switch` statement to determine the retail price for each product. It should calculate and display the total retail value of all products sold. Use a sentinel-controlled loop to determine when the app should stop looping and display the final results.

**6.18 (Modified Compound Interest Program)** In the future, you may work with other programming languages that do not have a type like `decimal` which supports precise monetary calculations. In those languages, you should perform such calculations using integers. Modify the app in Fig. 6.6 to use only integers to calculate the compound interest. Treat all monetary amounts as integral numbers of pennies. Then break the result into its dollars and cents portions by using the division and remainder operations, respectively. Insert a period between the dollars and the cents portions when you display the results.

**6.19** Assume that  $i = 1$ ,  $j = 2$ ,  $k = 3$  and  $m = 2$ . What does each of the following statements display?

- a) `Console.WriteLine(i == 1);`
- b) `Console.WriteLine(j == 3);`
- c) `Console.WriteLine((i >= 1) && (j < 4));`
- d) `Console.WriteLine((m <= 99) & (k < m));`

- e) `Console.WriteLine( ( j >= i ) || ( k == m ) );`
- f) `Console.WriteLine( ( k + m < j ) | ( 3 - j >= k ) );`
- g) `Console.WriteLine( !( k > m ) );`

**6.20** (*Calculating the Value of  $\pi$* ) Calculate the value of  $\pi$  from the infinite series

$$\pi = 4 - \frac{4}{3} + \frac{4}{5} - \frac{4}{7} + \frac{4}{9} - \frac{4}{11} + \dots$$

Display a table that shows the value of  $\pi$  approximated by computing one term of this series, by two terms, by three terms, and so on. How many terms of this series do you have to use before you first get 3.14? 3.141? 3.1415? 3.14159?

**6.21** (*Pythagorean Triples*) A right triangle can have sides whose lengths are all integers. The set of three integer values for the lengths of the sides of a right triangle is called a Pythagorean triple ([en.wikipedia.org/wiki/Pythagorean\\_triple](https://en.wikipedia.org/wiki/Pythagorean_triple)). The lengths of the three sides must satisfy the relationship that the sum of the squares of two of the sides is equal to the square of the hypotenuse. Write an app to find all Pythagorean triples for `side1`, `side2` and the `hypotenuse`, all no larger than 500. Use a triple-nested `for` loop that tries all possibilities. This method is an example of “brute-force” computing. You’ll learn in more advanced computer science courses that there are many interesting problems for which there’s no known algorithmic approach other than using sheer brute force.

**6.22** (*Modified Triangle Program*) Modify Exercise 6.15 to combine your code from the four separate triangles of asterisks such that all four patterns display side by side. Make clever use of nested `for` loops.

**6.23** (*Displaying a Diamond*) Write an app that displays the following diamond shape. You may use output statements that display a single asterisk (\*), a single space or a single newline character. Maximize your use of repetition (with nested `for` statements) and minimize the number of output statements.

```

*
 ***
 *****
 ******
 *****
 ******
 *****
 ****
 *

```

**6.24** (*Modified Diamond Program*) Modify the app you wrote in Exercise 6.23 to read an odd number in the range 1 to 19 to specify the number of rows in the diamond. Your app should then display a diamond of the appropriate size.

**6.25** (*Structured Equivalent of `break` Statement*) A criticism of the `break` statement and the `continue` statement (in a loop) is that each is unstructured. Actually, `break` and `continue` statements can always be replaced by structured statements, although doing so can be awkward. Describe in general how you would remove any `break` statement from a loop in an app and replace it with a structured equivalent. [Hint: The `break` statement exits a loop from the body of the loop. The other way to exit is by failing the loop-continuation test. Consider using in the loop-continuation test a second test that indicates “early exit because of a ‘break’ condition.”] Use the technique you develop here to remove the `break` statement from the app in Fig. 6.12.

**6.26** (*What Does This Code Do?*) What does the following code segment do?

```
for ( int i = 1; i <= 5; ++i )
{
    for ( int j = 1; j <= 3; ++j )
    {
        for ( int k = 1; k <= 4; ++k )
            Console.WriteLine( '*' );
        Console.WriteLine();
    } // end middle for
    Console.WriteLine();
} // end outer for
```

**6.27** (*Structured Equivalent of continue Statement*) Describe in general how you would remove any *continue* statement from a loop in an app and replace it with some structured equivalent. Use the technique you develop here to remove the *continue* statement from the app in Fig. 6.13.

## Making a Difference Exercises

**6.28** (*Global Warming Facts Quiz*) The controversial issue of global warming has been widely publicized by the film *An Inconvenient Truth*, featuring former Vice President Al Gore. Mr. Gore and a U.N. network of scientists, the Intergovernmental Panel on Climate Change, shared the 2007 Nobel Peace Prize in recognition of “their efforts to build up and disseminate greater knowledge about man-made climate change.” Research *both* sides of the global warming issue online (you might want to search for phrases like “global warming skeptics”). Create a five-question multiple-choice quiz on global warming, each question having four possible answers (numbered 1–4). Be objective and try to fairly represent both sides of the issue. Next, write an app that administers the quiz, calculates the number of correct answers (zero through five) and returns a message to the user. If the user correctly answers five questions, display “Excellent”; if four, display “Very good”; if three or fewer, display “Time to brush up on your knowledge of global warming,” and include a list of some of the websites where you found your facts.

**6.29** (*Tax Plan Alternatives; The “FairTax”*) There are many proposals to make taxation fairer. Check out the FairTax initiative in the United States at

[www.fairtax.org/site/PageServer?pagename=calculator](http://www.fairtax.org/site/PageServer?pagename=calculator)

Research how the proposed FairTax works. One suggestion is to eliminate income taxes and most other taxes in favor of a 23% consumption tax on all products and services that you buy. Some FairTax opponents question the 23% figure and say that because of the way the tax is calculated, it would be more accurate to say the rate is 30%—check this carefully. Write a program that prompts the user to enter expenses in various expense categories they have (e.g., housing, food, clothing, transportation, education, health care, vacations), then displays the estimated FairTax that person would pay.

# 7

## Methods: A Deeper Look



*E pluribus unum.  
(One composed of many.)*

—Virgil

*O! call back yesterday, bid time return.*

—William Shakespeare

*Call me Ishmael.*

—Herman Melville

*Answer me in one word.*

—William Shakespeare

*There is a point at which methods devour themselves.*

—Frantz Fanon

### Objectives

In this chapter you'll:

- Learn how **static** methods and variables are associated with classes rather than objects.
- Learn how the method call/return mechanism is supported by the method-call stack.
- Use random-number generation to implement game-playing apps.
- Learn how the visibility of declarations is limited to specific parts of apps.
- Create overloaded methods.
- Use optional and named parameters.
- Use recursive methods.
- Pass method arguments by value and by reference.

# Outline

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>7.1</b> Introduction<br><b>7.2</b> Packaging Code in C#<br><b>7.3</b> <code>static</code> Methods, <code>static</code> Variables and Class Math<br><b>7.4</b> Declaring Methods with Multiple Parameters<br><b>7.5</b> Notes on Declaring and Using Methods<br><b>7.6</b> Method-Call Stack and Activation Records<br><b>7.7</b> Argument Promotion and Casting<br><b>7.8</b> The .NET Framework Class Library<br><b>7.9</b> Case Study: Random-Number Generation | <b>7.9.1</b> Scaling and Shifting Random Numbers<br><b>7.9.2</b> Random-Number Repeatability for Testing and Debugging<br><b>7.10</b> Case Study: A Game of Chance; Introducing Enumerations<br><b>7.11</b> Scope of Declarations<br><b>7.12</b> Method Overloading<br><b>7.13</b> Optional Parameters<br><b>7.14</b> Named Parameters<br><b>7.15</b> Recursion<br><b>7.16</b> Passing Arguments: Pass-by-Value vs. Pass-by-Reference<br><b>7.17</b> Wrap-Up |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 7.1 Introduction

Most computer apps that solve real-world problems are much larger than the apps presented in this book's first few chapters. Experience has shown that the best way to develop and maintain a large app is to construct it from small, simple pieces. This technique is called **divide and conquer**. We introduced methods in Chapter 4. In this chapter we study methods in more depth. We emphasize how to declare and use methods to facilitate the design, implementation, operation and maintenance of large apps.

You'll see that it's possible for certain methods, called `static` methods, to be called without the need for an object of the class to exist. You'll learn how to declare a method with more than one parameter. You'll also learn how C# is able to keep track of which method is currently executing, how value-type and reference-type arguments are passed to methods, how local variables of methods are maintained in memory and how a method knows where to return after it completes execution.

We discuss **simulation** techniques with random-number generation and develop a version of the casino dice game called craps that uses most of the programming techniques you've learned to this point in the book. In addition, you'll learn to declare constant values. You'll also learn to write recursive methods—methods that call themselves.

Many of the classes you'll use or create will have more than one method of the same name. This technique, called *method overloading*, is used to implement methods that perform similar tasks but with different types and/or different numbers of arguments.

## 7.2 Packaging Code in C#

Common ways of packaging code are properties, methods, classes and namespaces. C# apps are written by combining new properties, methods and classes that you write with predefined properties, methods and classes available in the .NET Framework Class Library and in various other class libraries. Related classes are often grouped into namespaces and

compiled into class libraries so that they can be reused in other apps. You'll learn how to create your own namespaces and class libraries in Chapter 15. The Framework Class Library provides many *predefined* classes that contain methods for performing common mathematical calculations, string manipulations, character manipulations, input/output operations, database operations, networking operations, file processing, error checking, web-app development and more.



### Software Engineering Observation 7.1

*Don't try to "reinvent the wheel." When possible, reuse Framework Class Library classes and methods ([msdn.microsoft.com/en-us/library/ms229335.aspx](http://msdn.microsoft.com/en-us/library/ms229335.aspx)). This reduces app development time, avoids introducing programming errors and contributes to good app performance.*

### *Modularizing Programs*

Methods (called **functions** or **procedures** in other programming languages) allow you to modularize an app by separating its tasks into self-contained units. You've declared methods in every app you've written. These methods are sometimes referred to as **user-defined methods**. The actual statements in the method bodies are written only *once*, can be reused from several locations in an app and are *hidden* from other methods.

There are several motivations for modularizing an app by means of methods. One is the “divide-and-conquer” approach, which makes app development more manageable by constructing apps from small, simple pieces. Another is **software reusability**—existing methods can be used as *building blocks* to create new apps. Often, you can create apps mostly by reusing existing methods rather than by building customized code. For example, in earlier apps, we did not have to define how to read data values from the keyboard—the Framework Class Library provides these capabilities in class `Console`. A third motivation is to avoid repeating code. Dividing an app into meaningful methods makes the app easier to debug and maintain.

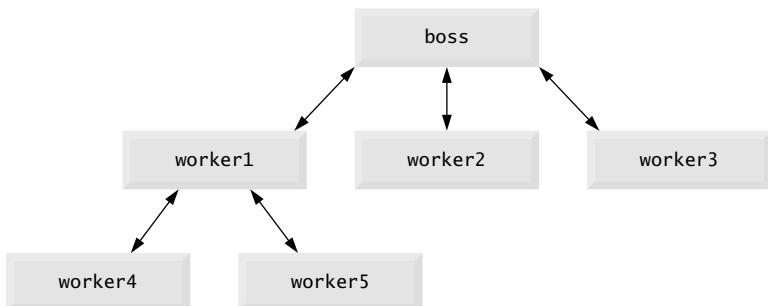


### Software Engineering Observation 7.2

*To promote software reusability, every method should be limited to performing a single, well-defined task, and the name of the method should express that task effectively. Such methods make apps easier to write, debug, maintain and modify.*

### *Calling Methods*

As you know, a method is invoked by a method call, and when the called method **completes its task**, it returns a result or simply returns control to the caller. The code that calls a method is also sometimes known as the **client code**—that is, any statement that calls the object's method from *outside* the object is a client of the method. An analogy to the method-call-and-return structure is the hierarchical form of management (Figure 7.1). A boss (the caller) asks a worker (the called method) to perform a task and report back (i.e., return) the results after completing the task. The boss method does not know how the worker method performs its designated tasks. The worker may also call other worker methods, unbeknown to the boss. This *hiding* of implementation details promotes good software engineering. Figure 7.1 shows the boss method communicating with several worker methods in a hierarchical manner. The **boss** method divides the responsibilities among the various **worker** methods. Note that **worker1** also acts as a “boss method” to **worker4** and **worker5**.



**Fig. 7.1** | Hierarchical boss-method/worker-method relationship.

### 7.3 static Methods, static Variables and Class Math

Although most methods execute on specific objects in response to method calls, this is not always the case. Sometimes a method performs a task that does *not* depend on the contents of any object. Such a method applies to the class in which it's declared as a whole and is known as a **static method**. It's not uncommon for a class to contain a group of static methods to perform common tasks. For example, recall that we used static method Pow of class Math to raise a value to a power in Fig. 6.6. To declare a method as static, place the keyword static before the return type in the method's declaration. You call any static method by specifying the name of the class in which the method is declared, followed by the member access (.) operator and the method name, as in

```
ClassName.MethodName( arguments )
```

We use various methods of the Math class here to present the concept of static methods. Class Math (from the System namespace) provides a collection of methods that enable you to perform common mathematical calculations. For example, you can calculate the square root of 900.0 with the static method call

```
Math.Sqrt( 900.0 )
```

The preceding expression evaluates to 30.0. Method Sqrt takes an argument of type double and returns a result of type double. To output the value of the preceding method call in the console window, you might write the statement

```
Console.WriteLine( Math.Sqrt( 900.0 ) );
```

In this statement, the value that Sqrt returns becomes the argument to method WriteLine. We did not create a Math object before calling method Sqrt. Also, *all* of Math's methods are static—therefore, each is called by preceding the name of the method with the class name Math and the member access (.) operator. Similarly, Console method WriteLine is a static method of class Console, so we invoke the method by preceding its name with the class name Console and the member access (.) operator.

Method arguments may be constants, variables or expressions. If c = 13.0, d = 3.0 and f = 4.0, then the statement

```
Console.WriteLine( Math.Sqrt( c + d * f ) );
```

calculates and displays the square root of  $13.0 + 3.0 * 4.0 = 25.0$ —namely, 5.0. Figure 7.2 summarizes several Math class methods. In the figure,  $x$  and  $y$  are of type double.

Method	Description	Example
<code>Abs( x )</code>	absolute value of $x$	<code>Abs( 23.7 )</code> is 23.7 <code>Abs( 0.0 )</code> is 0.0 <code>Abs( -23.7 )</code> is 23.7
<code>Ceiling( x )</code>	rounds $x$ to the smallest integer not less than $x$	<code>Ceiling( 9.2 )</code> is 10.0 <code>Ceiling( -9.8 )</code> is -9.0
<code>Cos( x )</code>	trigonometric cosine of $x$ ( $x$ in radians)	<code>Cos( 0.0 )</code> is 1.0
<code>Exp( x )</code>	exponential method $e^x$	<code>Exp( 1.0 )</code> is 2.71828 <code>Exp( 2.0 )</code> is 7.38906
<code>Floor( x )</code>	rounds $x$ to the largest integer not greater than $x$	<code>Floor( 9.2 )</code> is 9.0 <code>Floor( -9.8 )</code> is -10.0
<code>Log( x )</code>	natural logarithm of $x$ (base $e$ )	<code>Log( Math.E )</code> is 1.0 <code>Log( Math.E * Math.E )</code> is 2.0
<code>Max( x, y )</code>	larger value of $x$ and $y$	<code>Max( 2.3, 12.7 )</code> is 12.7 <code>Max( -2.3, -12.7 )</code> is -2.3
<code>Min( x, y )</code>	smaller value of $x$ and $y$	<code>Min( 2.3, 12.7 )</code> is 2.3 <code>Min( -2.3, -12.7 )</code> is -12.7
<code>Pow( x, y )</code>	$x$ raised to the power $y$ (i.e., $x^y$ )	<code>Pow( 2.0, 7.0 )</code> is 128.0 <code>Pow( 9.0, 0.5 )</code> is 3.0
<code>Sin( x )</code>	trigonometric sine of $x$ ( $x$ in radians)	<code>Sin( 0.0 )</code> is 0.0
<code>Sqrt( x )</code>	square root of $x$	<code>Sqrt( 900.0 )</code> is 30.0
<code>Tan( x )</code>	trigonometric tangent of $x$ ( $x$ in radians)	<code>Tan( 0.0 )</code> is 0.0

**Fig. 7.2** | Math class methods.

### Math Class Constants PI and E

Class Math also declares two static double constants that represent commonly used mathematical values: `Math.PI` and `Math.E`. The constant `Math.PI` (3.14159265358979323846) is the ratio of a circle's circumference to its diameter. `Math.E` (2.7182818284590452354) is the base value for natural logarithms (calculated with static Math method Log). These constants are declared in class Math with the modifiers public and const. Making them public allows other programmers to use these variables in their own classes. A constant is declared with the keyword const—its value cannot be changed after the constant is declared. Both PI and E are declared const. Because these constants are static, you can access them via the class name Math and the member access (.) operator, just like class Math's methods.

Recall from Section 4.5 that when each object of a class maintains its own copy of an attribute, the variable that represents the attribute is also known as an *instance variable*—each object (instance) of the class has a separate instance of the variable. There are also variables for which each object of a class does *not* have a separate instance of the variable. That's the case with static variables. When objects of a class containing static variables

are created, all the objects of that class share one copy of the class's **static** variables. Together the **static** variables and instance variables represent the **fields** of a class.



### Common Programming Error 7.1

*Every constant declared in a class, but not inside a method of the class is implicitly static, so it's a syntax error to declare such a constant with keyword static explicitly.*

#### Why Is Method `Main` Declared `static`?

Why must `Main` be declared `static`? During app *startup*, when *no objects* of the class have been created, the `Main` method must be called to begin program execution. `Main` is sometimes called the app's **entry point**. Declaring `Main` as `static` allows the execution environment to invoke `Main` without creating an instance of the class. Method `Main` is often declared with the header:

```
public static void Main( string args[] )
```

When you execute your app from the command line, you type the app name, as in

```
AppName argument1 argument2 ...
```

In the preceding command, `argument1` and `argument2` are the **command-line arguments** to the app that specify a list of strings (separated by spaces) the execution environment will pass to the `Main` method of your app. Such arguments might be used to specify options (e.g., a file name) to run the app. As you'll learn in Chapter 8, your app can access its command-line arguments (via the `args` parameter) and use them to customize the app.

#### Additional Comments about Method `Main`

Apps that do not take command-line arguments may omit the `string[] args` parameter. The `public` keyword may also be omitted. In addition, you can declare `Main` with return type `int` (instead of `void`) to enable `Main` to return an error code. A `Main` method declared with any one of these headers can be used as the app's entry point—but you can declare only one `Main` method in each class.

Most earlier examples had one class that contained only `Main`, and some examples had a second class that was used by `Main` to create and manipulate objects. Actually, *any* class can contain a `Main` method. In fact, each of our two-class examples could have been implemented as one class. For example, in the app in Figs. 6.9 and 6.10, method `Main` (lines 6–16 of Fig. 6.10) could have been taken as is and placed in class `GradeBook` (Fig. 6.9). The app results would have been identical to those of the two-class version. You can place a `Main` method in every class you declare. Some programmers take advantage of this to build a small test app into each class they declare. However, if you declare more than one `Main` method among the classes of your project, you'll need to indicate to the IDE which one you would like to be the *app's* entry point. You can do this by selecting **PROJECT > [ProjectName] Properties...** (where `[ProjectName]` is the name of your project) and selecting the class containing the `Main` method that should be the entry point from the **Startup object** list box.

## 7.4 Declaring Methods with Multiple Parameters

We now consider how to write your own methods with multiple parameters. The app in Fig. 7.3 uses a user-defined method called `Maximum` to determine and return the largest of

*three* double values. When the app begins execution, the Main method (lines 8–22) executes. Line 18 calls method Maximum (declared in lines 25–38) to determine and return the largest of the three double values. At the end of this section, we'll discuss the use of operator + in line 21.

```

1 // Fig. 7.3: MaximumFinder.cs
2 // User-defined method Maximum.
3 using System;
4
5 public class MaximumFinder
6 {
7     // obtain three floating-point values and determine maximum value
8     public static void Main( string[] args )
9     {
10         // prompt for and input three floating-point values
11         Console.WriteLine( "Enter three floating-point values,\n" +
12             " pressing 'Enter' after each one: " );
13         double number1 = Convert.ToDouble( Console.ReadLine() );
14         double number2 = Convert.ToDouble( Console.ReadLine() );
15         double number3 = Convert.ToDouble( Console.ReadLine() );
16
17         // determine the maximum value
18         double result = Maximum( number1, number2, number3 );
19
20         // display maximum value
21         Console.WriteLine( "Maximum is: " + result );
22     } // end Main
23
24     // returns the maximum of its three double parameters
25     public static double Maximum( double x, double y, double z )
26     {
27         double maximumValue = x; // assume x is the largest to start
28
29         // determine whether y is greater than maximumValue
30         if ( y > maximumValue )
31             maximumValue = y;
32
33         // determine whether z is greater than maximumValue
34         if ( z > maximumValue )
35             maximumValue = z;
36
37         return maximumValue;
38     } // end method Maximum
39 } // end class MaximumFinder

```

```

Enter three floating-point values,
pressing 'Enter' after each one:
2.22
3.33
1.11
Maximum is: 3.33

```

**Fig. 7.3** | User-defined method Maximum.

### The `public` and `static` Keywords

Method `Maximum`'s declaration begins with keyword `public` to indicate that the method is “available to the public”—it can be called from methods of other classes. The keyword `static` enables the `Main` method (another `static` method) to call `Maximum` as shown in line 18 without qualifying the method name with the class name `MaximumFinder`—`static` methods in the *same* class can call each other directly. Any other class that uses `Maximum` must fully qualify the method name with the class name.

### Method `Maximum`

Consider the declaration of method `Maximum` (lines 25–38). Line 25 indicates that the method returns a `double` value, that the method's name is `Maximum` and that the method requires *three* `double` parameters (`x`, `y` and `z`) to accomplish its task. When a method has more than one parameter, the parameters are specified as a *comma-separated list*. When `Maximum` is called in line 18, the parameter `x` is initialized with the value of the argument `number1`, the parameter `y` is initialized with the value of the argument `number2` and the parameter `z` is initialized with the value of the argument `number3`. There must be one argument in the method call for each required parameter (sometimes called a **formal parameter**) in the method declaration. Also, each argument must be *consistent* with the type of the corresponding parameter. For example, a parameter of type `double` can receive values like `7.35` (a `double`), `22` (an `int`) or `-0.03456` (a `double`), but not strings like `"hello"`. Section 7.7 discusses the argument types that can be provided in a method call for each parameter of a simple type.



### Common Programming Error 7.2

*Declaring method parameters of the same type as `double x, y` instead of `double x, double y` is a syntax error—a type is required for each parameter in the parameter list.*

### Logic of Determining the Maximum Value

To determine the maximum value, we begin with the assumption that parameter `x` contains the largest value, so line 27 declares local variable `maximumValue` and initializes it with the value of parameter `x`. Of course, it's possible that parameter `y` or `z` contains the largest value, so we must compare each of these values with `maximumValue`. The `if` statement at lines 30–31 determines whether `y` is greater than `maximumValue`. If so, line 31 assigns `y` to `maximumValue`. The `if` statement at lines 34–35 determines whether `z` is greater than `maximumValue`. If so, line 35 assigns `z` to `maximumValue`. At this point, the largest of the three values resides in `maximumValue`, so line 37 returns that value to line 18. When program control returns to the point in the app where `Maximum` was called, `Maximum`'s parameters `x`, `y` and `z` are no longer accessible. Methods can return *at most one* value; the returned value can be a value type that contains one or more values (implemented as a `struct`) or a reference to an object that contains one or more values.

### When to Declare Variables as Fields of a Class

Variable `result` is a local variable in method `Main` because it's declared in the block that represents the method's body. Variables should be declared as fields of a class (i.e., as either instance variables or `static` variables of the class) *only* if they're required for use in more than one method of the class or if the app should save their values between calls to a given method.

### **Implementing Method `Maximum` by Reusing Method `Math.Max`**

Recall from Fig. 7.2 that class `Math` has a `Max` method that can determine the larger of two values. The entire body of our maximum method could also be implemented with nested calls to `Math.Max`, as follows:

```
return Math.Max( x, Math.Max( y, z ) );
```

The leftmost call to `Math.Max` specifies arguments `x` and `Math.Max( y, z )`. Before any method can be called, the .NET runtime evaluates *all* its arguments to determine their values. If an argument is a method call, the method call must be performed to determine its return value. So, in the preceding statement, `Math.Max( y, z )` is evaluated first to determine the maximum of `y` and `z`. Then the result is passed as the second argument to the other call to `Math.Max`, which returns the larger of its two arguments. Using `Math.Max` in this manner is a good example of *software reuse*—we find the largest of three values by reusing `Math.Max`, which finds the larger of two values. Note how concise this code is compared to lines 27–37 of Fig. 7.3.

### **Assembling Strings with String Concatenation**

C# allows `string` objects to be created by assembling smaller `string` objects into larger `string` objects using operator `+` (or the compound assignment operator `+=`). This is known as **string concatenation**. When both operands of operator `+` are `string` objects, operator `+` creates a new `string` object in which a copy of the characters of the *right* operand is placed at the end of a copy of the characters in the *left* operand. For example, the expression `"hello" + "there"` creates the `string` `"hello there"` without disturbing the original `strings`.

In line 21 of Fig. 7.3, the expression `"Maximum is: " + result` uses operator `+` with operands of types `string` and `double`. Every value of a simple type in C# has a `string` representation. When one of the `+` operator's operands is a `string`, the other is implicitly converted to a `string`, then the two are *concatenated*. In line 21, the `double` value is *implicitly* converted to its `string` representation and placed at the end of the `string` `"Maximum is: "`. If there are any trailing zeros in a `double` value, these will be *discarded* when the number is converted to a `string`. Thus, the number `9.3500` would be represented as `9.35` in the resulting `string`.

### **Anything Can Be Converted to a `string`**

For values of simple types used in `string` concatenation, the values are converted to `strings`. If a `bool` is concatenated with a `string`, the `bool` is converted to the `string` `"True"` or `"False"` (each is capitalized). All objects have a `ToString` method that returns a `string` representation of the object. When an object is concatenated with a `string`, the object's `ToString` method is called *implicitly* to obtain the `string` representation of the object. If the object is `null`, an *empty string* is written.

### **Outputting `strings` with Format Items**

Line 21 of Fig. 7.3 could also be written using `string` formatting as

```
Console.WriteLine( "Maximum is: {0}", result );
```

As with `string` concatenation, using a format item to substitute an object into a `string` *implicitly* calls the object's `ToString` method to obtain the object's `string` representation. You'll learn more about method `ToString` in Chapter 8.

***Breaking a Large string Literal into Smaller strings***

When a large `string` literal is typed into an app's source code, you can break that `string` into several smaller `strings` and place them on multiple lines for readability. The `strings` can be reassembled using either string concatenation or string formatting. We discuss the details of `strings` in Chapter 16.

**Common Programming Error 7.3**

*It's a syntax error to break a string literal across multiple lines in an app. If a string does not fit on one line, split the string into several smaller strings and use concatenation to form the desired string. C# also provides so-called verbatim string literals, which are preceded by the @ character. Such literals can be split over multiple lines and the characters in the literal, including whitespace, are processed exactly as they appear in the literal.*

**Common Programming Error 7.4**

*Confusing the + operator used for string concatenation with the + operator used for addition can lead to strange results. The + operator is left-associative. For example, if integer variable y has the value 5, the expression "y + 2 = " + y + 2 results in the string "y + 2 = 52", not "y + 2 = 7", because first the value of y (5) is concatenated with the string "y + 2 = ", then the value 2 is concatenated with the new larger string "y + 2 = 5". The expression "y + 2 = " + (y + 2) produces the desired result "y + 2 = 7".*

## 7.5 Notes on Declaring and Using Methods

You've seen three ways to call a method:

1. Using a method name by itself to call a method of the *same* class—such as `Maximum(number1, number2, number3)` in line 18 of Fig. 7.3.
2. Using a variable that contains a reference to an object, followed by the member access (.) operator and the method name to call a non-static method of the referenced object—such as the method call in line 13 of Fig. 6.10, `myGradeBook.DisplayMessage()`, which calls a method of class `GradeBook` from the `Main` method of `GradeBookTest`.
3. Using the class name and the member access (.) operator to call a *static* method of a class—such as `Convert.ToDouble(Console.ReadLine())` in lines 13–15 of Fig. 7.3 or `Math.Sqrt(900.0)` in Section 7.3.

There are three ways to return control to the statement that calls a method. If the method's return type is `void` (that is, it does not return a result), control returns when the method-ending right brace is reached or when the statement

```
return;
```

is executed. If the method returns a result, the statement

```
return expression;
```

evaluates the `expression`, then returns the result (and control) to the caller.

**Common Programming Error 7.5**

*Declaring a method outside the body of a class declaration or inside the body of another method is a syntax error.*



### Common Programming Error 7.6

*Redeclaring a method parameter as a local variable in the method's body is a compilation error.*



### Common Programming Error 7.7

*Forgetting to return a value from a method that should return one is a compilation error. If a return type other than void is specified, the method must use a return statement to return a value and that value must be consistent with the method's return type. Returning a value from a method whose return type has been declared void is a compilation error.*

A **static** method can call *only* other **static** methods of the same class directly (i.e., using the method name by itself) and can manipulate *only static* variables in the same class directly. To access the class's non-**static** members, a **static** method must use a reference to an object of the class. Recall that **static** methods relate to a class as a whole, whereas non-**static** methods are associated with a specific instance (object) of the class and may manipulate the instance variables of that object. Many objects of a class, each with its own copies of the instance variables, may exist at the same time. Suppose a **static** method were to invoke a non-**static** method directly. How would the method know which object's instance variables to manipulate? What would happen if no objects of the class existed at the time the non-**static** method was invoked? Thus, C# does not allow a **static** method to access non-**static** members of the same class directly.

## 7.6 Method-Call Stack and Activation Records

To understand how C# performs method calls, we first need to consider a data structure (i.e., collection of related data items) known as a **stack** (we discuss data structures in more detail in Chapters 18–21). You can think of a stack as analogous to a pile of dishes. When a dish is placed on the pile, it's normally placed at the top (referred to as **pushing** the dish onto the stack). Similarly, when a dish is removed from the pile, it's always removed from the top (referred to as **popping** the dish off the stack). Stacks are known as **last-in, first-out (LIFO) data structures**—the last item pushed (inserted) on the stack is the first item popped off (removed from) the stack.

When an app calls a method, the called method must know how to return to its caller, so the return address of the calling method is *pushed* onto the **program-execution stack** (sometimes referred to as the **method-call stack**). If a series of method calls occurs, the successive return addresses are *pushed* onto the stack in last-in, first-out order so that each method can return to its caller.

The program-execution stack also contains the *memory for the local variables* used in each invocation of a method during an app's execution. This data, stored as a portion of the program-execution stack, is known as the **activation record** or **stack frame** of the method call. When a method call is made, the activation record for it is pushed onto the program-execution stack. When the method returns to its caller, the activation record for this method call is *popped* off the stack, and those local variables are no longer known to the app. If a local variable holding a reference to an object is the only variable in the app with a reference to that object, when the activation record containing that local variable is popped off the stack, the object can no longer be accessed by the app and will eventually

be deleted from memory during “garbage collection.” We’ll discuss garbage collection in Section 10.8.

Of course, the amount of memory in a computer is finite, so only a certain amount of memory can be used to store activation records on the program-execution stack. If more method calls occur than can have their activation records stored on the program-execution stack, a fatal error known as a **stack overflow** occurs.

## 7.7 Argument Promotion and Casting

Another important feature of method calls is **argument promotion**—implicitly converting an argument’s value to the type that the method expects to receive (if possible) in its corresponding parameter. For example, an app can call Math method `Sqrt` with an integer argument even though the method expects to receive a `double` argument. The statement

```
Console.WriteLine( Math.Sqrt( 4 ) );
```

correctly evaluates `Math.Sqrt(4)` and displays the value `2.0`. `Sqrt`’s parameter list causes C# to convert the `int` value `4` to the `double` value `4.0` before passing the value to `Sqrt`. Such conversions may lead to compilation errors if C#’s **promotion rules** are not satisfied. The promotion rules specify which conversions are allowed—that is, which conversions can be performed *without losing data*. In the `Sqrt` example above, an `int` is converted to a `double` without changing its value. However, converting a `double` to an `int` *truncates* the fractional part of the `double` value—thus, part of the value is lost. Also, `double` variables can hold values much larger (and much smaller) than `int` variables, so assigning a `double` to an `int` can cause a loss of information when the `double` value doesn’t fit in the `int`. Converting large integer types to small integer types (e.g., `long` to `int`) can also result in changed values.

### Promotion Rules

The promotion rules apply to expressions containing values of two or more simple types and to simple-type values passed as arguments to methods. Each value is promoted to the appropriate type in the expression. (Actually, the expression uses a *temporary* copy of each value—the types of the original values remain unchanged.) Figure 7.4 lists the simple types alphabetically and the types to which each can be promoted. Values of all simple types can also be implicitly converted to type `object`. We demonstrate such implicit conversions in Chapter 19, Data Structures.

Type	Conversion types
<code>bool</code>	no possible implicit conversions to other simple types
<code>byte</code>	<code>ushort, short, uint, int, ulong, long, decimal, float or double</code>
<code>char</code>	<code>ushort, int, uint, long, ulong, decimal, float or double</code>
<code>decimal</code>	no possible implicit conversions to other simple types
<code>double</code>	no possible implicit conversions to other simple types

**Fig. 7.4** | Implicit conversions between simple types. (Part I of 2.)

Type	Conversion types
float	double
int	long, decimal, float or double
long	decimal, float or double
sbyte	short, int, long, decimal, float or double
short	int, long, decimal, float or double
uint	ulong, long, decimal, float or double
ulong	decimal, float or double
ushort	uint, int, ulong, long, decimal, float or double

**Fig. 7.4** | Implicit conversions between simple types. (Part 2 of 2.)

### Sometimes Explicit Casts Are Required

By default, C# does not allow you to implicitly convert values between simple types if the target type cannot represent the value of the original type (e.g., the `int` value 2000000 cannot be represented as a `short`, and any floating-point number with digits after its decimal point cannot be represented in an integer type such as `long`, `int` or `short`). Therefore, to prevent a compilation error in cases where information may be lost due to an implicit conversion between simple types, the compiler requires you to use a *cast operator* to force the conversion. This enables you to “take control” from the compiler. You essentially say, “I know this conversion might cause loss of information, but for my purposes here, that’s fine.” Suppose you create a method `Square` that calculates the square of an integer and thus requires an `int` argument. To call `Square` with the whole part of a `double` argument named `doubleValue`, you’d write `Square((int) doubleValue)`. This method call explicitly casts (converts) the value of `doubleValue` to an integer for use in method `Square`. Thus, if `doubleValue`’s value is 4.5, the method receives the value 4 and returns 16, not 20.25 (which does, unfortunately, result in the loss of information).



### Common Programming Error 7.8

Converting a simple-type value to a value of another simple type may change the value if the promotion is not allowed. For example, converting a floating-point value to an integral value may introduce truncation errors (loss of the fractional part) in the result.

## 7.8 The .NET Framework Class Library

Many predefined classes are grouped into categories of related classes called *namespaces*. Together, these namespaces are referred to as the .NET Framework Class Library.

Throughout the text, `using` directives allow us to use library classes from the Framework Class Library without specifying their fully qualified names. For example, an app includes the declaration

```
using System;
```

in order to use the class names from the `System` namespace without fully qualifying their names. This allows you to use the **unqualified class name** `Console`, rather than the fully

qualified class name `System.Console`, in your code. A strength of C# is the large number of classes in the namespaces of the .NET Framework Class Library. Some key Framework Class Library namespaces are described in Fig. 7.5, which represents only a small portion of the reusable classes in the .NET Framework Class Library.

Namespace	Description
<code>System.Windows.Forms</code>	Contains the classes required to create and manipulate GUIs. (Various classes in this namespace are discussed in Chapter 14, Graphical User Interfaces with Windows Forms: Part 1, and Chapter 15, Graphical User Interfaces with Windows Forms: Part 2.)
<code>System.Windows.Controls</code>	Contain the classes of the Windows Presentation Foundation for GUIs, 2-D and 3-D graphics, multimedia and animation. (See Chapter 32, GUI with Windows Presentation Foundation and Chapter 33, WPF Graphics and Multimedia.)
<code>System.Windows.Input</code>	
<code>System.Windows.Media</code>	
<code>System.Windows.Shapes</code>	
<code>System.Linq</code>	Contains the classes that support Language Integrated Query (LINQ). (See Chapter 9, Introduction to LINQ and the <code>List</code> Collection, and several other chapters throughout the book.)
<code>System.Data.Entity</code>	Contains the classes for manipulating data in databases (i.e., organized collections of data), including support for LINQ to Entities. (See Chapter 22, Databases and LINQ.)
<code>System.IO</code>	Contains the classes that enable programs to input and output data. (See Chapter 17, Files and Streams.)
<code>System.Web</code>	Contains the classes used for creating and maintaining web apps, which are accessible over the Internet. (See Chapter 23, Web App Development with ASP.NET.)
<code>System.Xml</code>	Contains the classes for creating and manipulating XML data. Data can be read from or written to XML files. (See Chapter 24, XML and LINQ to XML.)
<code>System.Xml.Linq</code>	Contains the classes that support Language Integrated Query (LINQ) for XML documents. (See Chapter 24, XML and LINQ to XML, and several other chapters throughout the book.)
<code>System.Collections</code>	Contain the classes that define data structures for maintaining collections of data. (See Chapter 21, Collections.)
<code>System.Collections.Generic</code>	
<code>System.Text</code>	Contains classes that enable programs to manipulate characters and strings. (See Chapter 16, Strings and Characters: A Deeper Look.)

**Fig. 7.5** | .NET Framework Class Library namespaces (a subset).

The .NET Framework Class Library also contains namespaces for complex graphics, advanced graphical user interfaces, printing, advanced networking, security, database processing, multimedia, accessibility (for people with disabilities) and many other capabilities—over 200 namespaces in all.

### Locating Additional Information About a .NET Class's Methods

You can locate additional information about a .NET class's methods in the *.NET Framework Class Library* reference ([msdn.microsoft.com/en-us/library/ms229335.aspx](http://msdn.microsoft.com/en-us/library/ms229335.aspx)). When you visit this site, you'll see an alphabetical listing of all the namespaces in the Framework Class Library. Locate the namespace and click its link to see an alphabetical listing of all its classes, with a brief description of each. Click a class's link to see a more complete description of the class. Click the **Methods** link in the left-hand column to see a listing of the class's methods.



### Good Programming Practice 7.1

*The online .NET Framework documentation is easy to search and provides many details about each class. As you learn each class in this book, you should review the class in the online documentation for additional information.*

## 7.9 Case Study: Random-Number Generation

In this and the next section, we develop a nicely structured game-playing app with multiple methods. The app uses most of the control statements presented thus far in the book and introduces several new programming concepts.

There's something in the air of a casino that invigorates people—from the high rollers at the plush mahogany-and-felt craps tables to the quarter poppers at the one-armed bandits. It's the **element of chance**, the possibility that luck will convert a pocketful of money into a mountain of wealth. The element of chance can be introduced in an app via an object of class **Random** (of namespace **System**). Objects of class **Random** can produce random **byte**, **int** and **double** values. In the next several examples, we use objects of class **Random** to produce random numbers.

### Creating a Random Number Generator Object

A new random-number generator object can be created as follows:

```
Random randomNumbers = new Random();
```

The random-number generator object can then be used to generate random **byte**, **int** and **double** values—we discuss only random **int** values here.

### Generating a Random Integer

Consider the following statement:

```
int randomValue = randomNumbers.Next();
```

Method **Next** of class **Random** generates a random **int** value in the range 0 to +2,147,483,646, inclusive. If the **Next** method truly produces values at random, then every value in that range should have an equal chance (or probability) of being chosen each time method **Next** is called. The values returned by **Next** are actually **pseudorandom numbers**—a sequence of values produced by a complex mathematical calculation. The calculation uses the current time of day (which, of course, changes constantly) to **seed** the random-number generator such that each execution of an app yields a different sequence of random values.

### Scaling the Range of Random Numbers Produced

The range of values produced directly by method **Next** often differs from the range of values required in a particular C# app. For example, an app that simulates coin tossing might

require only 0 for “heads” and 1 for “tails.” An app that simulates the rolling of a six-sided die might require random integers in the range 1–6. A video game that randomly predicts the next type of spaceship (out of four possibilities) that will fly across the horizon might require random integers in the range 1–4. For cases like these, class `Random` provides other versions of method `Next`. One receives an `int` argument and returns a value from 0 up to, but not including, the argument’s value. For example, you might use the statement

```
int randomValue = randomNumbers.Next( 6 );
```

which returns 0, 1, 2, 3, 4 or 5. The argument 6—called the **scaling factor**—represents the number of unique values that `Next` should produce (in this case, six—0, 1, 2, 3, 4 and 5). This manipulation is called **scaling** the range of values produced by `Random` method `Next`.

### *Shifting the Range of Random Numbers Produced*

Suppose we wanted to simulate a six-sided die that has the numbers 1–6 on its faces, not 0–5. Scaling the range of values alone is not enough. So we **shift** the range of numbers produced. We could do this by adding a **shifting value**—in this case 1—to the result of method `Next`, as in

```
face = 1 + randomNumbers.Next( 6 );
```

The shifting value (1) specifies the first value in the desired set of random integers. The preceding statement assigns to `face` a random integer in the range 1–6.

### *Combining Shifting and Scaling*

The third alternative of method `Next` provides a more intuitive way to express both shifting and scaling. This method receives two `int` arguments and returns a value from the first argument’s value up to, but not including, the second argument’s value. We could use this method to write a statement equivalent to our previous statement, as in

```
face = randomNumbers.Next( 1, 7 );
```

### *Rolling a Six-Sided Die*

To demonstrate random numbers, let’s develop an app that simulates 20 rolls of a six-sided die and displays each roll’s value. Figure 7.6 shows two sample outputs, which confirm that the results of the preceding calculation are integers in the range 1–6 and that each run of the app can produce a *different* sequence of random numbers. The `using` directive (line 3) enables us to use class `Random` without fully qualifying its name. Line 9 creates the `Random` object `randomNumbers` to produce random values. Line 16 executes 20 times in a loop to roll the die. The `if` statement (lines 21–22) starts a new line of output after every five numbers, so the results will be presented on multiple lines.

---

```
1 // Fig. 7.6: RandomIntegers.cs
2 // Shifted and scaled random integers.
3 using System;
4
5 public class RandomIntegers
6 {
```

**Fig. 7.6** | Shifted and scaled random integers. (Part 1 of 2.)

```

7  public static void Main( string[] args )
8  {
9      Random randomNumbers = new Random(); // random-number generator
10     int face; // stores each random integer generated
11
12     // Loop 20 times
13     for ( int counter = 1; counter <= 20; counter++ )
14     {
15         // pick random integer from 1 to 6
16         face = randomNumbers.Next( 1, 7 );
17
18         Console.WriteLine( "{0} ", face ); // display generated value
19
20         // if counter is divisible by 5, start a new line of output
21         if ( counter % 5 == 0 )
22             Console.WriteLine();
23     } // end for
24 } // end Main
25 } // end class RandomIntegers

```

```

3 3 3 1 1
2 1 2 4 2
2 3 6 2 5
3 4 6 6 1

```

```

6 2 5 1 3
5 2 1 6 5
4 1 6 1 3
3 1 4 3 4

```

**Fig. 7.6** | Shifted and scaled random integers. (Part 2 of 2.)

### *Rolling a Six-Sided Die 6,000,000 Times*

To show that the numbers produced by `Next` occur with approximately equal likelihood, let's simulate 6,000,000 rolls of a die (Fig. 7.7). Each integer from 1 to 6 should appear approximately 1,000,000 times.

```

1  // Fig. 7.7: RollDie.cs
2  // Roll a six-sided die 6,000,000 times.
3  using System;
4
5  public class RollDie
6  {
7      public static void Main( string[] args )
8      {
9          Random randomNumbers = new Random(); // random-number generator
10
11         int frequency1 = 0; // count of 1s rolled
12         int frequency2 = 0; // count of 2s rolled

```

**Fig. 7.7** | Roll a six-sided die 6,000,000 times. (Part 1 of 3.)

```

13     int frequency3 = 0; // count of 3s rolled
14     int frequency4 = 0; // count of 4s rolled
15     int frequency5 = 0; // count of 5s rolled
16     int frequency6 = 0; // count of 6s rolled
17
18     int face; // stores most recently rolled value
19
20     // summarize results of 6,000,000 rolls of a die
21     for ( int roll = 1; roll <= 6000000; ++roll )
22     {
23         face = randomNumbers.Next( 1, 7 ); // number from 1 to 6
24
25         // determine roll value 1-6 and increment appropriate counter
26         switch ( face )
27         {
28             case 1:
29                 ++frequency1; // increment the 1s counter
30                 break;
31             case 2:
32                 ++frequency2; // increment the 2s counter
33                 break;
34             case 3:
35                 ++frequency3; // increment the 3s counter
36                 break;
37             case 4:
38                 ++frequency4; // increment the 4s counter
39                 break;
40             case 5:
41                 ++frequency5; // increment the 5s counter
42                 break;
43             case 6:
44                 ++frequency6; // increment the 6s counter
45                 break;
46         } // end switch
47     } // end for
48
49     Console.WriteLine( "Face\tFrequency" ); // output headers
50     Console.WriteLine(
51         "1\t{0}\n2\t{1}\n3\t{2}\n4\t{3}\n5\t{4}\n6\t{5}", frequency1,
52         frequency2, frequency3, frequency4, frequency5, frequency6 );
53 } // end Main
54 } // end class RollDie

```

Face	Frequency
1	999147
2	1001249
3	999929
4	1000301
5	1000294
6	999080

**Fig. 7.7** | Roll a six-sided die 6,000,000 times. (Part 2 of 3.)

Face	Frequency
1	1000538
2	1002700
3	1000294
4	997662
5	999507
6	999299

**Fig. 7.7** | Roll a six-sided die 6,000,000 times. (Part 3 of 3.)

As the two sample outputs show, the values produced by method `Next` enable the app to realistically simulate rolling a six-sided die. The app uses nested control statements (the `switch` is nested inside the `for`) to determine the number of times each side of the die occurred. The `for` statement (lines 21–47) iterates 6,000,000 times. During each iteration, line 23 produces a random value from 1 to 6. This face value is then used as the `switch expression` (line 26) in the `switch statement` (lines 26–46). Based on the `face` value, the `switch statement` increments one of the six counter variables during each iteration of the loop. (In Section 8.4, we show an elegant way to replace the entire `switch statement` in this app with a single statement.) The `switch statement` has no `default` label because we have a `case` label for every possible die value that the expression in line 23 can produce. Run the app several times and observe the results. You'll see that every time you execute this app, it produces different results.

### 7.9.1 Scaling and Shifting Random Numbers

Previously, we demonstrated the statement

```
face = randomNumbers.Next( 1, 7 );
```

which simulates the rolling of a six-sided die. This statement always assigns to variable `face` an integer in the range `1 ≤ face < 7`. The width of this range (i.e., the number of consecutive integers in the range) is 6, and the starting number in the range is 1. Referring to the preceding statement, we see that the width of the range is determined by the difference between the two integers passed to `Random` method `Next`, and the starting number of the range is the value of the first argument. We can generalize this result as

```
number = randomNumbers.Next( shiftingValue, shiftingValue + scalingFactor );
```

where `shiftingValue` specifies the first number in the desired range of consecutive integers and `scalingFactor` specifies how many numbers are in the range.

It's also possible to choose integers at random from sets of values *other* than ranges of consecutive integers. For this purpose, it's simpler to use the version of the `Next` method that takes only *one* argument. For example, to obtain a random value from the sequence 2, 5, 8, 11 and 14, you could use the statement

```
number = 2 + 3 * randomNumbers.Next( 5 );
```

In this case, `randomNumberGenerator.Next(5)` produces values in the range 0–4. Each value produced is multiplied by 3 to produce a number in the sequence 0, 3, 6, 9 and 12.

We then add 2 to that value to *shift* the range of values and obtain a value from the sequence 2, 5, 8, 11 and 14. We can generalize this result as

```
number = shiftingValue +
    differenceBetweenValues * randomNumbers.Next( scalingFactor );
```

where *shiftingValue* specifies the first number in the desired range of values, *differenceBetweenValues* represents the difference between consecutive numbers in the sequence and *scalingFactor* specifies how many numbers are in the range.

## 7.9.2 Random-Number Repeatability for Testing and Debugging

As we mentioned earlier in this section, the methods of class `Random` actually generate pseudorandom numbers based on complex mathematical calculations. Repeatedly calling any of `Random`'s methods produces a sequence of numbers that appears to be random. The calculation that produces the pseudorandom numbers uses the time of day as a **seed** value to change the sequence's starting point. Each new `Random` object seeds itself with a value based on the computer system's clock at the time the object is created, enabling each execution of an app to produce a *different* sequence of random numbers.

When debugging an app, it's sometimes useful to repeat the *same* sequence of pseudorandom numbers during each execution of the app. This repeatability enables you to prove that your app is working for a specific sequence of random numbers before you test the app with different sequences of random numbers. When repeatability is important, you can create a `Random` object as follows:

```
Random randomNumbers = new Random( seedValue );
```

The *seedValue* argument (type `int`) seeds the random-number calculation. If the *same* *seedValue* is used every time, the `Random` object produces the *same* sequence of random numbers.

## 7.10 Case Study: A Game of Chance; Introducing Enumerations

One popular game of chance is the dice game known as “craps,” which is played in casinos and back alleys throughout the world. The rules of the game are straightforward:

*You roll two dice. Each die has six faces, which contain one, two, three, four, five and six spots, respectively. After the dice have come to rest, the sum of the spots on the two upward faces is calculated. If the sum is 7 or 11 on the first throw, you win. If the sum is 2, 3 or 12 on the first throw (called “craps”), you lose (i.e., “the house” wins). If the sum is 4, 5, 6, 8, 9 or 10 on the first throw, that sum becomes your “point.” To win, you must continue rolling the dice until you “make your point” (i.e., roll that same point value). You lose by rolling a 7 before making your point.*

The app in Fig. 7.8 simulates the game of craps, using methods to define the logic of the game. The `Main` method (lines 24–70) calls the `static RollDice` method (lines 73–85) as needed to roll the two dice and compute their sum. The four sample outputs show winning on the first roll, losing on the first roll, winning on a subsequent roll and losing on a subsequent roll, respectively. Variable `randomNumbers` (line 8) is declared `static` so it can be created once during the program's execution and used in method `RollDice`.

```
1 // Fig. 7.8: Craps.cs
2 // Craps class simulates the dice game craps.
3 using System;
4
5 public class Craps
6 {
7     // create random-number generator for use in method RollDice
8     private static Random randomNumbers = new Random();
9
10    // enumeration with constants that represent the game status
11    private enum Status { CONTINUE, WON, LOST }
12
13    // enumeration with constants that represent common rolls of the dice
14    private enum DiceNames
15    {
16        SNAKE_EYES = 2,
17        TREY = 3,
18        SEVEN = 7,
19        YO_LEVEN = 11,
20        BOX_CARS = 12
21    }
22
23    // plays one game of craps
24    public static void Main( string[] args )
25    {
26        // gameStatus can contain CONTINUE, WON or LOST
27        Status gameStatus = Status.CONTINUE;
28        int myPoint = 0; // point if no win or loss on first roll
29
30        int sumOfDice = RollDice(); // first roll of the dice
31
32        // determine game status and point based on first roll
33        switch ( ( DiceNames ) sumOfDice )
34        {
35            case DiceNames.SEVEN: // win with 7 on first roll
36            case DiceNames.YO_LEVEN: // win with 11 on first roll
37                gameStatus = Status.WON;
38                break;
39            case DiceNames.SNAKE_EYES: // lose with 2 on first roll
40            case DiceNames.TREY: // lose with 3 on first roll
41            case DiceNames.BOX_CARS: // lose with 12 on first roll
42                gameStatus = Status.LOST;
43                break;
44            default: // did not win or lose, so remember point
45                gameStatus = Status.CONTINUE; // game is not over
46                myPoint = sumOfDice; // remember the point
47                Console.WriteLine( "Point is {0}", myPoint );
48                break;
49        } // end switch
50
51        // while game is not complete
52        while ( gameStatus == Status.CONTINUE ) // game not WON or LOST
53        {
```

**Fig. 7.8** | Craps class simulates the dice game craps. (Part I of 3.)

```

54         sumOfDice = RollDice(); // roll dice again
55
56         // determine game status
57         if ( sumOfDice == myPoint ) // win by making point
58             gameStatus = Status.WON;
59         else
60             // lose by rolling 7 before point
61             if ( sumOfDice == ( int ) DiceNames.SEVEN )
62                 gameStatus = Status.LOST;
63     } // end while
64
65     // display won or lost message
66     if ( gameStatus == Status.WON )
67         Console.WriteLine( "Player wins" );
68     else
69         Console.WriteLine( "Player loses" );
70 } // end Main
71
72 // roll dice, calculate sum and display results
73 public static int RollDice()
74 {
75     // pick random die values
76     int die1 = randomNumbers.Next( 1, 7 ); // first die roll
77     int die2 = randomNumbers.Next( 1, 7 ); // second die roll
78
79     int sum = die1 + die2; // sum of die values
80
81     // display results of this roll
82     Console.WriteLine( "Player rolled {0} + {1} = {2}",
83         die1, die2, sum );
84     return sum; // return sum of dice
85 }
86 } // end method RollDice
86 } // end class Craps

```

Player rolled 2 + 5 = 7  
Player wins

Player rolled 2 + 1 = 3  
Player loses

Player rolled 2 + 4 = 6  
Point is 6  
Player rolled 3 + 1 = 4  
Player rolled 5 + 5 = 10  
Player rolled 6 + 1 = 7  
Player loses

**Fig. 7.8** | Craps class simulates the dice game craps. (Part 2 of 3.)

```
Player rolled 4 + 6 = 10
Point is 10
Player rolled 1 + 3 = 4
Player rolled 1 + 3 = 4
Player rolled 2 + 3 = 5
Player rolled 4 + 4 = 8
Player rolled 6 + 6 = 12
Player rolled 4 + 4 = 8
Player rolled 4 + 5 = 9
Player rolled 2 + 6 = 8
Player rolled 6 + 6 = 12
Player rolled 6 + 4 = 10
Player wins
```

**Fig. 7.8** | Craps class simulates the dice game craps. (Part 3 of 3.)

### **Method RollDice**

In the rules of the game, the player must roll two dice on the first roll and must do the same on all subsequent rolls. We declare method `RollDice` (lines 73–85) to roll the dice and compute and display their sum. Method `RollDice` is declared once, but it's called from two places (lines 30 and 54) in method `Main`, which contains the logic for one complete game of craps. Method `RollDice` takes no arguments, so it has an empty parameter list. Each time it's called, `RollDice` returns the sum of the dice, so the return type `int` is indicated in the method header (line 73). Although lines 76 and 77 look the same (except for the die names), they do not necessarily produce the same result. Each of these statements produces a random value in the range 1–6. Variable `randomNumbers` (used in lines 76 and 77) is *not* declared in the method. Rather it's declared as a `private static` variable of the class and initialized in line 8. This enables us to create one `Random` object that's reused in each call to `RollDice`.

### **Method Main's Local Variables**

The game is reasonably involved. The player may win or lose on the first roll or may win or lose on any subsequent roll. Method `Main` (lines 24–70) uses local variable `gameStatus` (line 27) to keep track of the overall game status, local variable `myPoint` (line 28) to store the “point” if the player does not win or lose on the first roll and local variable `sumOfDice` (line 30) to maintain the sum of the dice for the most recent roll. Variable `myPoint` is initialized to 0 to ensure that the app will compile. If you do not initialize `myPoint`, the compiler issues an error, because `myPoint` is not assigned a value in every case of the `switch` statement—thus, the app could try to use `myPoint` before it's definitely assigned a value. By contrast, `gameStatus` does not require initialization because it's assigned a value in every branch of the `switch` statement—thus, it's guaranteed to be initialized before it's used. However, as good programming practice, we initialize it anyway.

### **enum Type Status**

Local variable `gameStatus` is declared to be of a new type called `Status`, which we declared in line 11. Type `Status` is declared as a `private` member of class `Craps`, because `Status` will be used only in that class. `Status` is a user-defined type called an **enumeration**, which declares a set of *constants* represented by identifiers. An enumeration is introduced by the keyword `enum` and a type name (in this case, `Status`). As with a class, braces (`{` and `}`) de-

limit the body of an `enum` declaration. Inside the braces is a comma-separated list of **enumeration constants**. The enum constant names must be *unique*, but the value associated with each constant need not be.

Variables of type `Status` should be assigned only one of the three constants declared in the enumeration. When the game is won, the app sets local variable `gameStatus` to `Status.WON` (lines 37 and 58). When the game is lost, the app sets local variable `gameStatus` to `Status.LOST` (lines 42 and 62). Otherwise, the app sets local variable `gameStatus` to `Status.CONTINUE` (line 45) to indicate that the dice must be rolled again.



### Good Programming Practice 7.2

*Using enumeration constants (like `Status.WON`, `Status.LOST` and `Status.CONTINUE`) rather than literal integer values (such as 0, 1 and 2) can make code easier to read and maintain.*

#### *The First Roll*

Line 30 in method `Main` calls `RollDice`, which picks two random values from 1 to 6, displays the value of the first die, the value of the second die and the sum of the dice, and returns the sum of the dice. Method `Main` next enters the `switch` statement at lines 33–49, which uses the `sumOfDice` value from line 30 to determine whether the game has been won or lost, or whether it should continue with another roll.

#### *DiceNames Enumeration*

The sums of the dice that would result in a win or loss on the first roll are declared in the `DiceNames` enumeration in lines 14–21. These are used in the cases of the `switch` statement. The identifier names use casino parlance for these sums. Notice that in the `DiceNames` enumeration, a value is explicitly assigned to each identifier name. When the `enum` is declared, each constant in the `enum` declaration is a constant value of type `int`. If you do not assign a value to an identifier in the `enum` declaration, the compiler will do so. If the first `enum` constant is unassigned, the compiler gives it the value 0. If any other `enum` constant is unassigned, the compiler gives it a value one higher than that of the preceding `enum` constant. For example, in the `Status` enumeration, the compiler implicitly assigns 0 to `Status.WON`, 1 to `Status.CONTINUE` and 2 to `Status.LOST`.

#### *Underlying Type of an `enum`*

You could also declare an `enum`'s underlying type to be `byte`, `sbyte`, `short`, `ushort`, `int`, `uint`, `long` or `ulong` by writing

```
private enum MyEnum : typeName { Constant1, Constant2, ... }
```

where `typeName` represents one of the integral simple types.

#### *Comparing an Integral Type to an `enum` Constant*

If you need to compare a simple integral type value to the underlying value of an enumeration constant, you must use a cast operator to make the two types match. In the `switch` statement at lines 33–49, we use the `cast` operator to convert the `int` value in `sumOfDice` to type `DiceNames` and compare it to each of the constants in `DiceNames`. Lines 35–36 de-

termine whether the player won on the first roll with SEVEN (7) or YO\_LEVEN (11). Lines 39–41 determine whether the player lost on the first roll with SNAKE\_EYES (2), TREY (3) or BOX\_CARS (12). After the first roll, if the game is not over, the default case (lines 44–48) saves `sumOfDice` in `myPoint` (line 46) and displays the point (line 47).

### *Additional Rolls of the Dice*

If we’re still trying to “make our point” (i.e., the game is continuing from a prior roll), the loop in lines 52–63 executes. Line 54 rolls the dice again. If `sumOfDice` matches `myPoint` in line 57, line 58 sets `gameStatus` to `Status.WON`, and the loop terminates because the game is complete. In line 61, we use the cast operator (`int`) to obtain the underlying value of `DiceNames.SEVEN` so that we can compare it to `sumOfDice`. If `sumOfDice` is equal to `SEVEN` (7), line 62 sets `gameStatus` to `Status.LOST`, and the loop terminates because the game is over. When the game completes, lines 66–69 display a message indicating whether the player won or lost, and the app terminates.

### *Summary of the Craps Example*

Note the use of the various program-control mechanisms we’ve discussed. The `Craps` class uses two methods—`Main` and `RollDice` (called twice from `Main`)—and the `switch`, `while`, `if...else` and nested `if` control statements. Also, notice that we use multiple case labels in the `switch` statement to execute the same statements for sums of `SEVEN` and `YO_LEVEN` (lines 35–36) and for sums of `SNAKE_EYES`, `TREY` and `BOX_CARS` (lines 39–41). To easily create a `switch` statement with all possible values for an `enum` type, you can use the `switch` code snippet. Type `switch` in the C# code then press *Tab* twice. If you specify a variable of an `enum` type in the `switch` statement’s expression and press *Enter*, a case for each `enum` constant will be generated automatically.

## 7.11 Scope of Declarations

You’ve seen declarations of C# entities, such as classes, methods, properties, variables and parameters. Declarations introduce names that can be used to refer to such C# entities. The **scope** of a declaration is the portion of the app that can refer to the declared entity by its unqualified name. Such an entity is said to be “in scope” for that portion of the app. This section introduces several important scope issues. The basic scope rules are as follows:

1. The scope of a parameter declaration is the body of the method in which the declaration appears.
2. The scope of a local-variable declaration is from the point at which the declaration appears to the end of the block containing the declaration.
3. The scope of a local-variable declaration that appears in the initialization section of a `for` statement’s header is the body of the `for` statement and the other expressions in the header.
4. The scope of a method, property or field of a class is the entire body of the class. This enables non-`static` methods and properties of a class to use any of the class’s fields, methods and properties, regardless of the order in which they’re declared. Similarly, `static` methods and properties can use any of the `static` members of the class.

Any block may contain variable declarations. If a local variable or parameter in a method has the same name as a field, the field is hidden until the block terminates. A compilation error occurs if a *nested block* in a method contains a variable with the same name as a local variable in an *outer block* of the method. In Chapter 10, we discuss how to access hidden fields. The app in Fig. 7.9 demonstrates scoping issues with fields and local variables.



### Error-Prevention Tip 7.1

*Use different names for fields and local variables to help prevent subtle logic errors that occur when a method is called and a local variable of the method hides a field of the same name in the class.*

```

1 // Fig. 7.9: Scope.cs
2 // Scope class demonstrates static and local variable scopes.
3 using System;
4
5 public class Scope
6 {
7     // static variable that's accessible to all methods of this class
8     private static int x = 1;
9
10    // Main creates and initializes local variable x
11    // and calls methods UseLocalVariable and UseStaticVariable
12    public static void Main( string[] args )
13    {
14        int x = 5; // method's local variable x hides static variable x
15
16        Console.WriteLine( "local x in method Main is {0}", x );
17
18        // UseLocalVariable has its own local x
19        UseLocalVariable();
20
21        // UseStaticVariable uses class Scope's static variable x
22        UseStaticVariable();
23
24        // UseLocalVariable reinitializes its own local x
25        UseLocalVariable();
26
27        // class Scope's static variable x retains its value
28        UseStaticVariable();
29
30        Console.WriteLine( "\nlocal x in method Main is {0}", x );
31    } // end Main
32
33    // create and initialize local variable x during each call
34    public static void UseLocalVariable()
35    {
36        int x = 25; // initialized each time UseLocalVariable is called
37
38        Console.WriteLine(
39            "\nlocal x on entering method UseLocalVariable is {0}", x );
40        ++x; // modifies this method's local variable x

```

**Fig. 7.9** | Scope class demonstrates static and local variable scopes. (Part 1 of 2.)

```

41     Console.WriteLine(
42         "local x before exiting method UseLocalVariable is {0}", x );
43 } // end method UseLocalVariable
44
45 // modify class Scope's static variable x during each call
46 public static void UseStaticVariable()
47 {
48     Console.WriteLine( "\nstatic variable x on entering {0} is {1}",
49         "method UseStaticVariable", x );
50     x *= 10; // modifies class Scope's static variable x
51     Console.WriteLine( "static variable x before exiting {0} is {1}",
52         "method UseStaticVariable", x );
53 } // end method UseStaticVariable
54 } // end class Scope

```

```

local x in method Main is 5

local x on entering method UseLocalVariable is 25
local x before exiting method UseLocalVariable is 26

static variable x on entering method UseStaticVariable is 1
static variable x before exiting method UseStaticVariable is 10

local x on entering method UseLocalVariable is 25
local x before exiting method UseLocalVariable is 26

static variable x on entering method UseStaticVariable is 10
static variable x before exiting method UseStaticVariable is 100

local x in method Main is 5

```

**Fig. 7.9 |** Scope class demonstrates static and local variable scopes. (Part 2 of 2.)

Line 8 declares and initializes the `static` variable `x` to 1. This `static` variable is *hidden* in any block (or method) that declares local variable named `x`. Method `Main` (lines 12–31) declares local variable `x` (line 14) and initializes it to 5. This local variable's value is output to show that `static` variable `x` (whose value is 1) is hidden in method `Main`. The app declares two other methods—`UseLocalVariable` (lines 34–43) and `UseStaticVariable` (lines 46–53)—that each take no arguments and do not return results. Method `Main` calls each method twice (lines 19–28). Method `UseLocalVariable` declares local variable `x` (line 36). When `UseLocalVariable` is first called (line 19), it creates local variable `x` and initializes it to 25 (line 36), outputs the value of `x` (lines 38–39), increments `x` (line 40) and outputs the value of `x` again (lines 41–42). When `UseLocalVariable` is called a second time (line 25), it re-creates local variable `x` and reinitializes it to 25, so the output of each `UseLocalVariable` call is identical.

Method `UseStaticVariable` does not declare any local variables. Therefore, when it refers to `x`, `static` variable `x` (line 8) of the class is used. When method `UseStaticVariable` is first called (line 22), it outputs the value (1) of `static` variable `x` (lines 48–49), multiplies the `static` variable `x` by 10 (line 50) and outputs the value (10) of `static` variable `x` again (lines 51–52) before returning. The next time method `UseStaticVariable` is called (line 28), the `static` variable has its modified value, 10, so the method outputs 10,

then 100. Finally, in method `Main`, the app outputs the value of local variable `x` again (line 30) to show that none of the method calls modified `Main`'s local variable `x`, because the methods all referred to variables named `x` in other scopes.

## 7.12 Method Overloading

Methods of the same name can be declared in the same class, as long as they have different sets of parameters (determined by the number, types and order of the parameters). This is called **method overloading**. When an **overloaded method** is called, the C# compiler selects the appropriate method by examining the number, types and order of the arguments in the call. Method overloading is commonly used to create several methods with the *same name* that perform the same or similar tasks, but on *different types* or *different numbers of arguments*. For example, `Math` methods `Min` and `Max` (summarized in Section 7.3) are overloaded with 11 versions. These find the minimum and maximum, respectively, of two values of each of the 11 numeric simple types. Our next example demonstrates declaring and invoking overloaded methods. You'll see examples of overloaded constructors in Chapter 10.

### *Declaring Overloaded Methods*

In class `MethodOverload` (Fig. 7.10), we include two overloaded versions of a method called `Square`—one that calculates the square of an `int` (and returns an `int`) and one that calculates the square of a `double` (and returns a `double`). Although these methods have the same name and similar parameter lists and bodies, you can think of them simply as *different methods*. It may help to think of the method names as “`Square of int`” and “`Square of double`,” respectively.

---

```

1 // Fig. 7.10: MethodOverload.cs
2 // Overloaded method declarations.
3 using System;
4
5 public class MethodOverload
6 {
7     // test overloaded square methods
8     public static void Main( string[] args )
9     {
10         Console.WriteLine( "Square of integer 7 is {0}", Square( 7 ) );
11         Console.WriteLine( "Square of double 7.5 is {0}", Square( 7.5 ) );
12     } // end Main
13
14     // square method with int argument
15     public static int Square( int intValue )
16     {
17         Console.WriteLine( "Called square with int argument: {0}",
18                         intValue );
19         return intValue * intValue;
20     } // end method Square with int argument
21 }
```

**Fig. 7.10** | Overloaded method declarations. (Part I of 2.)

```

22  // square method with double argument
23  public static double Square( double doubleValue )
24  {
25      Console.WriteLine( "Called square with double argument: {0}",
26          doubleValue );
27      return doubleValue * doubleValue;
28  } // end method Square with double argument
29 } // end class MethodOverload

```

```

Called square with int argument: 7
Square of integer 7 is 49
Called square with double argument: 7.5
Square of double 7.5 is 56.25

```

**Fig. 7.10** | Overloaded method declarations. (Part 2 of 2.)

Line 10 in Main invokes method Square with the argument 7. Literal integer values are treated as type `int`, so the method call in line 10 invokes the version of Square at lines 15–20 that specifies an `int` parameter. Similarly, line 11 invokes method Square with the argument 7.5. Literal real-number values are treated as type `double`, so the method call in line 11 invokes the version of Square at lines 23–28 that specifies a `double` parameter. Each method first outputs a line of text to prove that the proper method was called in each case.

Notice that the overloaded methods in Fig. 7.10 perform the same calculation, but with two different types. C#'s generics feature provides a mechanism for writing a single “generic method” that can perform the same tasks as an entire set of overloaded methods. We discuss generic methods in Chapter 20.

### Distinguishing Between Overloaded Methods

The compiler distinguishes overloaded methods by their **signature**—a combination of the method's name and the number, types and order of its parameters. The signature also includes the way those parameters are passed, which can be modified by the `ref` and `out` keywords (discussed in Section 7.16). If the compiler looked only at method names during compilation, the code in Fig. 7.10 would be *ambiguous*—the compiler would not know how to distinguish between the Square methods (lines 15–20 and 23–28). Internally, the compiler uses signatures to determine whether a class's methods are unique in that class.

For example, in Fig. 7.10, the compiler will use the method signatures to distinguish between the “Square of `int`” method (the Square method that specifies an `int` parameter) and the “Square of `double`” method (the Square method that specifies a `double` parameter). If Method1's declaration begins as

```
void Method1( int a, float b )
```

then that method will have a different signature than the method declared beginning with

```
void Method1( float a, int b )
```

The *order* of the parameter types is important—the compiler considers the preceding two Method1 headers to be distinct.

### *Return Types of Overloaded Methods*

In discussing the logical names of methods used by the compiler, we did not mention the return types of the methods. This is because method *calls* cannot be distinguished by return type. The app in Fig. 7.11 illustrates the compiler errors generated when two methods have the *same* signature but *different* return types. Overloaded methods can have the *same* or *different* return types if the methods have *different* parameter lists. Also, overloaded methods need not have the same number of parameters.



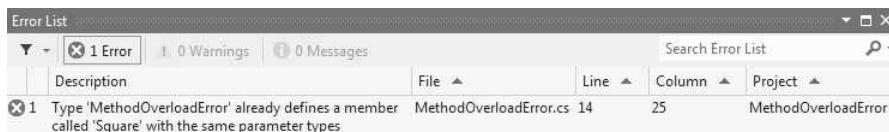
### Common Programming Error 7.9

*Declaring overloaded methods with identical parameter lists is a compilation error regardless of whether the return types are different.*

```

1 // Fig. 7.11: MethodOverload.cs
2 // Overloaded methods with identical signatures
3 // cause compilation errors, even if return types are different.
4 public class MethodOverloadError
5 {
6     // declaration of method Square with int argument
7     public int Square( int x )
8     {
9         return x * x;
10    } // end method Square
11
12    // second declaration of method Square with int argument
13    // causes compilation error even though return types are different
14    public double Square( int y )
15    {
16        return y * y;
17    } // end method Square
18 } // end class MethodOverloadError

```



**Fig. 7.11** | Overloaded methods with identical signatures cause compilation errors, even if return types are different.

## 7.13 Optional Parameters

Methods can have **optional parameters** that allow the calling method to *vary the number of arguments* to pass. An optional parameter specifies a **default value** that's assigned to the parameter if the optional argument is omitted.

You can create methods with one or more optional parameters. *All optional parameters must be placed to the right of the method's non-optional parameters*—that is, at the end of the parameter list.



### Common Programming Error 7.10

*Declaring a non-optional parameter to the right of an optional one is a compilation error.*

When a parameter has a default value, the caller has the *option* of passing that particular argument. For example, the method header

```
public int Power( int baseValue, int exponentValue = 2)
```

specifies an optional second parameter. Any call to Power must pass at least an argument for the parameter `baseValue`, or a compilation error occurs. Optionally, a second argument (for the `exponentValue` parameter) can be passed to Power. Consider the following calls to Power:

```
Power()
Power(10)
Power(10, 3)
```

The first call generates a compilation error because this method requires a minimum of one argument. The second call is valid because one argument (10) is being passed—the optional `exponentValue` is not specified in the method call. The last call is also valid—10 is passed as the required argument and 3 is passed as the optional argument.

In the call that passes only one argument (10), parameter `exponentValue` defaults to 2, which is the default value specified in the method's header. Each optional parameter must specify a default value by using an equal (=) sign followed by the value. For example, the header for Power sets 2 as `exponentValue`'s default value.

Figure 7.12 demonstrates an optional parameter. The program calculates the result of raising a base value to an exponent. Method Power (lines 15–23) specifies that its second parameter is optional. In method `DisplayPowers`, lines 10–11 call method Power. Line 10 calls the method without the optional second argument. In this case, the compiler provides the second argument, 2, using the default value of the optional argument, which is not visible to you in the call.

---

```

1 // Fig. 7.12: Power.vb
2 // Optional argument demonstration with method Power.
3 using System;
4
5 class CalculatePowers
6 {
7     // call Power with and without optional arguments
8     public static void Main( string[] args )
9     {
10        Console.WriteLine( "Power(10) = {0}", Power( 10 ) );
11        Console.WriteLine( "Power(2, 10) = {0}", Power( 2, 10 ) );
12    } // end Main
13
14    // use iteration to calculate power
15    public int Power( int baseValue, int exponentValue = 2 )
16    {
17        int result = 1; // initialize total
18
19        for ( int i = 1; i <= exponentValue; i++ )
20            result *= baseValue;
21    }

```

**Fig. 7.12** | Optional argument demonstration with method Power. (Part I of 2.)

---

```

22     return result;
23 } // end method Power
24 } // end class CalculatePowers

```

```

Power(10) = 100
Power(2, 10) = 1024

```

**Fig. 7.12** | Optional argument demonstration with method `Power`. (Part 2 of 2.)

## 7.14 Named Parameters

Normally, when calling a method that has optional parameters, the argument values—in order—are assigned to the parameters from left to right in the parameter list. Consider a `Time` class that stores the time of day in 24-hour clock format as `int` values representing the hour (0–23), minute (0–59) and second (0–59). Such a class might provide a `SetTime` method with optional parameters like

```
public void SetTime( int hour = 0, int minute = 0, int second = 0 )
```

In the preceding method header, all three of `SetTime`'s parameters are optional. Assuming that we have a `Time` object named `t`, we can call `SetTime` as follows:

```

t.SetTime(); // sets the time to 12:00:00 AM
t.SetTime( 12 ); // sets the time to 12:00:00 PM
t.SetTime( 12, 30 ); // sets the time to 12:30:00 PM
t.SetTime( 12, 30, 22 ); // sets the time to 12:30:22 PM

```

In the first call, no arguments are specified, so the compiler assigns 0 to each parameter. In the second call, the compiler assigns the argument, 12, to the first parameter, `hour`, and assigns default values of 0 to the `minute` and `second` parameters. In the third call, the compiler assigns the two arguments, 12 and 30, to the parameters `hour` and `minute`, respectively, and assigns the default value 0 to the parameter `second`. In the last call, the compiler assigns the three arguments, 12, 30 and 22, to the parameters `hour`, `minute` and `second`, respectively.

What if you wanted to specify only arguments for the `hour` and `second`? You might think that you could call the method as follows:

```
t.SetTime( 12, , 22 ); // COMPILATION ERROR
```

Unlike some programming languages, C# doesn't allow you to skip an argument as shown in the preceding statement. C# provides a feature called **named parameters**, which enable you to call methods that receive optional parameters by providing *only* the optional arguments you wish to specify. To do so, you explicitly specify the parameter's name and value—separated by a colon (:)—in the argument list of the method call. For example, the preceding statement can be implemented as follows:

```
t.SetTime( hour: 12, second: 22 ); // sets the time to 12:00:22
```

In this case, the compiler assigns parameter `hour` the argument 12 and parameter `second` the argument 22. The parameter `minute` is not specified, so the compiler assigns it the default value 0. It's also possible to specify the arguments *out of order* when using named parameters. The arguments for the required parameters must always be supplied.

## 7.15 Recursion

The apps we've discussed thus far are generally structured as methods that call one another in a disciplined, hierarchical manner. For some problems, however, it's useful to have a method call itself. A **recursive method** is a method that calls itself, either *directly* or *indirectly through another method*.

We consider recursion conceptually first. Then we examine an app containing a recursive method. Recursive problem-solving approaches have a number of elements in common. When a recursive method is called to solve a problem, it actually is capable of solving *only* the simplest case(s), or **base case(s)**. If the method is called with a base case, it returns a result. If the method is called with a more complex problem, it divides the problem into two conceptual pieces: a piece that the method knows how to do and a piece that it does not know how to do. To make recursion feasible, the latter piece must resemble the original problem, but be a slightly simpler or slightly smaller version of it. Because this new problem looks like the original problem, the method calls a fresh copy (or several fresh copies) of itself to work on the smaller problem; this is referred to as a **recursive call** and is also called the **recursion step**. The recursion step normally includes a return statement, because its result will be combined with the portion of the problem the method knew how to solve to form a result that will be passed back to the original caller.

The recursion step executes while the original call to the method is still active (i.e., while it has not finished executing). The recursion step can result in many more recursive calls, as the method divides each new subproblem into two conceptual pieces. For the recursion to *terminate* eventually, each time the method calls itself with a slightly simpler version of the original problem, the sequence of smaller and smaller problems must converge on the base case. At that point, the method recognizes the base case and returns a result to the previous copy of the method. A sequence of returns ensues until the original method call returns the result to the caller. This process sounds complex compared with the conventional problem solving we've performed to this point.

### *Recursive Factorial Calculations*

As an example of recursion concepts at work, let's write a recursive app to perform a popular mathematical calculation. Consider the factorial of a nonnegative integer  $n$ , written  $n!$  (and pronounced “ $n$  factorial”), which is the product

$$n \cdot (n - 1) \cdot (n - 2) \cdot \dots \cdot 1$$

$1!$  is equal to 1 and  $0!$  is defined to be 1. For example,  $5!$  is the product  $5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$ , which is equal to 120.

The factorial of an integer, `number`, greater than or equal to 0 can be calculated iteratively (nonrecursively) using the `for` statement as follows:

```
factorial = 1;
for ( int counter = number; counter >= 1; --counter )
    factorial *= counter;
```

A recursive declaration of the factorial method is arrived at by observing the following relationship:

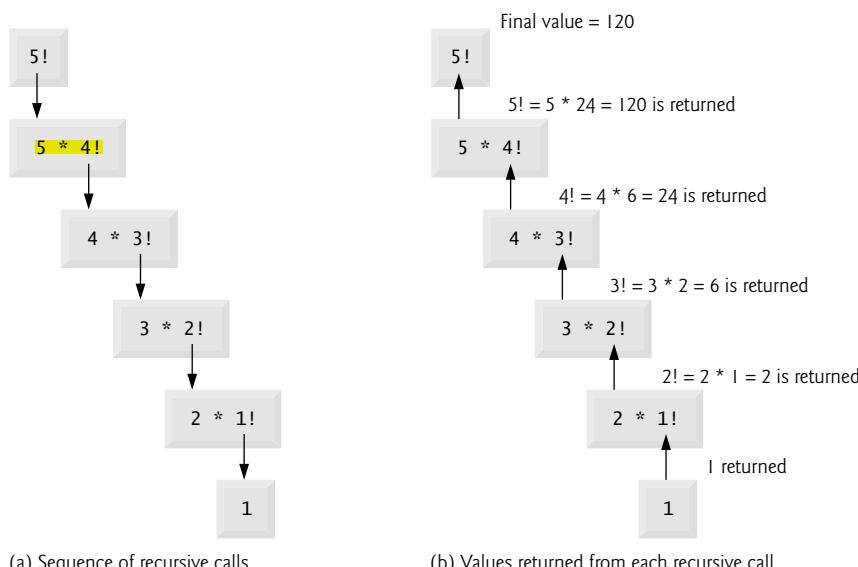
$$n! = n \cdot (n - 1)!$$

For example,  $5!$  is clearly equal to  $5 \cdot 4!$ , as is shown by the following equations:

$$\begin{aligned}5! &= 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 \\5! &= 5 \cdot (4 \cdot 3 \cdot 2 \cdot 1) \\5! &= 5 \cdot (4!)\\ \end{aligned}$$

The evaluation of  $5!$  would proceed as shown in Fig. 7.13. Figure 7.13(a) shows how the succession of recursive calls proceeds until  $1!$  is evaluated to be 1, which terminates the recursion. Figure 7.13(b) shows the values returned from each recursive call to its caller until the value is calculated and returned.

Figure 7.14 uses recursion to calculate and display the factorials of the integers from 0 to 10. The recursive method Factorial (lines 16–24) first tests to determine whether a terminating condition (line 19) is true. If `number` is less than or equal to 1 (the base case), Factorial returns 1, no further recursion is necessary and the method returns. If `number` is greater than 1, line 23 expresses the problem as the product of `number` and a recursive call to Factorial evaluating the factorial of `number - 1`, which is a slightly simpler problem than the original calculation, Factorial(`number`).



**Fig. 7.13** | Recursive evaluation of  $5!$ .

```

1 // Fig. 7.14: FactorialTest.cs
2 // Recursive Factorial method.
3 using System;
4
5 public class FactorialTest
6 {
7     public static void Main( string[] args )
8     {

```

**Fig. 7.14** | Recursive Factorial method. (Part 1 of 2.)

```

9      // calculate the factorials of 0 through 10
10     for ( long counter = 0; counter <= 10; ++counter )
11         Console.WriteLine( "{0}! = {1}",
12                           counter, Factorial( counter ) );
13 } // end Main
14
15 // recursive declaration of method Factorial
16 public static long Factorial( long number )
17 {
18     // base case
19     if ( number <= 1 )
20         return 1;
21     // recursion step
22     else
23         return number * Factorial( number - 1 );
24 } // end method Factorial
25 } // end class FactorialTest

```

```

0! = 1
1! = 1
2! = 2
3! = 6
4! = 24
5! = 120
6! = 720
7! = 5040
8! = 40320
9! = 362880
10! = 3628800

```

**Fig. 7.14** | Recursive Factorial method. (Part 2 of 2.)

Method `Factorial` (lines 16–24) receives a parameter of type `long` and returns a result of type `long`. As you can see in Fig. 7.14, factorial values become large quickly. We chose type `long` (which can represent relatively large integers) so that the app could calculate factorials greater than  $20!$ . Unfortunately, the `Factorial` method produces large values so quickly that factorial values soon exceed even the maximum value that can be stored in a `long` variable. Due to the restrictions on the integral types, variables of type `float`, `double` or `decimal` might ultimately be needed to calculate factorials of larger numbers. This situation points to a weakness in many programming languages—the languages are *not easily extended* to handle the unique requirements of various apps. As you know, C# allows you to create a type that supports arbitrarily large integers if you wish. For example, you could create a `HugeInteger` class (which we ask you to do in Exercise 10.10) that would enable an app to calculate the factorials of arbitrarily large numbers. You can also use the new type `BigInteger` from the .NET Framework’s class library.



### Common Programming Error 7.11

*Either omitting the base case or writing the recursion step incorrectly so that it does not converge on the base case will cause infinite recursion, eventually exhausting memory. This error is analogous to the problem of an infinite loop in an iterative (nonrecursive) solution.*

## 7.16 Passing Arguments: Pass-by-Value vs. Pass-by-Reference

Two ways to pass arguments to functions in many programming languages are **pass-by-value** and **pass-by-reference**. When an argument is passed by *value* (the default in C#), a *copy* of its value is made and passed to the called function. Changes to the *copy* do *not* affect the original variable's value in the caller. This prevents the accidental side effects that so greatly hinder the development of correct and reliable software systems. Each argument that's been passed in the programs in this chapter so far has been passed by value. When an argument is passed by *reference*, the caller gives the method the ability to access and modify the caller's original variable.



### Software Engineering Observation 7.3

*Pass-by-reference can weaken security, because the called function can corrupt the caller's data.*

To pass an object by reference into a method, simply provide as an argument in the method call the variable that refers to the object. Then, in the method body, reference the object using the parameter name. The parameter refers to the original object in memory, so the called method can access the original object directly.

Previously, we discussed the difference between *value types* and *reference types*. A major difference between them is that *value-type variables store values*, so specifying a value-type variable in a method call passes a *copy* of that variable's value to the method. *Reference-type variables store references to objects*, so specifying a reference-type variable as an argument passes the method a copy of the actual reference that refers to the object. Even though the reference itself is passed by value, the method can still use the reference it receives to interact with—and possibly modify—the original object. Similarly, when returning information from a method via a *return* statement, the method returns a copy of the value stored in a value-type variable or a copy of the reference stored in a reference-type variable. When a reference is returned, the calling method can use that reference to interact with the referenced object.

#### **ref** and **out** Parameters

What if you would like to pass a variable by reference so the called method can modify the variable's value? To do this, C# provides keywords **ref** and **out**. Applying the **ref** keyword to a parameter declaration allows you to pass a variable to a method by reference—the called method will be able to modify the original variable in the caller. The **ref** keyword is used for variables that already have been initialized in the calling method. When a method call contains an uninitialized variable as an argument to a **ref** parameter, the compiler generates an error. Preceding a parameter with keyword **out** creates an **output parameter**. This indicates to the compiler that the argument will be passed into the called method by reference and that the called method will assign a value to the original variable in the caller. If the method does *not* assign a value to the output parameter in *every* possible path of execution, the compiler generates an error. This also prevents the compiler from generating an error message for an uninitialized variable that's passed as an argument to a method. A method can return only one value to its caller via a *return* statement, but can return many values by specifying multiple output (**ref** and/or **out**) parameters.

You can also pass a reference-type variable by reference, which allows you to modify it so that it refers to a new object. Passing a reference by reference is a tricky but powerful technique that we discuss in Section 8.8.

### Demonstrating `ref`, `out` and Value Parameters

The app in Fig. 7.15 uses the `ref` and `out` keywords to manipulate integer values. The class contains three methods that calculate the square of an integer. Method `SquareRef` (lines 37–40) multiplies its parameter `x` by itself and assigns the new value to `x`. `SquareRef`'s parameter is declared as `ref int`, which indicates that the argument passed to this method must be an integer that's passed by reference. Because the argument is passed by reference, the assignment at line 39 modifies the original argument's value in the caller.

Method `SquareOut` (lines 44–48) assigns its parameter the value 6 (line 46), then squares that value. `SquareOut`'s parameter is declared as `out int`, which indicates that the argument passed to this method must be an integer that's passed by reference and that the argument does not need to be initialized in advance.

```

1 // Fig. 7.15: ReferenceAndOutputParameters.cs
2 // Reference, output and value parameters.
3 using System;
4
5 class ReferenceAndOutputParameters
6 {
7     // call methods with reference, output and value parameters
8     public static void Main( string[] args )
9     {
10         int y = 5; // initialize y to 5
11         int z; // declares z, but does not initialize it
12
13         // display original values of y and z
14         Console.WriteLine( "Original value of y: {0}", y );
15         Console.WriteLine( "Original value of z: uninitialized\n" );
16
17         // pass y and z by reference
18         SquareRef( ref y ); // must use keyword ref
19         SquareOut( out z ); // must use keyword out
20
21         // display values of y and z after they're modified by
22         // methods SquareRef and SquareOut, respectively
23         Console.WriteLine( "Value of y after SquareRef: {0}", y );
24         Console.WriteLine( "Value of z after SquareOut: {0}\n", z );
25
26         // pass y and z by value
27         Square( y );
28         Square( z );
29
30         // display values of y and z after they're passed to method Square
31         // to demonstrate that arguments passed by value are not modified
32         Console.WriteLine( "Value of y after Square: {0}", y );
33         Console.WriteLine( "Value of z after Square: {0}", z );
34     } // end Main

```

**Fig. 7.15** | Reference, output and value parameters. (Part 1 of 2.)

```

35 // uses reference parameter x to modify caller's variable
36 static void SquareRef( ref int x )
37 {
38     x = x * x; // squares value of caller's variable
39 } // end method SquareRef
40
41 // uses output parameter x to assign a value
42 // to an uninitialized variable
43 static void SquareOut( out int x )
44 {
45     x = 6; // assigns a value to caller's variable
46     x = x * x; // squares value of caller's variable
47 } // end method SquareOut
48
49 // parameter x receives a copy of the value passed as an argument,
50 // so this method cannot modify the caller's variable
51 static void Square( int x )
52 {
53     x = x * x;
54 } // end method Square
55 } // end class ReferenceAndOutputParameters

```

Original value of y: 5  
 Original value of z: uninitialized

Value of y after SquareRef: 25  
 Value of z after SquareOut: 36

Value of y after Square: 25  
 Value of z after Square: 36

**Fig. 7.15** | Reference, output and value parameters. (Part 2 of 2.)

Method `Square` (lines 52–55) multiplies its parameter `x` by itself and assigns the new value to `x`. When this method is called, a *copy* of the argument is passed to the parameter `x`. Thus, even though parameter `x` is modified in the method, the original value in the caller is *not* modified.

Method `Main` (lines 8–34) invokes methods `SquareRef`, `SquareOut` and `Square`. We begin by initializing variable `y` to 5 and declaring, but *not* initializing, variable `z`. Lines 18–19 call methods `SquareRef` and `SquareOut`. Notice that when you pass a variable to a method with a reference parameter, you must precede the argument with the same keyword (`ref` or `out`) that was used to declare the reference parameter. Lines 23–24 display the values of `y` and `z` after the calls to `SquareRef` and `SquareOut`. Notice that `y` has been changed to 25 and `z` has been set to 36.

Lines 27–28 call method `Square` with `y` and `z` as arguments. In this case, both variables are passed by *value*—only *copies* of their values are passed to `Square`. As a result, the values of `y` and `z` remain 25 and 36, respectively. Lines 32–33 output the values of `y` and `z` to show that they were *not* modified.



### Common Programming Error 7.12

*The ref and out arguments in a method call must match the parameters specified in the method declaration; otherwise, a compilation error occurs.*



### Software Engineering Observation 7.4

*By default, C# does not allow you to choose whether to pass each argument by value or by reference. Value types are passed by value. Objects are not passed to methods; rather, references to objects are passed to methods. The references themselves are passed by value. When a method receives a reference to an object, the method can manipulate the object directly, but the reference value cannot be changed to refer to a new object. In Section 8.8, you'll see that references also can be passed by reference.*

## 7.17 Wrap-Up

In this chapter, we discussed the difference between non-static and static methods, and we showed how to call static methods by preceding the method name with the name of the class in which it appears and the member access (.) operator. You saw that the Math class in the .NET Framework Class Library provides many static methods to perform mathematical calculations. We presented several commonly used Framework Class Library namespaces. You learned how to use operator + to perform string concatenations. You also learned how to declare constant values in two ways—with the const keyword and with enum types. We demonstrated simulation techniques and used class Random to generate sets of random numbers. We discussed the scope of fields and local variables in a class. You saw how to overload methods in a class by providing methods with the same name but different signatures. You learned how to use optional and named parameters. We discussed how recursive methods call themselves, breaking larger problems into smaller subproblems until eventually the original problem is solved. You learned the differences between value types and reference types with respect to how they're passed to methods, and how to use the ref and out keywords to pass arguments by reference.

In Chapter 8, you'll learn how to maintain lists and tables of data in arrays. You'll see a more elegant implementation of the app that rolls a die 6,000,000 times and two enhanced versions of our GradeBook case study. You'll also learn how to access an app's command-line arguments that are passed to method Main when a console app begins execution.

## Summary

### Section 7.1 Introduction

- Experience has shown that the best way to develop and maintain a large app is to construct it from small, simple pieces. This technique is called divide and conquer.

### Section 7.2 Packaging Code in C#

- Three common ways of packaging code are methods, classes and namespaces.
- Methods allow you to modularize an app by separating its tasks into self-contained units.
- Dividing an app into meaningful methods makes it easier to debug and maintain.

### **Section 7.3 static Methods, static Variables and Class Math**

- You can call any **static** method by specifying the name of the class in which it's declared, followed by the member access (.) operator and the method name, as in

`ClassName.MethodName( arguments )`

- Method arguments may be constants, variables or expressions.
- A constant is declared with the keyword **const**—its value cannot be changed after the constant is declared.
- **Math.PI** (3.14159265358979323846) is the ratio of a circle's circumference to its diameter. **Math.E** (2.7182818284590452354) is the base value for natural logarithms.
- When each object of a class maintains its own copy of an attribute, each object (instance) of the class has a separate instance of the variable. When objects of a class containing **static** variables are created, all objects of that class share one copy of the class's **static** variables.
- Together the **static** variables and instance variables represent the fields of a class.
- When you execute an app, you can specify command-line arguments. The execution environment will pass these arguments as **strings** to the **Main** method of your app.
- If you declare more than one **Main** method among all the classes of your project, you'll need to indicate which one you would like to be the app's entry point. You can do this by clicking the menu **PROJECT > [ProjectName] Properties...** and selecting the class containing the **Main** method that should be the entry point from the **Startup** object list box.

### **Section 7.4 Declaring Methods with Multiple Parameters**

- Multiple parameters are specified as a comma-separated list.
- When a method is called, each parameter is initialized with the value of the corresponding argument. There must be one argument in the method call for each required parameter in the method declaration. Each argument must be consistent with the type of the corresponding parameter.
- When program control returns to the point in the app where a method was called, the method's parameters are no longer accessible.
- Methods can return at most one value; the returned value can be a value type that contains many values (implemented as a **struct**) or a reference to an object that contains many values.
- C# allows **string** objects to be created by assembling smaller **strings** into larger **strings** using operator **+**. This is known as **string** concatenation.
- Every value of a simple type in C# has a **string** representation. When one of the **+** operator's operands is a **string**, the other is implicitly converted to a **string**, then the two are concatenated.
- All objects have a **ToString** method that returns a **string** representation of the object. When an object is concatenated with a **string**, the object's **ToString** method is implicitly called to obtain the **string** representation of the object.

### **Section 7.5 Notes on Declaring and Using Methods**

- You've seen three ways to call a method—using a method name by itself to call another method of the same class; using a variable that contains a reference to an object, followed by the member access (.) operator and the method name to call a non-**static** method of the referenced object; and using the class name and the member access (.) operator to call a **static** method of a class.
- A **static** method can call only other **static** methods of the same class directly and can manipulate only **static** variables in the same class directly.
- There are three ways to return control to the statement that calls a method. If the method doesn't return a result, control returns when the method-ending right brace is reached or the statement

```
return;
```

is executed. If the method returns a result, the statement

```
return expression;
```

evaluates the *expression*, then returns the result to the caller.

### **Section 7.6 Method-Call Stack and Activation Records**

- Stacks are known as last-in, first-out (LIFO) data structures—the last item pushed (inserted) on the stack is the first item popped off (removed from) the stack.
- When an app calls a method, the called method must know how to return to its caller, so the return address of the calling method is pushed onto the program-execution stack. If a series of method calls occurs, the successive return addresses are pushed onto the stack in last-in, first-out order so that each method can return to its caller.
- The program-execution stack also contains the memory for the local variables used in each invocation of a method during an app’s execution. This data, stored as a portion of the program-execution stack, is known as the activation record or stack frame of the method call.
- If a local variable holding a reference to an object is the only variable in the app with a reference to that object, when the activation record containing that local variable is popped off the stack, the object will eventually be deleted from memory during “garbage collection.”
- The amount of memory in a computer is finite. If more method calls occur than can have their activation records stored on the program-execution stack, a fatal error called a stack overflow occurs.

### **Section 7.7 Argument Promotion and Casting**

- Another important feature of method calls is argument promotion—implicitly converting an argument’s value to the type that the method expects to receive in its corresponding parameter.
- The argument-promotion rules apply to expressions containing values of two or more simple types and to simple-type values passed as arguments to methods.
- In cases where information may be lost due to conversion between simple types, the compiler requires you to use a cast operator to explicitly force the conversion.

### **Section 7.8 The .NET Framework Class Library**

- Many predefined classes are grouped into categories of related classes called namespaces. Together, these namespaces are referred to as the .NET Framework Class Library.

### **Section 7.9 Case Study: Random-Number Generation**

- Random method Next generates a random int value in the range 0 to +2,147,483,646, inclusive.
- Class Random provides other versions of method Next. One receives an int and returns a value from 0 up to, but not including, the argument’s value. The other receives two ints and returns a value from the first argument’s value up to, but not including, the second argument’s value.
- The methods of class Random actually generate pseudorandom numbers based on complex mathematical calculations. The calculation that produces the pseudorandom numbers uses the time of day as a seed value to change the sequence’s starting point.
- If the same seed value is used every time, the Random object produces the same sequence of random numbers. Class Random’s constructor can receive the seed value as an argument.

### **Section 7.10 Case Study: A Game of Chance; Introducing Enumerations**

- An enumeration is introduced by the keyword enum and a type name. Braces delimit the body of an enum declaration. Inside the braces is a comma-separated list of enumeration constants.

- Variables of an `enum` type should be assigned only constants of that `enum` type.
- When an `enum` is declared, each constant in the `enum` declaration is a constant value of type `int`. If you do not assign a value to an identifier in the `enum` declaration, the compiler will do so. If the first `enum` constant is unassigned, the compiler gives it the value 0. If any other `enum` constant is unassigned, the compiler gives it a value equal to one more than the value of the preceding `enum` constant. The `enum` constant names must be unique, but their underlying values need not be.
- If you need to compare a simple integral type value to the underlying value of an enumeration constant, you must use a cast operator to make the two types match.

### ***Section 7.11 Scope of Declarations***

- The scope of a declaration is the portion of the app that can refer to the declared entity by its unqualified name.
- The scope of a parameter declaration is the body of the method in which the declaration appears.
- A local variable's scope is from the point at which the declaration appears to the end of that block.
- The scope of a local-variable declaration that appears in the initialization section of a `for` statement's header is the body of the `for` statement and the other expressions in the header.
- The scope of a method, property or field of a class is the entire body of the class.
- Any block may contain variable declarations. If a local variable or parameter in a method has the same name as a field, the field is hidden until the block terminates execution.

### ***Section 7.12 Method Overloading***

- Methods of the same name can be declared in the same class, as long as they have different sets of parameters. This is called method overloading. When an overloaded method is called, the C# compiler selects the appropriate method by examining the number, types and order of the arguments in the call.
- The compiler distinguishes overloaded methods by their signature—a combination of the method's name and the number, types and order of its parameters. The signature also includes the way those parameters are passed, which can be modified by the `ref` and `out` keywords.
- The compiler will generate an error when two methods have the same signature but different return types. Overloaded methods can have the same or different return types if the methods have different parameter lists.

### ***Section 7.13 Optional Parameters***

- Methods can have optional parameters, which allow the calling method to vary the number of arguments to pass. An optional parameter specifies a default value that's assigned to the parameter if the optional argument is omitted.
- Methods can have one or more optional parameters. All optional parameters must be placed to the right of the method's non-optional parameters.
- When a parameter has a default value, the caller has the option of passing that particular argument.

### ***Section 7.14 Named Parameters***

- Normally, when calling a method that has optional parameters, the argument values—in order—are assigned to the parameters from left to right in the parameter list.
- C# provides a feature called named parameters, which enable you to call methods that receive optional parameters by providing only the optional arguments you wish to specify. To do so, you explicitly specify the parameter's name and value—separated by a colon (`:`)—in the argument list of the method call.

### **Section 7.15 Recursion**

- A recursive method calls itself, either directly or indirectly through another method.
- When a recursive method is called to solve a problem, the method actually is capable of solving only the simplest case(s), or base case(s). If the method is called with a base case, the method returns a result.
- If the method is called with a more complex problem, the method divides the problem into two conceptual pieces: a piece that the method knows how to do and a piece that it does not know how to do. Because this new problem looks like the original problem, the method calls a fresh copy of itself to work on the smaller problem; this procedure is referred to as a recursive call and is also called the recursion step.
- A recursive declaration of the factorial method is arrived at by observing the relationship:

$$n! = n \cdot (n - 1)!$$

### **Section 7.16 Passing Arguments: Pass-by-Value vs. Pass-by-Reference**

- Two ways to pass arguments to functions in many programming languages are pass-by-value and pass-by-reference.
- When an argument is passed by value (the default), a *copy* of the argument's value is passed to the called function. Changes to the copy do not affect the original variable's value in the caller.
- When an argument is passed by reference, the caller gives the method the ability to access and modify the caller's original data directly.
- Value-type variables store values, so specifying a value-type variable in a method call passes a copy of that variable's value to the method. Reference-type variables store references to objects, so specifying a reference-type variable as an argument passes the method a copy of the actual reference that refers to the object.
- When returning information from a method via a `return` statement, the method returns a copy of the value stored in a value-type variable or a copy of the reference stored in a reference-type variable.
- C# provides the keywords `ref` and `out` to pass variables by reference.
- A `ref` parameter indicates that an argument will be passed to the method by reference—the called method will be able to modify the original variable in the caller.
- An `out` parameter indicates that a possibly uninitialized variable will be passed into the method by reference and that the called method will assign a value to the original variable in the caller.
- A method can return only one value to its caller via a `return` statement, but can return many values by specifying multiple output (`ref` and/or `out`) parameters.
- When a variable is passed to a method with a reference parameter, you must precede the variable with the same keyword (`ref` or `out`) that was used to declare the reference parameter.

## **Terminology**

activation record	divide-and-conquer approach
argument promotion	element of chance
base case in recursion	entry point of an app
block	<code>enum</code> keyword
command-line argument	enumeration
<code>const</code> keyword	enumeration constant
constant	field of a class
default value	formal parameter

hierarchical boss-method/worker-method relationship	push data onto a stack pseudorandom number
implicit conversion	Random class
infinite recursion	random numbers
last-in, first-out (LIFO) data structure	ref keyword
local variable	recursion
Math.PI constant	recursion step
Math.E constant	recursive call
method-call stack	recursive method
method overloading	reusable software components
modularizing an app with methods	scaling factor (with random numbers)
named parameter	scope of a declaration
namespace	seed value (with random numbers)
Next method of class Random	shift a range (with random numbers)
optional parameter	shifting value (with random numbers)
out keyword	signature of a method
output parameter	simulation
overloaded method	simple type promotions
parameter list	stack
pass by reference	stack frame
pass by value	stack overflow
pop data from a stack	string concatenation
program-execution stack	unqualified class name
promotion rules	user-defined method

## Self-Review Exercises

**7.1** Fill in the blanks in each of the following statements:

- a) A method is invoked with a(n) \_\_\_\_\_.
- b) A variable known only within the method in which it's declared is called a(n) \_\_\_\_\_.
- c) The \_\_\_\_\_ statement in a called method can be used to pass the value of an expression back to the calling method.
- d) The keyword \_\_\_\_\_ indicates that a method does not return a value.
- e) Data can be added to or removed from only the \_\_\_\_\_ of a stack.
- f) Stacks are known as \_\_\_\_\_ data structures—the last item pushed (inserted) on the stack is the first item popped off (removed from) the stack.
- g) The three ways to return control from a called method to a caller are \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.
- h) An object of class \_\_\_\_\_ produces pseudorandom numbers.
- i) The program-execution stack contains the memory for local variables on each invocation of a method during an app's execution. This data, stored as a portion of the program-execution stack, is known as the \_\_\_\_\_ or \_\_\_\_\_ of the method call.
- j) If there are more method calls than can be stored on the program execution stack, an error known as a(n) \_\_\_\_\_ occurs.
- k) The \_\_\_\_\_ of a declaration is the portion of an app that can refer to the entity in the declaration by its unqualified name.
- l) It's possible to have several methods with the same name that each operate on different types or numbers of arguments. This feature is called method \_\_\_\_\_.
- m) The program-execution stack is also referred to as the \_\_\_\_\_ stack.
- n) A method that calls itself either directly or indirectly is a(n) \_\_\_\_\_ method.

- o) A recursive method typically has two components: one that provides a means for the recursion to terminate by testing for a(n) \_\_\_\_\_ case and one that expresses the problem as a recursive call for a slightly simpler problem than does the original call.**
- 7.2** For the class `Craps` in Fig. 7.8, state the scope of each of the following entities:
- the variable `randomNumbers`.
  - the variable `die1`.
  - the method `RollDice`.
  - the method `Main`.
  - the variable `sumOfDice`.
- 7.3** Write an app that tests whether the examples of the `Math` class method calls shown in Fig. 7.2 actually produce the indicated results.
- 7.4** Give the method header for each of the following methods:
- Method `Hypotenuse`, which takes two double-precision, floating-point arguments `side1` and `side2` and returns a double-precision, floating-point result.
  - Method `Smallest`, which takes three integers `x`, `y` and `z` and returns an integer.
  - Method `Instructions`, which does not take any arguments and does not return a value.  
[Note: Such methods are commonly used to display instructions to a user.]
  - Method `Int.ToDouble`, which takes integer argument `number` and returns a `double` value.
- 7.5** Find the error in each of the following code segments. Explain how to correct the error.
- `void G()`  

```

    {
        Console.WriteLine( "Inside method G" );
        void H()
        {
            Console.WriteLine( "Inside method H" );
        }
    }

```
  - `int Sum( int x, int y )`  

```

    {
        int result;
        result = x + y;
    }

```
  - `void F( float a );`  

```

    {
        float a;
        Console.WriteLine( a );
    }

```
  - `void Product()`  

```

    {
        int a = 6, b = 5, c = 4, result;
        result = a * b * c;
        Console.WriteLine( "Result is " + result );
        return result;
    }

```
- 7.6** Write a complete C# app to prompt the user for the `double` radius of a sphere, and call method `SphereVolume` to calculate and display the volume of the sphere. Use the following statement to calculate the volume:
- ```
double volume = ( 4.0 / 3.0 ) * Math.PI * Math.Pow( radius, 3 )
```

## Answers to Self-Review Exercises

**7.1** a) method call. b) local variable. c) return. d) void. e) top. f) last-in-first-out (LIFO). g) return; or return *expression*; or encountering the closing right brace of a method. h) Random. i) activation record, stack frame. j) stack overflow. k) scope. l) overloading. m) method call. n) recursive. o) base.

**7.2** a) class body. b) block that defines method RollDice's body. c) class body. d) class body. e) block that defines method Main's body.

**7.3** The following solution demonstrates the Math class methods in Fig. 7.2:

```

1 // Exercise 7.3 Solution: MathTest.cs
2 // Testing the Math class methods.
3 using System;
4
5 public class MathTest
6 {
7     public static void Main( string[] args )
8     {
9         Console.WriteLine( "Math.Abs( 23.7 ) = {0}", Math.Abs( 23.7 ) );
10        Console.WriteLine( "Math.Abs( 0.0 ) = {0}", Math.Abs( 0.0 ) );
11        Console.WriteLine( "Math.Abs( -23.7 ) = {0}", Math.Abs( -23.7 ) );
12        Console.WriteLine( "Math.Ceiling( 9.2 ) = {0}",
13                         Math.Ceiling( 9.2 ) );
14        Console.WriteLine( "Math.Ceiling( -9.8 ) = {0}",
15                         Math.Ceiling( -9.8 ) );
16        Console.WriteLine( "Math.Cos( 0.0 ) = {0}", Math.Cos( 0.0 ) );
17        Console.WriteLine( "Math.Exp( 1.0 ) = {0}", Math.Exp( 1.0 ) );
18        Console.WriteLine( "Math.Exp( 2.0 ) = {0}", Math.Exp( 2.0 ) );
19        Console.WriteLine( "Math.Floor( 9.2 ) = {0}", Math.Floor( 9.2 ) );
20        Console.WriteLine( "Math.Floor( -9.8 ) = {0}",
21                         Math.Floor( -9.8 ) );
22        Console.WriteLine( "Math.Log( Math.E ) = {0}",
23                         Math.Log( Math.E ) );
24        Console.WriteLine( "Math.Log( Math.E * Math.E ) = {0}",
25                         Math.Log( Math.E * Math.E ) );
26        Console.WriteLine( "Math.Max( 2.3, 12.7 ) = {0}",
27                         Math.Max( 2.3, 12.7 ) );
28        Console.WriteLine( "Math.Max( -2.3, -12.7 ) = {0}",
29                         Math.Max( -2.3, -12.7 ) );
30        Console.WriteLine( "Math.Min( 2.3, 12.7 ) = {0}",
31                         Math.Min( 2.3, 12.7 ) );
32        Console.WriteLine( "Math.Min( -2.3, -12.7 ) = {0}",
33                         Math.Min( -2.3, -12.7 ) );
34        Console.WriteLine( "Math.Pow( 2.0, 7.0 ) = {0}",
35                         Math.Pow( 2.0, 7.0 ) );
36        Console.WriteLine( "Math.Pow( 9.0, 0.5 ) = {0}",
37                         Math.Pow( 9.0, 0.5 ) );
38        Console.WriteLine( "Math.Sin( 0.0 ) = {0}", Math.Sin( 0.0 ) );
39        Console.WriteLine( "Math.Sqrt( 900.0 ) = {0}",
40                         Math.Sqrt( 900.0 ) );
41        Console.WriteLine( "Math.Tan( 0.0 ) = {0}", Math.Tan( 0.0 ) );
42    } // end Main
43 } // end class MathTest

```

```

Math.Abs( 23.7 ) = 23.7
Math.Abs( 0.0 ) = 0
Math.Abs( -23.7 ) = 23.7

```

```

Math.Ceiling( 9.2 ) = 10
Math.Ceiling( -9.8 ) = -9
Math.Cos( 0.0 ) = 1
Math.Exp( 1.0 ) = 2.71828182845905
Math.Exp( 2.0 ) = 7.38905609893065
Math.Floor( 9.2 ) = 9
Math.Floor( -9.8 ) = -10
Math.Log( Math.E ) = 1
Math.Log( Math.E * Math.E ) = 2
Math.Max( 2.3, 12.7 ) = 12.7
Math.Max( -2.3, -12.7 ) = -2.3
Math.Min( 2.3, 12.7 ) = 2.3
Math.Min( -2.3, -12.7 ) = -12.7
Math.Pow( 2.0, 7.0 ) = 128
Math.Pow( 9.0, 0.5 ) = 3
Math.Sin( 0.0 ) = 0
Math.Sqrt( 900.0 ) = 30
Math.Tan( 0.0 ) = 0

```

- 7.4** a) **double** Hypotenuse( **double** side1, **double** side2 )  
 b) **int** Smallest( **int** x, **int** y, **int** z )  
 c) **void** Instructions()  
 d) **double** Int.ToDouble( **int** number )

- 7.5** a) *Error:* Method H is declared within method G.

*Correction:* Move the declaration of H outside the declaration of G.

- b) *Error:* The method is supposed to return an integer, but does not.

*Correction:* Delete variable result and place the statement

```
return x + y;
```

in the method, or add the following statement at the end of the method body:

```
return result;
```

- c) *Error:* The semicolon after the right parenthesis of the parameter list is incorrect, and the parameter a should not be redeclared in the method.

*Correction:* Delete the semicolon after the right parenthesis of the parameter list, and delete the declaration float a;.

- d) *Error:* The method returns a value when it's not supposed to.

*Correction:* Change the return type from void to int.

- 7.6** The following solution calculates the volume of a sphere, using the radius entered by the user:

```

1 // Exercise 7.6 Solution: Sphere.cs
2 // Calculate the volume of a sphere.
3 using System;
4
5 public class Sphere
6 {
7     // obtain radius from user and display volume of sphere
8     public static void Main( string[] args )
9     {
10         Console.Write( "Enter radius of sphere: " );
11         double radius = Convert.ToDouble( Console.ReadLine() );
12
13         Console.WriteLine( "Volume is {0:F3}", SphereVolume( radius ) );
14     } // end Main
15
16     // calculate and return sphere volume
17     public static double SphereVolume( double radius )
18     {

```

```

19     double volume = ( 4.0 / 3.0 ) * Math.PI * Math.Pow( radius, 3 );
20     return volume;
21 } // end method SphereVolume
22 } // end class Sphere

```

Enter radius of sphere: 4  
Volume is 268.083

## Exercises

**7.7** What is the value of *x* after each of the following statements is executed?

- a) *x* = Math.Abs( 7.5 );
- b) *x* = Math.Floor( 7.5 );
- c) *x* = Math.Abs( 0.0 );
- d) *x* = Math.Ceiling( 0.0 );
- e) *x* = Math.Abs( -6.4 );
- f) *x* = Math.Ceiling( -6.4 );
- g) *x* = Math.Ceiling( -Math.Abs( -8 + Math.Floor( -5.5 ) ) );

**7.8 (Parking Charges)** A parking garage charges a \$2.00 minimum fee to park for up to three hours. The garage charges an additional \$0.50 per hour for each hour *or part thereof* in excess of three hours. The maximum charge for any given 24-hour period is \$10.00. Assume that no car parks for longer than 24 hours at a time. Write an app that calculates and displays the parking charges for each customer who parked in the garage yesterday. You should enter the hours parked for each customer. The app should display the charge for the current customer and should calculate and display the running total of yesterday's receipts. The app should use method CalculateCharges to determine the charge for each customer.

**7.9 (Rounding to Nearest Integer)** An app of method Math.Floor is rounding a value to the nearest integer. The statement

```
y = Math.Floor( x + 0.5 );
```

will round the number *x* to the nearest integer and assign the result to *y*. Write an app that reads double values and uses the preceding statement to round each of the numbers to the nearest integer. For each number processed, display both the original number and the rounded number.

**7.10 (Rounding to a Specific Decimal Place)** Math.Floor may be used to round a number to a specific decimal place. The statement

```
y = Math.Floor( x * 10 + 0.5 ) / 10;
```

rounds *x* to the tenths position (i.e., the first position to the right of the decimal point). The statement

```
y = Math.Floor( x * 100 + 0.5 ) / 100;
```

rounds *x* to the hundredths position (i.e., the second position to the right of the decimal point). Write an app that defines four methods for rounding a number *x* in various ways:

- a) RoundToInteger( number )
- b) RoundToTenths( number )
- c) RoundToHundredths( number )
- d) RoundToThousands( number )

For each value read, your app should display the original value, the number rounded to the nearest integer, the number rounded to the nearest tenth, the number rounded to the nearest hundredth and the number rounded to the nearest thousandth.

**7.11** Answer each of the following questions:

- What does it mean to choose numbers “at random”?
- Why is the `Random` class useful for simulating games of chance?
- Why is it often necessary to scale or shift the values produced by a `Random` object?
- Why is computerized simulation of real-world situations a useful technique?

**7.12** Write statements that assign random integers to the variable `n` in the following ranges. Assume `Random randomNumbers = new Random()` has been defined and use the two-parameter version of the method `Random.Next`.

- $1 \leq n \leq 2$
- $1 \leq n \leq 100$
- $0 \leq n \leq 9$
- $1000 \leq n \leq 1112$
- $-1 \leq n \leq 1$
- $-3 \leq n \leq 11$

**7.13** For each of the following sets of integers, write a single statement that will display a number at random from the set. Assume `Random randomNumbers = new Random()` has been defined and use the one-parameter version of method `Random.Next`.

- 2, 4, 6, 8, 10.
- 3, 5, 7, 9, 11.
- 6, 10, 14, 18, 22.

**7.14** (*Exponentiation*) Write a method `IntegerPower( base, exponent )` that returns the value of

$$\text{base}^{\text{exponent}}$$

For example, `IntegerPower( 3, 4 )` calculates  $3^4$  (or  $3 * 3 * 3 * 3$ ). Assume that `exponent` is a positive integer and that `base` is an integer. Method `IntegerPower` should use a `for` or `while` loop to control the calculation. Do not use any Math-library methods. Incorporate this method into an app that reads integer values for `base` and `exponent` and performs the calculation with the `IntegerPower` method.

**7.15** (*Hypotenuse of a Right Triangle*) Write method `Hypotenuse` that calculates the length of the hypotenuse of a right triangle when the lengths of the other two sides are given. The method should take two arguments of type `double` and return the hypotenuse as a `double`. Incorporate this method into an app that reads values for `side1` and `side2` and performs the calculation with the `Hypotenuse` method. Determine the length of the hypotenuse for each of the triangles in Fig. 7.16.

| Triangle | Side 1 | Side 2 |
|----------|--------|--------|
| 1        | 3.0    | 4.0    |
| 2        | 5.0    | 12.0   |
| 3        | 8.0    | 15.0   |

**Fig. 7.16** | Values for the sides of triangles in Exercise 7.15.

**7.16** (*Multiples*) Write method `Multiple` that determines, for a pair of integers, whether the second integer is a multiple of the first. The method should take two integer arguments and return `true` if the second is a multiple of the first and `false` otherwise. Incorporate this method into an app that inputs a series of pairs of integers (one pair at a time) and determines whether the second value in each pair is a multiple of the first.

**7.17 (Even or Odd)** Write method `IsEven` that uses the remainder operator (%) to determine whether an integer is even. The method should take an integer argument and return `true` if the integer is even and `false` otherwise. Incorporate this method into an app that inputs a sequence of integers (one at a time) and determines whether each is even or odd.

**7.18 (Displaying a Square of Asterisks)** Write method `SquareOfAsterisks` that displays a solid square (the same number of rows and columns) of asterisks whose side length is specified in integer parameter `side`. For example, if `side` is 4, the method should display

```
*****
*****
*****
*****
```

Incorporate this method into an app that reads an integer value for `side` from the user and outputs the asterisks with the `SquareOfAsterisks` method.

**7.19 (Displaying a Square of Any Character)** Modify the method created in Exercise 7.18 to form the square out of whatever character is contained in character parameter `FillCharacter`. Thus, if `side` is 5 and `FillCharacter` is '#', the method should display

```
#####
#####
#####
#####
#####
```

[Hint: Use the expression `Convert.ToChar(Console.Read())` to read a character from the user.]

**7.20 (Circle Area)** Write an app that prompts the user for the radius of a circle and uses method `CircleArea` to calculate the area of the circle.

**7.21 (Separating Digits)** Write code segments that accomplish each of the following tasks:

- Calculate the integer part of the quotient when integer `a` is divided by integer `b`.
- Calculate the integer remainder when integer `a` is divided by integer `b`.
- Use the app pieces developed in parts (a) and (b) to write a method `DisplayDigits` that receives an integer between 1 and 99999 and displays it as a sequence of digits, separating each pair of digits by two spaces. For example, the integer 4562 should appear as:  
4 5 6 2.
- Incorporate the method developed in part (c) into an app that inputs an integer and calls `DisplayDigits` by passing the method the integer entered. Display the results.

**7.22 (Temperature Conversions)** Implement the following integer methods:

- Method `Celsius` returns the Celsius equivalent of a Fahrenheit temperature, using the calculation

$$c = 5.0 / 9.0 * (f - 32);$$

- Method `Fahrenheit` returns the Fahrenheit equivalent of a Celsius temperature, using the calculation

$$f = 9.0 / 5.0 * c + 32;$$

- Use the methods from parts (a) and (b) to write an app that enables the user either to enter a Fahrenheit temperature and display the Celsius equivalent or to enter a Celsius temperature and display the Fahrenheit equivalent.

**7.23 (Find the Minimum)** Write a method `Minimum3` that returns the smallest of three floating-point numbers. Use the `Math.Min` method to implement `Minimum3`. Incorporate the method into an app that reads three values from the user, determines the smallest value and displays the result.

**7.24 (Perfect Numbers)** An integer number is said to be a *perfect number* if its factors, including 1 (but not the number itself), sum to the number. For example, 6 is a perfect number, because  $6 = 1 + 2 + 3$ . Write method `Perfect` that determines whether parameter `value` is a perfect number. Use this method in an app that determines and displays all the perfect numbers between 2 and 1000. Display the factors of each perfect number to confirm that the number is indeed perfect.

**7.25 (Prime Numbers)** An integer is said to be *prime* if it's greater than 1 and divisible by only 1 and itself. For example, 2, 3, 5 and 7 are prime, but 4, 6, 8 and 9 are not.

- Write a method that determines whether a number is prime.
- Use this method in an app that displays all the prime numbers less than 10,000.
- Initially, you might think that  $n/2$  is the upper limit for which you must test to see whether a number is prime, but you need only go as high as the square root of  $n$ . Rewrite the app, and run it both ways.

**7.26 (Reversing Digits)** Write a method that takes an integer value and returns the number with its digits reversed. For example, given the number 7631, the method should return 1367. Incorporate the method into an app that reads a value from the user and displays the result.

**7.27 (Greatest Common Divisor)** The *greatest common divisor (GCD)* of two integers is the largest integer that evenly divides each of the two numbers. Write method `Gcd` that returns the greatest common divisor of two integers. Incorporate the method into an app that reads two values from the user and displays the result.

**7.28 (Converting Grade Averages to a Four-Point Scale)** Write method `QualityPoints` that inputs a student's average and returns 4 if the student's average is 90–100, 3 if the average is 80–89, 2 if the average is 70–79, 1 if the average is 60–69 and 0 if the average is lower than 60. Incorporate the method into an app that reads a value from the user and displays the result.

**7.29 (Coin Tossing)** Write an app that simulates coin tossing. Let the app toss a coin each time the user chooses the “Toss Coin” menu option. Count the number of times each side of the coin appears. Display the results. The app should call a separate method `Flip` that takes no arguments and returns `false` for tails and `true` for heads. [Note: If the app realistically simulates coin tossing, each side of the coin should appear approximately half the time.]

**7.30 (Guess the Number Game)** Write an app that plays “guess the number” as follows: Your app chooses the number to be guessed by selecting a random integer in the range 1 to 1000. The app displays the prompt `Guess a number between 1 and 1000`. The player inputs a first guess. If the player's guess is incorrect, your app should display `Too high. Try again.` or `Too low. Try again.` to help the player “zero in” on the correct answer. The app should prompt the user for the next guess. When the user enters the correct answer, display `Congratulations. You guessed the number!` and allow the user to choose whether to play again. [Note: The guessing technique employed in this problem is similar to a binary search, which is discussed in Chapter 18.]

**7.31 (Enhanced Guess the Number Game)** Modify the app of Exercise 7.30 to count the number of guesses the player makes. If the number is 10 or fewer, display `Either you know the secret or you got lucky!` If the player guesses the number in 10 tries, display `Aha! You know the secret!` If the player makes more than 10 guesses, display `You should be able to do better!` Why should it take no more than 10 guesses? Well, with each “good guess,” the player should be able to eliminate half of the numbers. Now show why any number from 1 to 1000 can be guessed in 10 or fewer tries.

**7.32 (Distance Between Two Points)** Write method `Distance` to calculate the distance between two points  $(x_1, y_1)$  and  $(x_2, y_2)$ . All numbers and return values should be of type `double`. Incorporate this method into an app that enables the user to enter the coordinates of the points.

**7.33 (Craps Game Modification)** Modify the craps app of Fig. 7.8 to allow wagering. Initialize variable `balance` to 1000 dollars. Prompt the player to enter a wager. Check that `wager` is less than

or equal to `balance`, and if it's not, have the user reenter `wager` until a valid `wager` is entered. After a correct `wager` is entered, run one game of craps. If the player wins, increase `balance` by `wager` and display the new `balance`. If the player loses, decrease `balance` by `wager`, display the new `balance`, check whether `balance` has become zero and, if so, display the message "Sorry. You busted!"

**7.34 (Binary, Octal and Hexadecimal)** Write an app that displays a table of the binary, octal, and hexadecimal equivalents of the decimal numbers in the range 1–256. If you're not familiar with these number systems, read Appendix D first.

**7.35 (Recursive Power Calculation)** Write recursive method `Power(base, exponent)` that, when called, returns

$$\text{base}^{\text{exponent}}$$

For example,  $\text{Power}(3, 4) = 3 * 3 * 3 * 3$ . Assume that `exponent` is an integer greater than or equal to 1. The recursion step should use the relationship

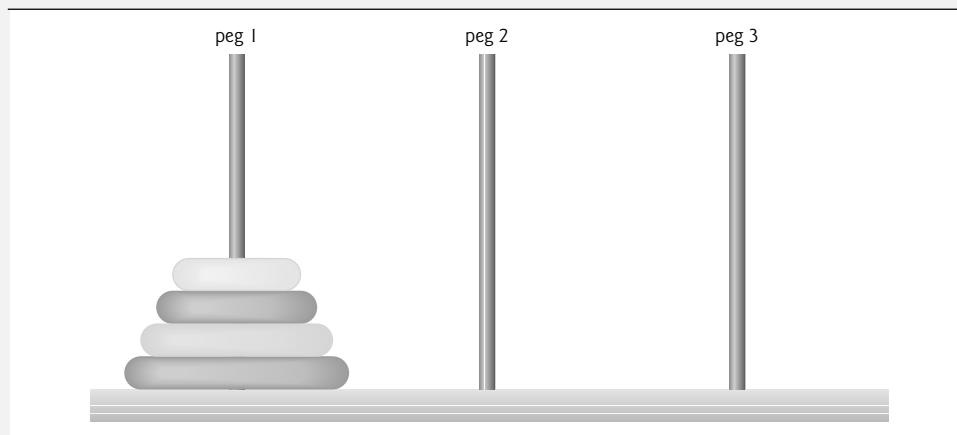
$$\text{base}^{\text{exponent}} = \text{base} \cdot \text{base}^{\text{exponent}-1}$$

The terminating condition occurs when `exponent` is equal to 1, because

$$\text{base}^1 = \text{base}$$

Incorporate this method into an app that enables the user to enter the `base` and `exponent`.

**7.36 (Towers of Hanoi)** Every budding computer scientist must grapple with certain classic problems, and the *Towers of Hanoi* (see Fig. 7.17) is one of the most famous. Legend has it that in a temple in the Far East, priests are attempting to move a stack of disks from one peg to another. The initial stack has 64 disks threaded onto one peg and arranged from bottom to top by decreasing size. The priests are attempting to move the stack from this peg to a second peg under the constraints that exactly one disk is moved at a time and at no time may a larger disk be placed above a smaller disk. A third peg is available for temporarily holding disks. Supposedly, the world will end when the priests complete their task, so there's little incentive for us to facilitate their efforts.



**Fig. 7.17** | The Towers of Hanoi for the case with four disks.

Let's assume that the priests are attempting to move the disks from peg 1 to peg 3. We wish to develop an algorithm that will display the precise sequence of peg-to-peg disk transfers.

If we were to approach this problem with conventional methods, we'd rapidly find ourselves hopelessly knotted up in managing the disks. Instead, if we attack the problem with recursion in

mind, it immediately becomes tractable. Moving  $n$  disks can be viewed in terms of moving only  $n - 1$  disks (hence the recursion) as follows:

- Move  $n - 1$  disks from peg 1 to peg 2, using peg 3 as a temporary holding area.
- Move the last disk (the largest) from peg 1 to peg 3.
- Move the  $n - 1$  disks from peg 2 to peg 3, using peg 1 as a temporary holding area.

The process ends when the last task involves moving  $n = 1$  disk (i.e., the base case). This task is accomplished by simply moving the disk, without the need for a temporary holding area.

Write an app to solve the Towers of Hanoi problem. Allow the user to enter the number of disks. Use a recursive Tower method with four parameters:

- the number of disks to be moved,
- the peg on which these disks are initially threaded,
- the peg to which this stack of disks is to be moved, and
- the peg to be used as a temporary holding area.

Your app should display the precise instructions it will take to move the disks from the starting peg to the destination peg. For example, to move a stack of three disks from peg 1 to peg 3, your app should display the following series of moves:

```
1 --> 3 (This notation means "Move one disk from peg 1 to peg 3.")
1 --> 2
3 --> 2
1 --> 3
2 --> 1
2 --> 3
1 --> 3
```

**7.37** (*What Does This Code Do?*) What does the following method do?

```
// Parameter b must be positive to prevent infinite recursion
public static int Mystery( int a, int b )
{
    if ( b == 1 )
        return a;
    else
        return a + Mystery( a, b - 1 );
}
```

**7.38** (*Find the Error*) Find the error in the following recursive method, and explain how to correct it:

```
public static int Sum( int n )
{
    if ( n == 0 )
        return 0;
    else
        return n + Sum( n );
}
```

## Making a Difference Exercises

As computer costs decline, it becomes feasible for every student, regardless of economic circumstance, to have a computer and use it in school. This creates exciting possibilities for improving the educational experience of all students worldwide as suggested by the next two exercises. [Note: Check out initiatives such as the One Laptop Per Child Project ([www.laptop.org](http://www.laptop.org)). Also, research “green” laptops—and note the key “going green” characteristics of these devices. Look into the Electronic Product Environmental Assessment Tool ([www.epeat.net](http://www.epeat.net)) which can help you assess the “greenness” of desktops, notebooks and monitors to help you decide which products to purchase.]

**7.39 (Computer-Assisted Instruction)** The use of computers in education is referred to as *computer-assisted instruction (CAI)*. Write a program that will help an elementary school student learn multiplication. Use a `Random` object to produce two positive one-digit integers. The program should then prompt the user with a question, such as

How much is 6 times 7?

The student then inputs the answer. Next, the program checks the student's answer. If it's correct, display the message "Very good!" and ask another multiplication question. If the answer is wrong, display the message "No. Please try again." and let the student try the same question repeatedly until the student gets it right. A separate function should be used to generate each new question. This function should be called once when the app begins execution and each time the user answers the question correctly.

**7.40 (Computer-Assisted Instruction: Reducing Student Fatigue)** One problem in CAI environments is student fatigue. This can be reduced by varying the computer's responses to hold the student's attention. Modify the program of Exercise 7.39 so that various comments are displayed for each answer. Possible responses to a correct answer:

Very good!  
Excellent!  
Nice work!  
Keep up the good work!

Possible responses to an incorrect answer:

No. Please try again.  
Wrong. Try once more.  
Don't give up!  
No. Keep trying.

Use random-number generation to choose a number from 1 to 4 that will be used to select one of the four appropriate responses to each correct or incorrect answer. Use a `switch` statement to issue the responses.

# 8

# Arrays; Introduction to Exception Handling



*Begin at the beginning, ... and go on till you come to the end: then stop.*

—Lewis Carroll

*Now go, write it before them in a table, and note it in a book.*

—Isaiah 30:8

*To go beyond is as wrong as to fall short.*

—Confucius

## Objectives

In this chapter you'll:

- Use arrays to store data in and retrieve data from lists and tables of values.
- Declare arrays, initialize arrays and refer to individual elements of arrays.
- Use `foreach` to iterate through arrays.
- Use exception handling to process runtime problems.
- Use implicitly typed local variables.
- Pass arrays to methods.
- Declare and manipulate multidimensional arrays.
- Write methods that use variable-length argument lists.
- Read command-line arguments into an app.

# Outline

- 8.1** Introduction
- 8.2** Arrays
- 8.3** Declaring and Creating Arrays
- 8.4** Examples Using Arrays
  - 8.4.1 Creating and Initializing an Array
  - 8.4.2 Using an Array Initializer
  - 8.4.3 Calculating a Value to Store in Each Array Element
  - 8.4.4 Summing the Elements of an Array
  - 8.4.5 Using Bar Charts to Display Array Data Graphically
  - 8.4.6 Using the Elements of an Array as Counters
  - 8.4.7 Using Arrays to Analyze Survey Results; Introduction to Exception Handling
- 8.5** Case Study: Card Shuffling and Dealing Simulation
- 8.6** foreach Statement
- 8.7** Passing Arrays and Array Elements to Methods
- 8.8** Passing Arrays by Value and by Reference
- 8.9** Case Study: GradeBook Using an Array to Store Grades
- 8.10** Multidimensional Arrays
- 8.11** Case Study: GradeBook Using a Rectangular Array
- 8.12** Variable-Length Argument Lists
- 8.13** Using Command-Line Arguments
- 8.14** Wrap-Up

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) |  
 Special Section: [Building Your Own Computer](#) | [Making a Difference Exercise](#)

## 8.1 Introduction

This chapter introduces the important topic of **data structures**—collections of related data items. **Arrays** are data structures consisting of related data items of the *same* type. Arrays are *fixed-length* entities—they remain the same length once they’re created, although an array variable may be reassigned such that it refers to a new array of a different length.

After discussing how arrays are declared, created and initialized, we present examples that demonstrate several common array manipulations. We use arrays to simulate shuffling and dealing playing cards. The chapter demonstrates C#’s last structured control statement—the **foreach** repetition statement—which provides a concise notation for accessing data in arrays (and other data structures, as you’ll see in Chapter 9 and later in the book). We enhance the **GradeBook** case study using arrays to enable the class to store a set of grades and analyze student grades from multiple exams.

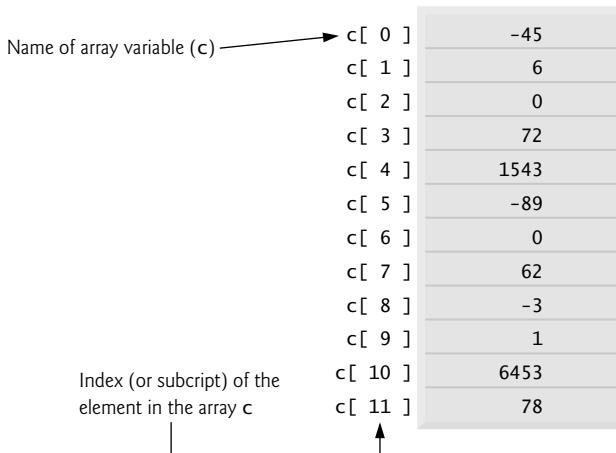
## 8.2 Arrays

An array is a group of variables (called **elements**) containing values that all have the *same type*. Recall that types are divided into two categories—*value types* and *reference types*. Arrays are reference types. As you’ll see, what we typically think of as an array is actually a reference to an array object. The elements of an array can be either value types or reference types, including other arrays. To refer to a particular element in an array, we specify the *name* of the reference to the array and the *position number* of the element in the array, which is known as the element’s **index**.

Figure 8.1 shows a logical representation of an integer array called **c** containing sample values. This array contains 12 elements. An app refers to any one of these elements with an **array-access expression** that includes the name of the array, followed by the index of the particular element in **square brackets** (`[]`). The first element in every array has **index**

**zero** and is sometimes called the **zeroth element**. Thus, the elements of array *c* are *c[0]*, *c[1]*, *c[2]* and so on. The highest index in array *c* is 11, which is one less than the number of elements in the array, because indices begin at 0. Array names follow the same conventions as other variable names.

---



|                |      |
|----------------|------|
| <i>c[ 0 ]</i>  | -45  |
| <i>c[ 1 ]</i>  | 6    |
| <i>c[ 2 ]</i>  | 0    |
| <i>c[ 3 ]</i>  | 72   |
| <i>c[ 4 ]</i>  | 1543 |
| <i>c[ 5 ]</i>  | -89  |
| <i>c[ 6 ]</i>  | 0    |
| <i>c[ 7 ]</i>  | 62   |
| <i>c[ 8 ]</i>  | -3   |
| <i>c[ 9 ]</i>  | 1    |
| <i>c[ 10 ]</i> | 6453 |
| <i>c[ 11 ]</i> | 78   |

**Fig. 8.1** | A 12-element array.

An index must be a nonnegative integer and can be an expression. For example, if we assume that variable *a* is 5 and variable *b* is 6, then the statement

```
c[ a + b ] += 2;
```

adds 2 to array element *c[11]*. An indexed array name is an array-access expression. Such expressions can be used on the left side of an assignment (i.e., as an *lvalue*) to place a new value into an array element. The array index must be a value of type *int*, *uint*, *long* or *ulong*, or a value of a type that can be implicitly promoted to one of these types.

Let's examine array *c* in Fig. 8.1 more closely. The **name** of the variable that references the array is *c*. Every array instance knows its own length and provides access to this information with the *Length* property. For example, the expression *c.Length* uses array *c*'s *Length* property to determine the length of the array (that is, 12). The *Length* property of an array *cannot* be changed, because it does not provide a set accessor. The array's 12 elements are referred to as *c[0]*, *c[1]*, *c[2]*, ..., *c[11]*. Referring to elements *outside* of this range, such as *c[-1]* or *c[12]*, is a runtime error (as we'll demonstrate in Fig. 8.8). The value of *c[0]* is -45, the value of *c[1]* is 6, the value of *c[2]* is 0, the value of *c[7]* is 62 and the value of *c[11]* is 78. To calculate the sum of the values contained in the first three elements of array *c* and store the result in variable *sum*, we would write

```
sum = c[ 0 ] + c[ 1 ] + c[ 2 ];
```

To divide the value of *c[6]* by 2 and assign the result to the variable *x*, we would write

```
x = c[ 6 ] / 2;
```

## 8.3 Declaring and Creating Arrays

Arrays occupy space in memory. Since they’re objects, they’re typically created with keyword `new`. To create an array object, you specify the type and the number of array elements as part of an **array-creation expression** that uses keyword `new`. Such an expression returns a reference that can be stored in an array variable. The following declaration and array-creation expression create an array object containing 12 `int` elements and store the array’s reference in variable `c`:

```
int[] c = new int[ 12 ];
```

This expression can be used to create the array shown in Fig. 8.1 (but not the initial values in the array—we’ll show how to initialize the elements of an array momentarily). This task also can be performed as follows:

```
int[] c; // declare the array variable
c = new int[ 12 ]; // create the array; assign to array variable
```

In the declaration, the square brackets following the type `int` indicate that `c` is a variable that will refer to an array of `ints` (i.e., `c` will store a reference to an array object). In the assignment statement, the array variable `c` receives the reference to a new array object of 12 `int` elements. The number of elements can also be specified as an expression that’s calculated at execution time. When an array is created, each element of the array receives a default value—0 for the numeric simple-type elements, `false` for `bool` elements and `null` for references. As we’ll soon see, we can provide specific, nondefault initial element values when we create an array.



### Common Programming Error 8.1

*In the declaration of a variable that will refer to an array, specifying the number of elements in the square brackets (e.g., `int[ 12 ] c;`) is a syntax error.*

An app can create several arrays in a single declaration. The following statement reserves 100 elements for `string` array `b` and 27 elements for `string` array `x`:

```
string[] b = new string[ 100 ], x = new string[ 27 ];
```

In this statement, `string[]` applies to each variable. For readability and ease of commenting, we prefer to split the preceding statement into two statements, as in:

```
string[] b = new string[ 100 ]; // create string array b
string[] x = new string[ 27 ]; // create string array x
```

An app can declare variables that will refer to arrays of value-type elements or reference-type elements. For example, every element of an `int` array is an `int value`, and every element of a `string` array is a `reference to a string object`.

### Resizing an Array

Though arrays are fixed-length entities, you can use the `static` `Array` method `Resize`, which takes two arguments—the array to be resized and the new length—to create a new array with the specified length. This method copies the contents of the old array into the new array and sets the variable it receives as its first argument to reference the new array. For example, consider the following statements:

```

int[] newArray = new int[ 5 ];
Array.Resize( ref newArray, 10 );

```

The variable `newArray` initially refers to a five-element array. The `resize` method sets `newArray` to refer to a new 10-element array. If the new array is *smaller* than the old array, any content that cannot fit into the new array is *truncated without warning*.

## 8.4 Examples Using Arrays

This section presents several examples that demonstrate declaring arrays, creating arrays, initializing arrays and manipulating array elements.

### 8.4.1 Creating and Initializing an Array

The app of Fig. 8.2 uses keyword `new` to create an array of five `int` elements that are initially 0 (the default for `int` variables).

---

```

1 // Fig. 8.2: InitArray.cs
2 // Creating an array.
3 using System;
4
5 public class InitArray
6 {
7     public static void Main( string[] args )
8     {
9         int[] array; // declare array named array
10
11        // create the space for array and initialize to default zeros
12        array = new int[ 5 ]; // 5 int elements
13
14        Console.WriteLine( "{0}{1,8}", "Index", "Value" ); // headings
15
16        // output each array element's value
17        for ( int counter = 0; counter < array.Length; ++counter )
18            Console.WriteLine( "{0,5}{1,8}", counter, array[ counter ] );
19    } // end Main
20 } // end class InitArray

```

| Index | Value |
|-------|-------|
| 0     | 0     |
| 1     | 0     |
| 2     | 0     |
| 3     | 0     |
| 4     | 0     |

**Fig. 8.2** | Creating an array.

Line 9 declares `array`—a variable capable of referring to an array of `int` elements. Line 12 creates the five-element array object and assigns its reference to variable `array`. Line 14 outputs the column headings. The first column contains the index (0–4) of each array element, and the second column contains the default value (0) of each array element right justified in a field width of 8.

The `for` statement in lines 17–18 outputs the index number (represented by `counter`) and the value (represented by `array[counter]`) of each array element. The loop-control variable `counter` is initially 0—index values start at 0, so using zero-based counting allows the loop to access *every* element of the array. The `for` statement’s loop-continuation condition uses the property `array.Length` (line 17) to obtain the length of the array. In this example, the length of the array is 5, so the loop continues executing as long as the value of control variable `counter` is less than 5. The highest index value of a five-element array is 4, so using the less-than operator in the loop-continuation condition guarantees that the loop does not attempt to access an element beyond the end of the array (i.e., during the *final* iteration of the loop, `counter` is 4). We’ll soon see what happens when an *out-of-range index* is encountered at execution time.

### 8.4.2 Using an Array Initializer

An app can create an array and initialize its elements with an **array initializer**, which is a comma-separated list of expressions (called an **initializer list**) enclosed in braces. In this case, the array length is determined by the number of elements in the initializer list. For example, the declaration

```
int[] n = { 10, 20, 30, 40, 50 };
```

creates a five-element array with index values 0, 1, 2, 3 and 4. Element `n[0]` is initialized to 10, `n[1]` is initialized to 20 and so on. This statement does *not* require new to create the array object. When the compiler encounters an array initializer list, it counts the number of initializers in the list to determine the array’s size, then sets up the appropriate new operation “behind the scenes.” The app in Fig. 8.3 initializes an integer array with 10 values (line 10) and displays the array in tabular format. The code for displaying the array elements (lines 15–16) is identical to that in Fig. 8.2 (lines 17–18).

---

```

1 // Fig. 8.3: InitArray.cs
2 // Initializing the elements of an array with an array initializer.
3 using System;
4
5 public class InitArray
6 {
7     public static void Main( string[] args )
8     {
9         // initializer list specifies the value for each element
10        int[] array = { 32, 27, 64, 18, 95, 14, 90, 70, 60, 37 };
11
12        Console.WriteLine( "{0}{1,8}", "Index", "Value" ); // headings
13
14        // output each array element's value
15        for ( int counter = 0; counter < array.Length; ++counter )
16            Console.WriteLine( "{0,5}{1,8}", counter, array[ counter ] );
17    } // end Main
18 } // end class InitArray

```

---

**Fig. 8.3** | Initializing the elements of an array with an array initializer. (Part 1 of 2.)

| Index | Value |
|-------|-------|
| 0     | 32    |
| 1     | 27    |
| 2     | 64    |
| 3     | 18    |
| 4     | 95    |
| 5     | 14    |
| 6     | 90    |
| 7     | 70    |
| 8     | 60    |
| 9     | 37    |

**Fig. 8.3** | Initializing the elements of an array with an array initializer. (Part 2 of 2.)

### 8.4.3 Calculating a Value to Store in Each Array Element

Some apps calculate the value to be stored in each array element. The app in Fig. 8.4 creates a 10-element array and assigns to each element one of the even integers from 2 to 20 (2, 4, 6, ..., 20). Then the app displays the array in tabular format. The **for** statement at lines 13–14 calculates an array element's value by multiplying the current value of the **for** loop's control variable **counter** by 2, then adding 2.

Line 9 uses the modifier **const** to declare the constant **ARRAY\_LENGTH**, whose value is 10. Constants must be initialized when they're declared and cannot be modified thereafter. We declare constants with *all capital letters by convention* to make them stand out in the code.

```

1 // Fig. 8.4: InitArray.cs
2 // Calculating values to be placed into the elements of an array.
3 using System;
4
5 public class InitArray
6 {
7     public static void Main( string[] args )
8     {
9         const int ARRAY_LENGTH = 10; // create a named constant
10        int[] array = new int[ ARRAY_LENGTH ]; // create array
11
12        // calculate value for each array element
13        for ( int counter = 0; counter < array.Length; ++counter )
14            array[ counter ] = 2 + 2 * counter;
15
16        Console.WriteLine( "{0}{1,8}", "Index", "Value" ); // headings
17
18        // output each array element's value
19        for ( int counter = 0; counter < array.Length; ++counter )
20            Console.WriteLine( "{0,5}{1,8}", counter, array[ counter ] );
21    } // end Main
22 } // end class InitArray

```

**Fig. 8.4** | Calculating values to be placed into the elements of an array. (Part 1 of 2.)

| Index | Value |
|-------|-------|
| 0     | 2     |
| 1     | 4     |
| 2     | 6     |
| 3     | 8     |
| 4     | 10    |
| 5     | 12    |
| 6     | 14    |
| 7     | 16    |
| 8     | 18    |
| 9     | 20    |

**Fig. 8.4** | Calculating values to be placed into the elements of an array. (Part 2 of 2.)



### Common Programming Error 8.2

*Assigning a value to a named constant after it's been initialized is a compilation error.*



### Common Programming Error 8.3

*Attempting to declare a named constant without initializing it is a compilation error.*



### Good Programming Practice 8.1

*Constants also are called named constants. Apps using constants often are more readable than those that use literal values (e.g., 10)—a named constant such as ARRAY\_LENGTH clearly indicates its purpose, whereas a literal value could have different meanings based on the context in which it's used. Another advantage to using named constants is that if the value of the constant must be changed, the change is necessary only in the declaration, thus reducing the cost of maintaining the code.*



### Good Programming Practice 8.2

*Defining the size of an array as a constant variable instead of a literal constant makes code clearer. This technique eliminates so-called magic numbers. For example, repeatedly mentioning the size 10 in array-processing code for a 10-element array gives the number 10 an artificial significance and can be confusing when the program includes other 10s that have nothing to do with the array size.*

#### 8.4.4 Summing the Elements of an Array

Often, the elements of an array represent a series of values to be used in a calculation. For example, if the elements of an array represent exam grades, an instructor may wish to total the elements and use that total to calculate the class average for the exam. The GradeBook examples later in the chapter (Fig. 8.15 and Fig. 8.20) use this technique.

```

1 // Fig. 8.5: SumArray.cs
2 // Computing the sum of the elements of an array.
3 using System;
4

```

**Fig. 8.5** | Computing the sum of the elements of an array. (Part 1 of 2.)

```

5  public class SumArray
6  {
7      public static void Main( string[] args )
8      {
9          int[] array = { 87, 68, 94, 100, 83, 78, 85, 91, 76, 87 };
10         int total = 0;
11
12         // add each element's value to total
13         for ( int counter = 0; counter < array.Length; ++counter )
14             total += array[ counter ];
15
16         Console.WriteLine( "Total of array elements: {0}", total );
17     } // end Main
18 } // end class SumArray

```

Total of array elements: 849

**Fig. 8.5** | Computing the sum of the elements of an array. (Part 2 of 2.)

The app in Fig. 8.5 sums the values contained in a 10-element integer array. The app creates and initializes the array at line 9. The **for** statement performs the calculations. [Note: The values supplied as array initializers are often read into an app, rather than specified in an initializer list. For example, an app could input the values from a user or from a file on disk (as discussed in Chapter 17, Files and Streams). Reading the data into an app makes the app more *reusable*, because it can be used with *different* sets of data.]

### 8.4.5 Using Bar Charts to Display Array Data Graphically

Many apps present data to users in a graphical manner. For example, numeric values are often displayed as bars in a bar chart. In such a chart, longer bars represent proportionally larger numeric values. One simple way to display numeric data graphically is with a bar chart that shows each numeric value as a bar of asterisks (\*).

An instructor might graph the number of grades in each of several categories to visualize the grade distribution for an exam. Suppose the grades on an exam were 87, 68, 94, 100, 83, 78, 85, 91, 76 and 87. There was one grade of 100, two grades in the 90s, four grades in the 80s, two grades in the 70s, one grade in the 60s and no grades below 60. Our next app (Fig. 8.6) stores this grade distribution data in an array of 11 elements, each corresponding to a category of grades. For example, **array[0]** indicates the number of grades in the range 0–9, **array[7]** the number of grades in the range 70–79 and **array[10]** the number of 100 grades. The two versions of class **GradeBook** later in the chapter (Figs. 8.15 and 8.20) contain code that calculates these grade frequencies based on a set of grades. For now, we manually create **array** by examining the set of grades and initializing the elements of **array** to the number of values in each range (line 9).

```

1  // Fig. 8.6: BarChart.cs
2  // Bar chart displaying app.
3  using System;
4

```

**Fig. 8.6** | Bar chart displaying app. (Part I of 2.)

```

5  public class BarChart
6  {
7      public static void Main( string[] args )
8      {
9          int[] array = { 0, 0, 0, 0, 0, 0, 1, 2, 4, 2, 1 }; // distribution
10
11         Console.WriteLine( "Grade distribution:" );
12
13         // for each array element, output a bar of the chart
14         for ( int counter = 0; counter < array.Length; ++counter )
15         {
16             // output bar labels ( "00-09: ", ..., "90-99: ", "100: " )
17             if ( counter == 10 )
18                 Console.Write( " 100: " );
19             else
20                 Console.Write( "{0:D2}-{1:D2}: ",
21                               counter * 10, counter * 10 + 9 );
22
23             // display bar of asterisks
24             for ( int stars = 0; stars < array[ counter ]; ++stars )
25                 Console.Write( "*" );
26
27             Console.WriteLine(); // start a new line of output
28         } // end outer for
29     } // end Main
30 } // end class BarChart

```

```

Grade distribution:
00-09:
10-19:
20-29:
30-39:
40-49:
50-59:
60-69: *
70-79: **
80-89: ****
90-99: **
100: *

```

**Fig. 8.6** | Bar chart displaying app. (Part 2 of 2.)

The app reads the numbers from the array and graphs the information as a bar chart. Each grade range is followed by a bar of asterisks indicating the number of grades in that range. To label each bar, lines 17–21 output a grade range (e.g., "70-79: ") based on the current value of counter. When counter is 10, line 18 outputs " 100: " to align the colon with the other bar labels. When counter is not 10, line 20 uses the format items {0:D2} and {1:D2} to output the label of the grade range. The format specifier D indicates that the value should be formatted as an integer, and the number after the D indicates how many digits this formatted integer must contain. The 2 indicates that values with fewer than two digits should begin with a **leading 0**.

The nested for statement (lines 24–25) outputs the bars. Note the loop-continuation condition at line 24 (`stars < array[ counter ]`). Each time the app reaches the inner for,

the loop counts from 0 up to one less than `array[ counter ]`, thus using a value in array to determine the number of asterisks to display. In this example, `array[0]`–`array[5]` contain 0s because no students received a grade below 60. Thus, the app displays no asterisks next to the first six grade ranges.

#### 8.4.6 Using the Elements of an Array as Counters

Sometimes, apps use counter variables to summarize data, such as the results of a survey. In Fig. 7.7, we used separate counters in our die-rolling app to track the number of times each face of a six-sided die appeared as the app rolled the die 6,000,000 times. An array version of the app in Fig. 7.7 is shown in Fig. 8.7.

---

```

1 // Fig. 8.7: RollDie.cs
2 // Roll a six-sided die 6,000,000 times.
3 using System;
4
5 public class RollDie
6 {
7     public static void Main( string[] args )
8     {
9         Random randomNumbers = new Random(); // random-number generator
10        int[] frequency = new int[ 7 ]; // array of frequency counters
11
12        // roll die 6,000,000 times; use die value as frequency index
13        for ( int roll = 1; roll <= 6000000; ++roll )
14            ++frequency[ randomNumbers.Next( 1, 7 ) ];
15
16        Console.WriteLine( "{0}{1,10}", "Face", "Frequency" );
17
18        // output each array element's value
19        for ( int face = 1; face < frequency.Length; ++face )
20            Console.WriteLine( "{0,4}{1,10}", face, frequency[ face ] );
21    } // end Main
22 } // end class RollDie

```

| Face | Frequency |
|------|-----------|
| 1    | 999924    |
| 2    | 1000939   |
| 3    | 1001249   |
| 4    | 998454    |
| 5    | 1000233   |
| 6    | 999201    |

**Fig. 8.7** | Roll a six-sided die 6,000,000 times.

The app uses array `frequency` (line 10) to count the occurrences of each side of the die. *The single statement in line 14 of this app replaces lines 26–46 of Fig. 7.7.* Line 14 uses the random value to determine which `frequency` element to increment during each iteration of the loop. The calculation in line 14 produces random numbers from 1 to 6, so array `frequency` must be large enough to store six counters. We use a seven-element array in which we ignore `frequency[0]`—it's more logical to have the face value 1 increment `frequency[1]` than `frequency[0]`. Thus, each face value is used as an index for array `fre-`

quency. We also replaced lines 50–52 of Fig. 7.7 by looping through array frequency to output the results (Fig. 8.7, lines 19–20).

### 8.4.7 Using Arrays to Analyze Survey Results; Introduction to Exception Handling

Our next example uses arrays to summarize data collected in a survey. Consider the following problem statement:

*Twenty students were asked to rate on a scale of 1 to 5 the quality of the food in the student cafeteria, with 1 being “awful” and 5 being “excellent.” Place the 20 responses in an integer array and determine the frequency of each rating.*

This is a typical array-processing app (Fig. 8.8). We wish to summarize the number of responses of each type (that is, 1–5). Array responses (lines 10–11) is a 20-element integer array containing the students’ survey responses. The last value in the array is intentionally an incorrect response (14). When a C# program executes, array element indices are checked for *validity*—all indices must be greater than or equal to 0 and less than the length of the array. Any attempt to access an element *outside* that range of indices results in a runtime error that’s known as an `IndexOutOfRangeException`. At the end of this section, we’ll discuss the invalid response value, demonstrate array **bounds checking** and introduce C#’s exception-handling mechanism, which can be used to detect and handle an `IndexOutOfRangeException`.

---

```

1 // Fig. 8.8: StudentPoll.cs
2 // Poll analysis app.
3 using System;
4
5 public class StudentPoll
6 {
7     public static void Main( string[] args )
8     {
9         // student response array (more typically, input at run time)
10        int[] responses = { 1, 2, 5, 4, 3, 5, 2, 1, 3, 3, 1, 4, 3, 3, 3,
11                      2, 3, 3, 2, 14 };
12        int[] frequency = new int[ 6 ]; // array of frequency counters
13
14        // for each answer, select responses element and use that value
15        // as frequency index to determine element to increment
16        for ( int answer = 0; answer < responses.Length; ++answer )
17        {
18            try
19            {
20                ++frequency[ responses[ answer ] ];
21            } // end try
22            catch ( IndexOutOfRangeException ex )
23            {
24                Console.WriteLine( ex.Message );
25                Console.WriteLine( "    responses[{0}] = {1}\n",
26                                answer, responses[ answer ] );
27            } // end catch
28        } // end for

```

**Fig. 8.8** | Poll analysis app. (Part I of 2.)

```

29      Console.WriteLine( "{0}{1,10}", "Rating", "Frequency" );
30
31
32      // output each array element's value
33      for ( int rating = 1; rating < frequency.Length; ++rating )
34          Console.WriteLine( "{0,6}{1,10}", rating, frequency[ rating ] );
35  } // end Main
36 } // end class StudentPoll

```

Index was outside the bounds of the array.  
 responses(19) = 14

| Rating | Frequency |
|--------|-----------|
| 1      | 3         |
| 2      | 4         |
| 3      | 8         |
| 4      | 2         |
| 5      | 2         |

**Fig. 8.8** | Poll analysis app. (Part 2 of 2.)

### The *frequency* Array

We use the *six-element* array *frequency* (line 12) to count the number of occurrences of each response. Each element is used as a counter for one of the possible types of survey responses—*frequency[1]* counts the number of students who rated the food as 1, *frequency[2]* counts the number of students who rated the food as 2, and so on.

### Summarizing the Results

The *for* statement (lines 16–28) reads the responses from the array *responses* one at a time and increments one of the counters *frequency[1]* to *frequency[5]*; we ignore *frequency[0]* because the survey responses are limited to the range 1–5. The key statement in the loop appears in line 20. This statement increments the appropriate *frequency* counter as determined by the value of *responses[answer]*.

Let's step through the first few iterations of the *for* statement:

- When the counter *answer* is 0, *responses[answer]* is the value of *responses[0]* (that is, 1—see line 10). In this case, *frequency[responses[answer]]* is interpreted as *frequency[1]*, and the counter *frequency[1]* is incremented by one. To evaluate the expression, we begin with the value in the *innermost* set of brackets (*answer*, currently 0). The value of *answer* is plugged into the expression, and the next set of brackets (*responses[answer]*) is evaluated. That value is used as the index for the *frequency* array to determine which counter to increment (in this case, *frequency[1]*).
- The next time through the loop *answer* is 1, *responses[answer]* is the value of *responses[1]* (that is, 2—see line 10), so *frequency[responses[answer]]* is interpreted as *frequency[2]*, causing *frequency[2]* to be incremented.
- When *answer* is 2, *responses[answer]* is the value of *responses[2]* (that is, 5—see line 10), so *frequency[responses[answer]]* is interpreted as *frequency[5]*, causing *frequency[5]* to be incremented, and so on.

Regardless of the number of responses processed in the survey, only a six-element array (in which we *ignore* element zero) is required to summarize the results, because all the correct response values are between 1 and 5, and the index values for a six-element array are 0–5. In the output in Fig. 8.8, the frequency column summarizes only 19 of the 20 values in the `responses` array—the last element of the array `responses` contains an *incorrect* response that was *not* counted.

### ***Exception Handling: Processing the Incorrect Response***

An **exception** indicates a problem that occurs while a program executes. The name “exception” suggests that the problem occurs infrequently—if the “rule” is that a statement normally executes correctly, then the problem represents the “exception to the rule.” **Exception handling** enables you to create **fault-tolerant programs** that can resolve (or handle) exceptions. In many cases, this allows a program to continue executing as if no problems were encountered. For example, the **Student Poll** app still displays results (Fig. 8.8), even though one of the responses was out of range. More severe problems might prevent a program from continuing normal execution, instead requiring the program to notify the user of the problem, then terminate. When the runtime or a method detects a problem, such as an invalid array index or an invalid method argument, it **throws** an exception—that is, an exception occurs.

### ***The try Statement***

To handle an exception, place any code that might throw an exception in a **try statement** (lines 18–27). The **try block** (lines 18–21) contains the code that might *throw* an exception, and the **catch block** (lines 22–27) contains the code that *handles* the exception if one occurs. You can have many catch blocks to handle different types of exceptions that might be thrown in the corresponding try block. When line 20 correctly increments an element of the `frequency` array, lines 22–27 are ignored. The braces that delimit the bodies of the try and catch blocks are required.

### ***Executing the catch Block***

When the program encounters the value 14 in the `responses` array, it attempts to add 1 to `frequency[14]`, which does *not* exist—the `frequency` array has only six elements. Because array bounds checking is performed at *execution time*, the Common Language Runtime generates an exception—specifically line 20 throws an **IndexOutOfRangeException** to notify the program of this problem. At this point the try block *terminates* and the catch block begins executing—if you declared any variables in the try block, they’re now *out of scope* and are *not accessible* in the catch block.

The catch block declares a type (`IndexOutOfRangeException`) and an exception parameter (`ex`). The catch block can handle exceptions of the specified type. Inside the catch block, you can use the parameter’s identifier to interact with a caught exception object.



#### **Error-Prevention Tip 8.1**

*When writing code to access an array element, ensure that the array index remains greater than or equal to 0 and less than the length of the array. This helps prevent IndexOutOfRangeExceptions in your program.*

***Message Property of the Exception Parameter***

When lines 22–27 *catch* the exception, the program displays a message indicating the problem that occurred. Line 24 uses the exception object's **Message** property to get the error message that's stored in the exception object and display it. Once the message is displayed in this example, the exception is considered handled and the program continues with the next statement after the *catch* block's closing brace. In this example, the end of the *for* statement is reached (line 28), so the program continues with the increment of the control variable in line 16. We use exception handling again in Chapter 10 and Chapter 13 presents a deeper look at exception handling.

## 8.5 Case Study: Card Shuffling and Dealing Simulation

So far, this chapter's examples have used arrays of value-type elements. This section uses random-number generation and an *array of reference-type elements*—namely, *objects* representing playing cards—to develop a class that simulates card shuffling and dealing. This class can then be used to implement apps that play card games. The exercises at the end of the chapter use the techniques developed here to build a poker app.

We first develop class **Card** (Fig. 8.9), which represents a playing card that has a face (e.g., "Ace", "Deuce", "Three", ..., "Jack", "Queen", "King") and a suit (e.g., "Hearts", "Diamonds", "Clubs", "Spades"). Next, we develop class **DeckOfCards** (Fig. 8.10), which creates a deck of 52 playing cards in which each element is a **Card** object. Then we build an app (Fig. 8.11) that uses class **DeckOfCards**'s card shuffling and dealing capabilities.

***Class Card***

Class **Card** (Fig. 8.9) contains two **string** instance variables—*face* and *suit*—that are used to store references to the *face value* and *suit name* for a specific **Card**. The constructor for the class (lines 9–13) receives two **strings** that it uses to initialize *face* and *suit*. Method **ToString** (lines 16–19) creates a **string** consisting of the *face* of the card, the **string** " of " and the *suit* of the card. Recall from Chapter 7 that the + operator can be used to concatenate (i.e., combine) several **strings** to form one larger **string**. **Card**'s **ToString** method can be invoked *explicitly* to obtain a **string** representation of a **Card** object (e.g., "Ace of Spades"). The **ToString** method of an object is called *implicitly* in many cases when the object is used where a **string** is expected (e.g., when **WriteLine** outputs the object or when the object is *concatenated* to a **string** using the + operator). For this behavior to occur, **ToString** must be declared with the header exactly as shown in line 16 of Fig. 8.9. We'll explain the purpose of the **override** keyword in more detail when we discuss inheritance in Chapter 11.

---

```

1 // Fig. 8.9: Card.cs
2 // Card class represents a playing card.
3 public class Card
4 {
5     private string face; // face of card ("Ace", "Deuce", ...)
6     private string suit; // suit of card ("Hearts", "Diamonds", ...)
7 }
```

**Fig. 8.9** | Card class represents a playing card. (Part I of 2.)

```
8 // two-parameter constructor initializes card's face and suit
9 public Card( string cardFace, string cardSuit )
10 {
11     face = cardFace; // initialize face of card
12     suit = cardSuit; // initialize suit of card
13 } // end two-parameter Card constructor
14
15 // return string representation of Card
16 public override string ToString()
17 {
18     return face + " of " + suit;
19 } // end method ToString
20 } // end class Card
```

**Fig. 8.9** | Card class represents a playing card. (Part 2 of 2.)

### *Class DeckOfCards*

Class DeckOfCards (Fig. 8.10) declares an instance-variable named deck that will refer to an array of Card objects (line 7). Like simple-type array variable declarations, the declaration of a variable for an array of objects (e.g., Card[] deck) includes the type of the elements in the array, followed by square brackets and the name of the array variable. Class DeckOfCards also declares int instance variable currentCard (line 8), representing the next Card to be dealt from the deck array, and named constant NUMBER\_OF\_CARDS (line 9), indicating the number of Cards in the deck (52).

---

```
1 // Fig. 8.10: DeckOfCards.cs
2 // DeckOfCards class represents a deck of playing cards.
3 using System;
4
5 public class DeckOfCards
6 {
7     private Card[] deck; // array of Card objects
8     private int currentCard; // index of next Card to be dealt (0-51)
9     private const int NUMBER_OF_CARDS = 52; // constant number of Cards
10    private Random randomNumbers; // random-number generator
11
12    // constructor fills deck of Cards
13    public DeckOfCards()
14    {
15        string[] faces = { "Ace", "Deuce", "Three", "Four", "Five", "Six",
16                           "Seven", "Eight", "Nine", "Ten", "Jack", "Queen", "King" };
17        string[] suits = { "Hearts", "Diamonds", "Clubs", "Spades" };
18
19        deck = new Card[ NUMBER_OF_CARDS ]; // create array of Card objects
20        currentCard = 0; // set currentCard so deck[ 0 ] is dealt first
21        randomNumbers = new Random(); // create random-number generator
22    }
```

**Fig. 8.10** | DeckOfCards class represents a deck of playing cards. (Part I of 2.)

```
23     // populate deck with Card objects
24     for ( int count = 0; count < deck.Length; ++count )
25         deck[ count ] =
26             new Card( faces[ count % 13 ], suits[ count / 13 ] );
27 } // end DeckOfCards constructor
28
29 // shuffle deck of Cards with one-pass algorithm
30 public void Shuffle()
31 {
32     // after shuffling, dealing should start at deck[ 0 ] again
33     currentCard = 0; // reinitialize currentCard
34
35     // for each Card, pick another random Card and swap them
36     for ( int first = 0; first < deck.Length; ++first )
37     {
38         // select a random number between 0 and 51
39         int second = randomNumbers.Next( NUMBER_OF_CARDS );
40
41         // swap current Card with randomly selected Card
42         Card temp = deck[ first ];
43         deck[ first ] = deck[ second ];
44         deck[ second ] = temp;
45     } // end for
46 } // end method Shuffle
47
48 // deal one Card
49 public Card DealCard()
50 {
51     // determine whether Cards remain to be dealt
52     if ( currentCard < deck.Length )
53         return deck[ currentCard++ ]; // return current Card in array
54     else
55         return null; // indicate that all Cards were dealt
56 } // end method DealCard
57 } // end class DeckOfCards
```

**Fig. 8.10** | DeckOfCards class represents a deck of playing cards. (Part 2 of 2.)

#### *Class DeckOfCards: Constructor*

The class's constructor instantiates the `deck` array (line 19) to be of size `NUMBER_OF_CARDS`. When first created, the elements of the `deck` array are `null` by default, so the constructor uses a `for` statement (lines 24–26) to fill the `deck` array with `Cards`. The `for` statement initializes control variable `count` to 0 and loops while `count` is less than `deck.Length`, causing `count` to take on each integer value from 0 to 51 (the indices of the `deck` array). Each `Card` is instantiated and initialized with two strings—one from the `faces` array (which contains the strings "Ace" through "King") and one from the `suits` array (which contains the strings "Hearts", "Diamonds", "Clubs" and "Spades"). The calculation `count % 13` always results in a value from 0 to 12 (the 13 indices of the `faces` array in lines 15–16), and the calculation `count / 13` always results in a value from 0 to 3 (the four indices of the `suits` array in line 17). When the `deck` array is initialized, it contains the `Cards` with faces "Ace" through "King" in order for each suit.

**Class DeckOfCards: Shuffle Method**

Method `Shuffle` (lines 30–46) shuffles the `Cards` in the deck. The method loops through all 52 `Cards` (array indices 0 to 51). For each `Card`, a number between 0 and 51 is picked randomly to select another `Card`. Next, the current `Card` object and the randomly selected `Card` object are swapped in the array. This exchange is performed by the three assignments in lines 42–44. The extra variable `temp` temporarily stores one of the two `Card` objects being swapped. *The swap cannot be performed with only the two statements*

```
deck[ first ] = deck[ second ];
deck[ second ] = deck[ first ];
```

If `deck[ first ]` is the "Ace" of "Spades" and `deck[ second ]` is the "Queen" of "Hearts", then after the first assignment, both array elements contain the "Queen" of "Hearts", and the "Ace" of "Spades" is lost—hence, the extra variable `temp` is needed. After the `for` loop terminates, the `Card` objects are randomly ordered. Only 52 swaps are made in a single pass of the entire array, and the array of `Card` objects is shuffled.

**Recommendation: Use an Unbiased Shuffling Algorithm**

It's recommended that you use a so-called unbiased shuffling algorithm for real card games. Such an algorithm ensures that all possible shuffled card sequences are equally likely to occur. A popular unbiased shuffling algorithm is the Fisher-Yates algorithm—[en.wikipedia.org/wiki/Fisher%20Yates\\_shuffle](https://en.wikipedia.org/wiki/Fisher%20Yates_shuffle). This page also shows how to implement the algorithm in several programming languages.

**Class DeckOfCards: DealCard Method**

Method `DealCard` (lines 49–56) deals one `Card` in the array. Recall that `currentCard` indicates the index of the next `Card` to be dealt (i.e., the `Card` at the top of the deck). Thus, line 52 compares `currentCard` to the length of the `deck` array. If the `deck` is not empty (i.e., `currentCard` is less than 52), line 53 returns the top `Card` and increments `currentCard` to prepare for the next call to `DealCard`—otherwise, `null` is returned.

**Shuffling and Dealing Cards**

The app of Fig. 8.11 demonstrates the card shuffling and dealing capabilities of class `DeckOfCards` (Fig. 8.10). Line 10 creates a `DeckOfCards` object named `myDeckOfCards`. Recall that the `DeckOfCards` constructor creates the deck with the 52 `Card` objects in order by suit and face. Line 11 invokes `myDeckOfCards`'s `Shuffle` method to rearrange the `Card` objects. The `for` statement in lines 14–20 deals all 52 `Cards` in the deck and displays them in four columns of 13 `Cards` each. Line 16 deals and displays a `Card` object by invoking `myDeckOfCards`'s `DealCard` method. When `Console.WriteLine` outputs a `Card` with `string` formatting, the `Card`'s `ToString` method (declared in lines 16–19 of Fig. 8.9) is invoked implicitly. Because the field width is *negative*, the result is output *left* justified in a field of width 19.

---

```
1 // Fig. 8.11: DeckOfCardsTest.cs
2 // Card shuffling and dealing app.
3 using System;
4
```

**Fig. 8.11** | Card shuffling and dealing app. (Part I of 2.)

```

5  public class DeckOfCardsTest
6  {
7      // execute app
8      public static void Main( string[] args )
9      {
10         DeckOfCards myDeckOfCards = new DeckOfCards();
11         myDeckOfCards.Shuffle(); // place Cards in random order
12
13         // display all 52 Cards in the order in which they are dealt
14         for ( int i = 0; i < 52; ++i )
15         {
16             Console.WriteLine( "{0,-19}", myDeckOfCards.DealCard() );
17
18             if ( ( i + 1 ) % 4 == 0 )
19                 Console.WriteLine();
20         } // end for
21     } // end Main
22 } // end class DeckOfCardsTest

```

|                   |                   |                  |                  |
|-------------------|-------------------|------------------|------------------|
| Eight of Clubs    | Ten of Clubs      | Ten of Spades    | Four of Spades   |
| Ace of Spades     | Jack of Spades    | Three of Spades  | Seven of Spades  |
| Three of Diamonds | Five of Clubs     | Eight of Spades  | Five of Hearts   |
| Ace of Hearts     | Ten of Hearts     | Deuce of Hearts  | Deuce of Clubs   |
| Jack of Hearts    | Nine of Spades    | Four of Hearts   | Seven of Clubs   |
| Queen of Spades   | Seven of Diamonds | Five of Diamonds | Ace of Clubs     |
| Four of Clubs     | Ten of Diamonds   | Jack of Clubs    | Six of Diamonds  |
| Eight of Diamonds | King of Hearts    | Three of Clubs   | King of Spades   |
| King of Diamonds  | Six of Spades     | Deuce of Spades  | Five of Spades   |
| Queen of Clubs    | King of Clubs     | Queen of Hearts  | Seven of Hearts  |
| Ace of Diamonds   | Deuce of Diamonds | Four of Diamonds | Nine of Clubs    |
| Queen of Diamonds | Jack of Diamonds  | Six of Hearts    | Nine of Diamonds |
| Nine of Hearts    | Three of Hearts   | Six of Clubs     | Eight of Hearts  |

**Fig. 8.11** | Card shuffling and dealing app. (Part 2 of 2.)

## 8.6 foreach Statement

In previous examples, we demonstrated how to use counter-controlled `for` statements to iterate through the elements in an array. In this section, we introduce the **foreach statement**, which iterates through the elements of an entire array or collection. This section discusses how to use the `foreach` statement to loop through an array. We show how to use it with collections in Chapter 21. The syntax of a `foreach` statement is:

```

foreach ( type identifier in arrayName )
    statement

```

where *type* and *identifier* are the type and name (e.g., `int number`) of the **iteration variable**, and *arrayName* is the array through which to iterate. The type of the iteration variable must be consistent with the type of the elements in the array. As the next example illustrates, the iteration variable represents successive values in the array on successive iterations of the `foreach` statement.

Figure 8.12 uses the `foreach` statement (lines 13–14) to calculate the sum of the integers in an array of student grades. The type specified is `int`, because `array` contains `int` values—therefore, the loop will select one `int` value from the array during each iteration. The `foreach` statement iterates through successive values in the array one by one. The `foreach` header can be read concisely as “for each iteration, assign the next element of array to `int` variable `number`, then execute the following statement.” Thus, for each iteration, identifier `number` represents the next `int` value in the array. Lines 13–14 are equivalent to the following counter-controlled repetition used in lines 13–14 of Fig. 8.5 to total the integers in array:

```
for ( int counter = 0; counter < array.Length; ++counter )
    total += array[ counter ];
```



### Common Programming Error 8.4

*The `foreach` statement’s iteration variable can be used only to access array elements—it cannot be used to modify elements. Any attempt to change the value of the iteration variable in the body of a `foreach` statement will cause a compilation error.*

---

```

1 // Fig. 8.12: ForEachTest.cs
2 // Using the foreach statement to total integers in an array.
3 using System;
4
5 public class ForEachTest
6 {
7     public static void Main( string[] args )
8     {
9         int[] array = { 87, 68, 94, 100, 83, 78, 85, 91, 76, 87 };
10        int total = 0;
11
12        // add each element's value to total
13        foreach ( int number in array )
14            total += number;
15
16        Console.WriteLine( "Total of array elements: {0}", total );
17    } // end Main
18 } // end class ForEachTest

```

```
Total of array elements: 849
```

**Fig. 8.12** | Using the `foreach` statement to total integers in an array.

The `foreach` statement can be used in place of the `for` statement whenever code looping through an array does not require access to the counter indicating the index of the current array element. For example, totaling the integers in an array requires access only to the element values—the index of each element is irrelevant. However, if an app must use a counter for some reason other than simply to loop through an array (e.g., to display an index number next to each array element value, as in the examples earlier in this chapter), use the `for` statement.

## 8.7 Passing Arrays and Array Elements to Methods

To pass an array argument to a method, specify the name of the array *without any brackets*. For example, if `hourlyTemperatures` is declared as

```
double[] hourlyTemperatures = new double[ 24 ];
```

then the method call

```
ModifyArray( hourlyTemperatures );
```

passes the reference of array `hourlyTemperatures` to method `ModifyArray`. Every array object “knows” its own length (and makes it available via its `Length` property). Thus, when we pass an array object’s reference to a method, we need not pass the array length as an additional argument.

### Specifying an Array Parameter

For a method to receive an array reference through a method call, the method’s parameter list must specify an array parameter. For example, the method header for method `ModifyArray` might be written as

```
void ModifyArray( double[] b )
```

indicating that `ModifyArray` receives the reference of an array of `doubles` in parameter `b`. The method call passes array `hourlyTemperature`’s reference, so when the called method uses the array variable `b`, it refers to the same array object as `hourlyTemperatures` in the calling method.

### Pass-By-Value vs. Pass-By-Reference

When an argument to a method is an entire array or an individual array element of a reference type, the called method receives a *copy of the reference*. However, when an argument to a method is an individual array element of a value type, the called method receives a *copy of the element’s value*. To pass an individual array element to a method, use the indexed name of the array as an argument in the method call. If you want to pass a value-type array element to a method by reference, you must use the `ref` keyword as shown in Section 7.16.

Figure 8.13 demonstrates the difference between passing an entire array and passing a value-type array element to a method. The `foreach` statement at lines 17–18 outputs the five elements of `array` (an array of `int` values). Line 20 invokes method `ModifyArray`, passing `array` as an argument. Method `ModifyArray` (lines 37–41) receives a *copy of array’s reference* and uses the reference to multiply each of array’s elements by 2. To prove that array’s elements (in `Main`) were modified, the `foreach` statement at lines 24–25 outputs the five elements of `array` again. As the output shows, method `ModifyArray` doubled the value of each element.

---

```

1 // Fig. 8.13: PassArray.cs
2 // Passing arrays and individual array elements to methods.
3 using System;
4
```

**Fig. 8.13** | Passing arrays and individual array elements to methods. (Part I of 3.)

```

5  public class PassArray
6  {
7      // Main creates array and calls ModifyArray and ModifyElement
8      public static void Main( string[] args )
9      {
10         int[] array = { 1, 2, 3, 4, 5 };
11
12         Console.WriteLine(
13             "Effects of passing reference to entire array:\n" +
14             "The values of the original array are:" );
15
16         // output original array elements
17         foreach ( int value in array )
18             Console.Write( "    {0}", value );
19
20         ModifyArray( array ); // pass array reference
21         Console.WriteLine( "\n\nThe values of the modified array are:" );
22
23         // output modified array elements
24         foreach ( int value in array )
25             Console.Write( "    {0}", value );
26
27         Console.WriteLine(
28             "\n\nEffects of passing array element value:\n" +
29             "array[3] before ModifyElement: {0}", array[ 3 ] );
30
31         ModifyElement( array[ 3 ] ); // attempt to modify array[ 3 ]
32         Console.WriteLine(
33             "array[3] after ModifyElement: {0}", array[ 3 ] );
34     } // end Main
35
36     // multiply each element of an array by 2
37     public static void ModifyArray( int[] array2 )
38     {
39         for ( int counter = 0; counter < array2.Length; ++counter )
40             array2[ counter ] *= 2;
41     } // end method ModifyArray
42
43     // multiply argument by 2
44     public static void ModifyElement( int element )
45     {
46         element *= 2;
47         Console.WriteLine(
48             "Value of element in ModifyElement: {0}", element );
49     } // end method ModifyElement
50 } // end class PassArray

```

Effects of passing reference to entire array:  
 The values of the original array are:  
 1 2 3 4 5

The values of the modified array are:  
 2 4 6 8 10

**Fig. 8.13** | Passing arrays and individual array elements to methods. (Part 2 of 3.)

```
Effects of passing array element value:  

array[3] before ModifyElement: 8  

Value of element in ModifyElement: 16  

array[3] after ModifyElement: 8
```

**Fig. 8.13** | Passing arrays and individual array elements to methods. (Part 3 of 3.)

Figure 8.13 next demonstrates that when a copy of an individual value-type array element is passed to a method, modifying the copy in the called method does *not* affect the original value of that element in the calling method's array. To show the value of `array[3]` before invoking method `ModifyElement`, lines 27–29 output the value of `array[3]`, which is 8. Line 31 calls method `ModifyElement` and passes `array[3]` as an argument. Remember that `array[3]` is actually one `int` value (8) in `array`. Therefore, the app passes a copy of the value of `array[3]`. Method `ModifyElement` (lines 44–49) multiplies the value received as an argument by 2, stores the result in its parameter `element`, then outputs the value of `element` (16). Since method parameters, like local variables, cease to exist when the method in which they're declared completes execution, the method parameter `element` is destroyed when method `ModifyElement` terminates. Thus, when the app returns control to `Main`, lines 32–33 output the unmodified value of `array[3]` (i.e., 8).

## 8.8 Passing Arrays by Value and by Reference

In C#, a variable that “stores” an object, such as an array, does not actually store the object itself. Instead, such a variable stores a *reference* to the object. The distinction between reference-type variables and value-type variables raises some subtle issues that you must understand to create secure, stable programs.

As you know, when an app passes an argument to a method, the called method receives a *copy* of that argument's value. Changes to the *local copy* in the called method do *not* affect the original variable in the caller. If the argument is of a *reference* type, the method makes a *copy* of the *reference*, *not* a *copy* of the actual object that's referenced. The local copy of the reference also refers to the original object, which means that changes to the object in the called method affect the original object.



### Performance Tip 8.1

*Passing references to arrays and other objects makes sense for performance reasons. If arrays were passed by value, a copy of each element would be passed. For large, frequently passed arrays, this would waste time and consume considerable storage for the copies of the arrays.*

In Section 7.16, you learned that C# allows variables to be passed by reference with keyword `ref`. You can also use keyword `ref` to pass a *reference-type variable* by reference, which allows the called method to modify the original variable in the caller and make that variable refer to a different object. This is a subtle capability, which, if misused, can lead to problems. For instance, when a reference-type object like an array is passed with `ref`, the called method actually gains control over the *reference itself*, allowing the called method to replace the original reference in the caller with a reference to a different object, or even with `null`. Such behavior can lead to *unpredictable effects*, which can be disastrous in mission-critical apps. The app in Fig. 8.14 demonstrates the subtle difference between passing a reference by value and passing a reference by reference with keyword `ref`.

```
1 // Fig. 8.14: ArrayReferenceTest.cs
2 // Testing the effects of passing array references
3 // by value and by reference.
4 using System;
5
6 public class ArrayReferenceTest
7 {
8     public static void Main( string[] args )
9     {
10         // create and initialize firstArray
11         int[] firstArray = { 1, 2, 3 };
12
13         // copy the reference in variable firstArray
14         int[] firstArrayCopy = firstArray;
15
16         Console.WriteLine(
17             "Test passing firstArray reference by value" );
18
19         Console.Write( "\nContents of firstArray " +
20             "before calling FirstDouble:\n\t" );
21
22         // display contents of firstArray
23         for ( int i = 0; i < firstArray.Length; ++i )
24             Console.Write( "{0} ", firstArray[ i ] );
25
26         // pass variable firstArray by value to FirstDouble
27         FirstDouble( firstArray );
28
29         Console.Write( "\n\nContents of firstArray after " +
30             "calling FirstDouble\n\t" );
31
32         // display contents of firstArray
33         for ( int i = 0; i < firstArray.Length; ++i )
34             Console.Write( "{0} ", firstArray[ i ] );
35
36         // test whether reference was changed by FirstDouble
37         if ( firstArray == firstArrayCopy )
38             Console.WriteLine(
39                 "\n\nThe references refer to the same array" );
40         else
41             Console.WriteLine(
42                 "\n\nThe references refer to different arrays" );
43
44         // create and initialize secondArray
45         int[] secondArray = { 1, 2, 3 };
46
47         // copy the reference in variable secondArray
48         int[] secondArrayCopy = secondArray;
49
50         Console.WriteLine( "\nTest passing secondArray " +
51             "reference by reference" );
```

---

Fig. 8.14 | Passing an array reference by value and by reference. (Part I of 3.)

```
52     Console.WriteLine( "\nContents of secondArray " +
53         "before calling SecondDouble:\n\t" );
54
55
56     // display contents of secondArray before method call
57     for ( int i = 0; i < secondArray.Length; ++i )
58         Console.WriteLine( "{0} ", secondArray[ i ] );
59
60
61     // pass variable secondArray by reference to SecondDouble
62     SecondDouble( ref secondArray );
63
64
65     Console.WriteLine( "\n\nContents of secondArray " +
66         "after calling SecondDouble:\n\t" );
67
68
69     // display contents of secondArray after method call
70     for ( int i = 0; i < secondArray.Length; ++i )
71         Console.WriteLine( "{0} ", secondArray[ i ] );
72
73
74     // test whether reference was changed by SecondDouble
75     if ( secondArray == secondArrayCopy )
76         Console.WriteLine(
77             "\n\nThe references refer to the same array" );
78     else
79         Console.WriteLine(
80             "\n\nThe references refer to different arrays" );
81 } // end Main
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101 }
```

Fig. 8.14 | Passing an array reference by value and by reference. (Part 2 of 3.)

```

Test passing firstArray reference by value

Contents of firstArray before calling FirstDouble:
1 2 3

Contents of firstArray after calling FirstDouble
2 4 6

The references refer to the same array

Test passing secondArray reference by reference

Contents of secondArray before calling SecondDouble:
1 2 3

Contents of secondArray after calling SecondDouble:
11 12 13

The references refer to different arrays

```

**Fig. 8.14** | Passing an array reference by value and by reference. (Part 3 of 3.)

Lines 11 and 14 declare two integer array variables, `firstArray` and `firstArrayCopy`. Line 11 initializes `firstArray` with the values 1, 2 and 3. The assignment statement at line 14 copies the reference stored in `firstArray` to variable `firstArrayCopy`, causing these variables to reference the same array object. We make the copy of the reference so that we can determine later whether reference `firstArray` gets overwritten. The `for` statement at lines 23–24 displays the contents of `firstArray` before it's passed to method `FirstDouble` (line 27) so that we can verify that the called method indeed changes the array's contents.

### ***Method FirstDouble***

The `for` statement in method `FirstDouble` (lines 83–84) multiplies the values of all the elements in the array by 2. Line 87 creates a new array containing the values 11, 12 and 13, and assigns the array's reference to parameter `array` in an attempt to overwrite reference `firstArray` in the caller—this, of course, does not happen, because the reference was passed by value. After method `FirstDouble` executes, the `for` statement at lines 33–34 displays the contents of `firstArray`, demonstrating that the values of the elements have been changed by the method. The `if...else` statement at lines 37–42 uses the `==` operator to compare references `firstArray` (which we just attempted to overwrite) and `firstArrayCopy`. The expression in line 37 evaluates to `true` if the operands of operator `==` reference the same object. In this case, the object represented by `firstArray` is the array created in line 11—not the array created in method `FirstDouble` (line 87)—so the original reference stored in `firstArray` was not modified.

### ***Method SecondDouble***

Lines 45–76 perform similar tests, using array variables `secondArray` and `secondArrayCopy`, and method `SecondDouble` (lines 92–100). Method `SecondDouble` performs the same operations as `FirstDouble`, but receives its array argument using keyword `ref`. In this case, the reference stored in `secondArray` after the method call is a reference to the array created in line 99 of `SecondDouble`, demonstrating that a variable passed with key-

word `ref` can be modified by the called method so that the variable in the caller actually points to a *different* object—in this case, an array created in `SecondDouble`. The `if...else` statement in lines 71–76 confirms that `secondArray` and `secondArrayCopy` no longer refer to the same array.



### Software Engineering Observation 8.1

*When a method receives a reference-type parameter by value, a copy of the object's reference is passed. This prevents a method from overwriting references passed to that method. In the vast majority of cases, protecting the caller's reference from modification is the desired behavior. If you encounter a situation where you truly want the called procedure to modify the caller's reference, pass the reference-type parameter using keyword `ref`—but, again, such situations are rare.*



### Software Engineering Observation 8.2

*In C#, references to objects (including arrays) are passed to called methods. A called method receiving a reference to an object in a caller can interact with, and possibly change, the caller's object.*

## 8.9 Case Study: GradeBook Using an Array to Store Grades

This section further evolves class `GradeBook`, introduced in Chapter 4 and expanded in Chapters 5–6. Recall that this class represents a grade book used by an instructor to store and analyze a set of student grades. Previous versions of the class process a set of grades entered by the user, but do not maintain the individual grade values in instance variables of the class. Thus, repeat calculations require the user to re-enter the same grades. One way to solve this problem would be to store each grade entered in an individual instance of the class. For example, we could create instance variables `grade1`, `grade2`, ..., `grade10` in class `GradeBook` to store 10 student grades. However, the code to total the grades and determine the class average would be cumbersome, and the class would not be able to process any more than 10 grades at a time. In this section, we solve this problem by storing grades in an array.

### *Storing Student Grades in an Array in Class `GradeBook`*

The version of class `GradeBook` (Fig. 8.15) presented here uses an array of integers to store the grades of several students on a single exam. This eliminates the need to repeatedly input the same set of grades. Variable `grades` (which will refer to an array of `int`s) is declared as an instance variable in line 7—therefore, each `GradeBook` object maintains its own set of grades. The class's constructor (lines 14–18) has two parameters—the name of the course and an array of grades. When an app (e.g., class `GradeBookTest` in Fig. 8.16) creates a `GradeBook` object, the app passes an existing `int` array to the constructor, which assigns the array's reference to instance variable `grades` (line 17). The size of array `grades` is determined by the class that passes the array to the constructor. Thus, a `GradeBook` object can process a variable number of grades—as many as are in the array in the caller. The grade values in the passed array could have been input from a user at the keyboard or read from a file on disk (as discussed in Chapter 17). In our test app, we simply initialize an array with a set of grade values (Fig. 8.16, line 9). Once the grades are stored in instance

variable `grades` of class `GradeBook`, all the class's methods can access the elements of `grades` as needed to perform various calculations.

```
1 // Fig. 8.15: GradeBook.cs
2 // Grade book using an array to store test grades.
3 using System;
4
5 public class GradeBook
6 {
7     private int[] grades; // array of student grades
8
9     // auto-implemented property CourseName
10    public string CourseName { get; set; }
11
12    // two-parameter constructor initializes
13    // auto-implemented property CourseName and grades array
14    public GradeBook( string name, int[] gradesArray )
15    {
16        CourseName = name; // set CourseName to name
17        grades = gradesArray; // initialize grades array
18    } // end two-parameter GradeBook constructor
19
20    // display a welcome message to the GradeBook user
21    public void DisplayMessage()
22    {
23        // auto-implemented property CourseName gets the name of course
24        Console.WriteLine( "Welcome to the grade book for\n{0}!\n",
25            CourseName );
26    } // end method DisplayMessage
27
28    // perform various operations on the data
29    public void ProcessGrades()
30    {
31        // output grades array
32        OutputGrades();
33
34        // call method GetAverage to calculate the average grade
35        Console.WriteLine( "\nClass average is {0:F}", GetAverage() );
36
37        // call methods GetMinimum and GetMaximum
38        Console.WriteLine( "Lowest grade is {0}\nHighest grade is {1}\n",
39            GetMinimum(), GetMaximum() );
40
41        // call OutputBarChart to display grade distribution chart
42        OutputBarChart();
43    } // end method ProcessGrades
44
45    // find minimum grade
46    public int GetMinimum()
47    {
48        int lowGrade = grades[ 0 ]; // assume grades[ 0 ] is smallest
49    }
```

**Fig. 8.15** | Grade book using an array to store test grades. (Part I of 3.)

```
50     // loop through grades array
51     foreach ( int grade in grades )
52     {
53         // if grade lower than lowGrade, assign it to lowGrade
54         if ( grade < lowGrade )
55             lowGrade = grade; // new lowest grade
56     } // end for
57
58     return lowGrade; // return lowest grade
59 } // end method GetMinimum
60
61 // find maximum grade
62 public int GetMaximum()
63 {
64     int highGrade = grades[ 0 ]; // assume grades[ 0 ] is largest
65
66     // loop through grades array
67     foreach ( int grade in grades )
68     {
69         // if grade greater than highGrade, assign it to highGrade
70         if ( grade > highGrade )
71             highGrade = grade; // new highest grade
72     } // end for
73
74     return highGrade; // return highest grade
75 } // end method GetMaximum
76
77 // determine average grade for test
78 public double GetAverage()
79 {
80     int total = 0; // initialize total
81
82     // sum grades for one student
83     foreach ( int grade in grades )
84         total += grade;
85
86     // return average of grades
87     return ( double ) total / grades.Length;
88 } // end method GetAverage
89
90 // output bar chart displaying grade distribution
91 public void OutputBarChart()
92 {
93     Console.WriteLine( "Grade distribution:" );
94
95     // stores frequency of grades in each range of 10 grades
96     int[] frequency = new int[ 11 ];
97
98     // for each grade, increment the appropriate frequency
99     foreach ( int grade in grades )
100        ++frequency[ grade / 10 ];
```

Fig. 8.15 | Grade book using an array to store test grades. (Part 2 of 3.)

```
102     // for each grade frequency, display bar in chart
103     for ( int count = 0; count < frequency.Length; ++count )
104     {
105         // output bar label ( "00-09: ", ... , "90-99: ", "100: " )
106         if ( count == 10 )
107             Console.WriteLine( " 100: " );
108         else
109             Console.WriteLine( "{0:D2}-{1:D2}: ",
110                             count * 10, count * 10 + 9 );
111
112         // display bar of asterisks
113         for ( int stars = 0; stars < frequency[ count ]; ++stars )
114             Console.Write( "*" );
115
116         Console.WriteLine(); // start a new line of output
117     } // end outer for
118 } // end method OutputBarChart
119
120 // output the contents of the grades array
121 public void OutputGrades()
122 {
123     Console.WriteLine( "The grades are:\n" );
124
125     // output each student's grade
126     for ( int student = 0; student < grades.Length; ++student )
127         Console.WriteLine( "Student {0,2}: {1,3}",
128                           student + 1, grades[ student ] );
129 } // end method OutputGrades
130 } // end class GradeBook
```

---

**Fig. 8.15** | Grade book using an array to store test grades. (Part 3 of 3.)

### ***Method ProcessGrades***

Method *ProcessGrades* (lines 29–43) contains a series of method calls that result in the output of a report summarizing the grades. Line 32 calls method *OutputGrades* to display the contents of array *grades*. Lines 126–128 in method *OutputGrades* use a *for* statement to output the student grades. A *for* statement, rather than a *foreach*, must be used in this case, because lines 127–128 use counter variable *student*'s value to output each grade next to a particular student number (see Fig. 8.16). Although array indices start at 0, an instructor would typically number students starting at 1. Thus, lines 127–128 output *student* + 1 as the student number to produce grade labels "Student 1:", "Student 2:" and so on.

### ***Method GetAverage***

Method *ProcessGrades* next calls method *GetAverage* (line 35) to obtain the average of the grades in the array. Method *GetAverage* (lines 78–88) uses a *foreach* statement to total the values in array *grades* before calculating the average. The iteration variable in the *foreach*'s header (e.g., *int grade*) indicates that for each iteration, *int* variable *grade* takes on a value in array *grades*. The averaging calculation in line 87 uses *grades.Length* to determine the number of grades being averaged.

***Methods GetMinimum and GetMaximum***

Lines 38–39 in method `ProcessGrades` call methods `GetMinimum` and `GetMaximum` to determine the lowest and highest grades of any student on the exam, respectively. Each of these methods uses a `foreach` statement to loop through array `grades`. Lines 51–56 in method `GetMinimum` loop through the array, and lines 54–55 compare each grade to `lowGrade`. If a grade is less than `lowGrade`, `lowGrade` is set to that grade. When line 58 executes, `lowGrade` contains the lowest grade in the array. Method `GetMaximum` (lines 62–75) works the same way as method `GetMinimum`.

***Method OutputBarChart***

Finally, line 42 in method `ProcessGrades` calls method `OutputBarChart` to display a distribution chart of the grade data, using a technique similar to that in Fig. 8.6. In that example, we manually calculated the number of grades in each category (i.e., 0–9, 10–19, ..., 90–99 and 100) by simply looking at a set of grades. In this example, lines 99–100 use a technique similar to that in Figs. 8.7 and 8.8 to calculate the frequency of grades in each category. Line 96 declares variable `frequency` and initializes it with an array of 11 `ints` to store the frequency of grades in each grade category. For each grade in array `grades`, lines 99–100 increment the appropriate element of the `frequency` array. To determine which element to increment, line 100 divides the current grade by 10, using integer division. For example, if grade is 85, line 100 increments `frequency[8]` to update the count of grades in the range 80–89. Lines 103–117 next display the bar chart (see Fig. 8.6) based on the values in array `frequency`. Like lines 24–25 of Fig. 8.6, lines 113–114 of Fig. 8.15 use a value in array `frequency` to determine the number of asterisks to display in each bar.

***Class GradeBookTest That Demonstrates Class GradeBook***

The app of Fig. 8.16 creates an object of class `GradeBook` (Fig. 8.15) using `int` array `gradesArray` (declared and initialized in line 9). Lines 11–12 pass a course name and `gradesArray` to the `GradeBook` constructor. Line 13 displays a welcome message, and line 14 invokes the `GradeBook` object's `ProcessGrades` method. The output reveals the summary of the 10 grades in `myGradeBook`.

---

```

1 // Fig. 8.16: GradeBookTest.cs
2 // Create a GradeBook object using an array of grades.
3 public class GradeBookTest
4 {
5     // Main method begins app execution
6     public static void Main( string[] args )
7     {
8         // one-dimensional array of student grades
9         int[] gradesArray = { 87, 68, 94, 100, 83, 78, 85, 91, 76, 87 };
10
11        GradeBook myGradeBook = new GradeBook(
12            "CS101 Introduction to C# Programming", gradesArray );
13        myGradeBook.DisplayMessage();
14        myGradeBook.ProcessGrades();
15    } // end Main
16 } // end class GradeBookTest

```

---

**Fig. 8.16** | Create a `GradeBook` object using an array of grades. (Part I of 2.)

```
Welcome to the grade book for
CS101 Introduction to C# Programming!
```

The grades are:

```
Student 1: 87
Student 2: 68
Student 3: 94
Student 4: 100
Student 5: 83
Student 6: 78
Student 7: 85
Student 8: 91
Student 9: 76
Student 10: 87
```

```
Class average is 84.90
Lowest grade is 68
Highest grade is 100
```

Grade distribution:

```
00-09:
10-19:
20-29:
30-39:
40-49:
50-59:
60-69: *
70-79: **
80-89: ****
90-99: **
100: *
```

**Fig. 8.16** | Create a GradeBook object using an array of grades. (Part 2 of 2.)



### Software Engineering Observation 8.3

A *test harness* (or *test app*) is responsible for creating an object of the class being tested and providing it with data. This data could come from any of several sources. Test data can be placed directly into an array with an array initializer, it can come from the user at the keyboard or it can come from a file (as you'll see in Chapter 17). After passing this data, typically through the class's constructor, to instantiate the object, the test harness should call the object to test its methods and manipulate its data. Gathering data in the test harness like this allows the class to manipulate data from several sources.

## 8.10 Multidimensional Arrays

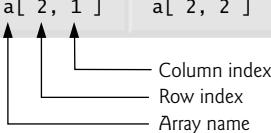
Multidimensional arrays with two dimensions are often used to represent **tables of values** consisting of information arranged in **rows** and **columns**. To identify a particular table element, we must specify *two* indices. By convention, the first identifies the element's row and the second its column. Arrays that require two indices to identify a particular element are called **two-dimensional arrays**. (Multidimensional arrays can have more than two dimensions, but such arrays are beyond the scope of this book.) C# supports two types of two-dimensional arrays—**rectangular arrays** and **jagged arrays**.

### Rectangular Arrays

Rectangular arrays are used to represent tables of information in the form of rows and columns, where each row has the same number of columns. Figure 8.17 illustrates a rectangular array named *a* containing three rows and four columns—a three-by-four array. In general, an array with *m* rows and *n* columns is called an ***m*-by-*n* array**.

---

|       | Column 0               | Column 1               | Column 2               | Column 3               |
|-------|------------------------|------------------------|------------------------|------------------------|
| Row 0 | <code>a[ 0, 0 ]</code> | <code>a[ 0, 1 ]</code> | <code>a[ 0, 2 ]</code> | <code>a[ 0, 3 ]</code> |
| Row 1 | <code>a[ 1, 0 ]</code> | <code>a[ 1, 1 ]</code> | <code>a[ 1, 2 ]</code> | <code>a[ 1, 3 ]</code> |
| Row 2 | <code>a[ 2, 0 ]</code> | <code>a[ 2, 1 ]</code> | <code>a[ 2, 2 ]</code> | <code>a[ 2, 3 ]</code> |



The diagram shows a 3x4 rectangular array labeled 'a'. The array is organized into 3 rows (labeled Row 0, Row 1, Row 2) and 4 columns (labeled Column 0, Column 1, Column 2, Column 3). Each element is represented by a code snippet like 'a[ 0, 0 ]'. A bracket below the array is labeled 'Array name'. Three arrows point from the labels 'Column index', 'Row index', and 'Array name' to their respective components: the column index part of the element code, the row index part, and the array name.

**Fig. 8.17** | Rectangular array with three rows and four columns.

### Array-Access Expression for a Two-Dimensional Rectangular Array

Every element in array *a* is identified in Fig. 8.17 by an array-access expression of the form `a[row, column]`; *a* is the name of the array, and *row* and *column* are the indices that uniquely identify each element in array *a* by row and column number. The names of the elements in row 0 all have a first index of 0, and the names of the elements in column 3 all have a second index of 3.

### Array Initializer for a Two-Dimensional Rectangular Array

Like one-dimensional arrays, multidimensional arrays can be initialized with array initializers in declarations. A rectangular array *b* with two rows and two columns could be declared and initialized with **nested array initializers** as follows:

```
int [ , ] b = { { 1, 2 }, { 3, 4 } };
```

The initializer values are grouped by row in braces. So 1 and 2 initialize  $b[0, 0]$  and  $b[0, 1]$ , respectively, and 3 and 4 initialize  $b[1, 0]$  and  $b[1, 1]$ , respectively. The compiler counts the number of nested array initializers (represented by sets of two inner braces within the outer braces) in the initializer list to determine the number of rows in array *b*. The compiler counts the initializer values in the nested array initializer for a row to determine the number of columns (two) in that row. The compiler will generate an error if the number of initializers in each row is not the same, because every row of a rectangular array must have the *same* length.

### Jagged Arrays

A jagged array is maintained as a one-dimensional array in which each element refers to a one-dimensional array. The manner in which jagged arrays are represented makes them quite flexible, because the lengths of the rows in the array need *not* be the same. For example, jagged arrays could be used to store a single student's exam grades across multiple classes, where the number of exams may vary from class to class.

***Array Initializer for a Two-Dimensional Jagged Array***

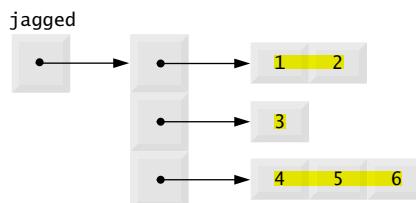
We can access the elements in a jagged array by an array-access expression of the form `arrayName[row][column]`—similar to the array-access expression for rectangular arrays, but with a separate set of square brackets for each dimension. A jagged array with three rows of different lengths could be declared and initialized as follows:

```
int[][] jagged = { new int[] { 1, 2 },
                   new int[] { 3 },
                   new int[] { 4, 5, 6 } };
```

In this statement, 1 and 2 initialize `jagged[0][0]` and `jagged[0][1]`, respectively; 3 initializes `jagged[1][0]`; and 4, 5 and 6 initialize `jagged[2][0]`, `jagged[2][1]` and `jagged[2][2]`, respectively. Therefore, array `jagged` in the preceding declaration is actually composed of four separate one-dimensional arrays—one that represents the rows, one containing the values in the first row (`{1, 2}`), one containing the value in the second row (`{3}`) and one containing the values in the third row (`{4, 5, 6}`). Thus, array `jagged` itself is an array of three elements, each a reference to a one-dimensional array of `int` values.

***Diagram of a Two-Dimensional Jagged Array in Memory***

Observe the differences between the array-creation expressions for rectangular arrays and for jagged arrays. Two sets of square brackets follow the type of `jagged`, indicating that this is an array of `int` arrays. Furthermore, in the array initializer, C# requires the keyword `new` to create an array object for each row. Figure 8.18 illustrates the array reference `jagged` after it's been declared and initialized.



**Fig. 8.18** | Jagged array with three rows of different lengths.

***Creating Two-Dimensional Arrays with Array-Creation Expressions***

A rectangular array can be created with an array-creation expression. For example, the following lines declare variable `b` and assign it a reference to a three-by-four rectangular array:

```
int[, ] b;
b = new int[ 3, 4 ];
```

In this case, we use the literal values 3 and 4 to specify the number of rows and number of columns, respectively, but this is *not* required—apps can also use variables and expressions to specify array dimensions. As with one-dimensional arrays, the elements of a rectangular array are initialized when the array object is created.

A jagged array cannot be completely created with a single array-creation expression. The following statement is a syntax error:

```
int[][] c = new int[ 2 ][ 5 ]; // error
```

Instead, each one-dimensional array in the jagged array must be initialized separately. A jagged array can be created as follows:

```
int[][] c;
c = new int[ 2 ][ ]; // create 2 rows
c[ 0 ] = new int[ 5 ]; // create 5 columns for row 0
c[ 1 ] = new int[ 3 ]; // create 3 columns for row 1
```

The preceding statements create a jagged array with two rows. Row 0 has five columns, and row 1 has three columns.

### *Two-Dimensional Array Example: Displaying Element Values*

Figure 8.19 demonstrates initializing rectangular and jagged arrays with array initializers and using nested for loops to **traverse** the arrays (i.e., visit every element of each array). Class **InitArray**'s **Main** method creates two arrays. Line 12 uses nested array initializers to initialize variable **rectangular** with an array in which row 0 has the values 1, 2 and 3, and row 1 has the values 4, 5 and 6. Lines 17–19 uses nested initializers of different lengths to initialize variable **jagged**. In this case, the initializer uses the keyword **new** to create a one-dimensional array for each row. Row 0 is initialized to have two elements with values 1 and 2, respectively. Row 1 is initialized to have one element with value 3. Row 2 is initialized to have three elements with the values 4, 5 and 6, respectively.

---

```

1 // Fig. 8.19: InitArray.cs
2 // Initializing rectangular and jagged arrays.
3 using System;
4
5 public class InitArray
6 {
7     // create and output rectangular and jagged arrays
8     public static void Main( string[] args )
9     {
10         // with rectangular arrays,
11         // every row must be the same length.
12         int[ , ] rectangular = { { 1, 2, 3 }, { 4, 5, 6 } };
13
14         // with jagged arrays,
15         // we need to use "new int[]" for every row,
16         // but every row does not need to be the same length.
17         int[][] jagged = { new int[] { 1, 2 },
18                           new int[] { 3 },
19                           new int[] { 4, 5, 6 } };
20
21         OutputArray( rectangular ); // displays array rectangular by row
22         Console.WriteLine(); // output a blank line
23         OutputArray( jagged ); // displays array jagged by row
24     } // end Main
25
26     // output rows and columns of a rectangular array
27     public static void OutputArray( int[ , ] array )
28     {
29         Console.WriteLine( "Values in the rectangular array by row are" );

```

**Fig. 8.19** | Initializing jagged and rectangular arrays. (Part I of 2.)

```

30     // loop through array's rows
31     for ( int row = 0; row < array.GetLength( 0 ); ++row )
32     {
33         // loop through columns of current row
34         for ( int column = 0; column < array.GetLength( 1 ); ++column )
35             Console.WriteLine( "{0} ", array[ row, column ] );
36
37         Console.WriteLine(); // start new line of output
38     } // end outer for
39 } // end method OutputArray
40
41 // output rows and columns of a jagged array
42 public static void OutputArray( int[][] array )
43 {
44     Console.WriteLine( "Values in the jagged array by row are" );
45
46     // loop through each row
47     foreach ( int[] row in array )
48     {
49         // loop through each element in current row
50         foreach ( int element in row )
51             Console.WriteLine( "{0} ", element );
52
53         Console.WriteLine(); // start new line of output
54     } // end outer foreach
55 } // end method OutputArray
56 } // end class InitArray
57 }
```

Values in the rectangular array by row are

```

1 2 3
4 5 6
```

Values in the jagged array by row are

```

1 2
3
4 5 6
```

**Fig. 8.19** | Initializing jagged and rectangular arrays. (Part 2 of 2.)

### Overloaded Method **OutputArray**

Method **OutputArray** has been overloaded with two versions. The first version (lines 27–40) specifies the array parameter as **int[,] array** to indicate that it takes a rectangular array. The second version (lines 43–56) takes a jagged array, because its array parameter is listed as **int[][] array**.

### Method **OutputArray** for Rectangular Arrays

Line 21 invokes method **OutputArray** with argument **rectangular**, so the version of **OutputArray** at lines 27–40 is called. The nested **for** statement (lines 32–39) outputs the rows of a rectangular array. The loop-continuation condition of each **for** statement (lines 32 and 35) uses the rectangular array's **GetLength** method to obtain the length of each dimension. Dimensions are numbered starting from 0, so the method call **GetLength(0)** on

array returns the size of the first dimension of the array (the number of rows), and the call `GetLength(1)` returns the size of the second dimension (the number of columns).

### ***Method OutputArray for Jagged Arrays***

Line 23 invokes method `OutputArray` with argument `jagged`, so the version of `OutputArray` at lines 43–56 is called. The nested `foreach` statement (lines 48–55) outputs the rows of a jagged array. The inner `foreach` statement (lines 51–52) iterates through each element in the current row of the array. This allows the loop to determine the exact number of columns in each row. Since the jagged array is created as an array of arrays, we can use nested `foreach` statements to output the elements in the console window. The outer loop iterates through the elements of `array`, which are references to one-dimensional arrays of `int` values that represent each row. The inner loop iterates through the elements of the current row. A `foreach` statement can also iterate through all the elements in a rectangular array. In this case, `foreach` iterates through all the rows and columns starting from row 0, as if the elements were in a one-dimensional array.

### ***Common Multidimensional-Array Manipulations Performed with for Statements***

Many common array manipulations use `for` statements. As an example, the following `for` statement sets all the elements in row 2 of rectangular array `a` in Fig. 8.17 to 0:

```
for ( int column = 0; column < a.GetLength( 1 ); ++column )
    a[ 2, column ] = 0;
```

We specified row 2; therefore, we know that the first index is always 2 (0 is the first row, and 1 is the second row). This `for` loop varies only the second index (i.e., the **column index**). The preceding `for` statement is equivalent to the assignment statements

```
a[ 2, 0 ] = 0;
a[ 2, 1 ] = 0;
a[ 2, 2 ] = 0;
a[ 2, 3 ] = 0;
```

The following nested `for` statement totals the values of all the elements in array `a`:

```
int total = 0;
for ( int row = 0; row < a.GetLength( 0 ); ++row )
{
    for ( int column = 0; column < a.GetLength( 1 ); ++column )
        total += a[ row, column ];
} // end outer for
```

These nested `for` statements total the array elements one row at a time. The outer `for` statement begins by setting the row index to 0 so that row 0's elements can be totaled by the inner `for` statement. The outer `for` then increments `row` to 1 so that row 1's elements can be totaled. Then the outer `for` increments `row` to 2 so that row 2's elements can be totaled. The variable `total` can be displayed when the outer `for` statement terminates. In the next example, we show how to process a rectangular array in a more concise manner using `foreach` statements.

## **8.11 Case Study: GradeBook Using a Rectangular Array**

In Section 8.9, we presented class `GradeBook` (Fig. 8.15), which used a one-dimensional array to store student grades on a single exam. In most courses, students take several exams.

Instructors are likely to want to analyze grades across the entire course, both for a single student and for the class as a whole.

### *Storing Student Grades in a Rectangular Array in Class GradeBook*

Figure 8.20 contains a version of class GradeBook that uses a rectangular array grades to store the grades of a number of students on multiple exams. Each row of the array represents a single student's grades for the entire course, and each column represents the grades for the whole class on one of the exams the students took during the course. An app such as GradeBookTest (Fig. 8.21) passes the array as an argument to the GradeBook constructor. In this example, we use a 10-by-3 array containing 10 students' grades on three exams. Five methods perform array manipulations to process the grades. Each method is similar to its counterpart in the earlier one-dimensional-array version of class GradeBook (Fig. 8.15). Method GetMinimum (lines 44–58 in Fig. 8.20) determines the lowest grade of any student for the semester. Method GetMaximum (lines 61–75) determines the highest grade of any student for the semester. Method GetAverage (lines 78–90) determines a particular student's semester average. Method OutputBarChart (lines 93–122) outputs a bar chart of the distribution of all student grades for the semester. Method OutputGrades (lines 125–149) outputs the two-dimensional array in tabular format, along with each student's semester average.

---

```

1 // Fig. 8.20: GradeBook.cs
2 // Grade book using a rectangular array to store grades.
3 using System;
4
5 public class GradeBook
6 {
7     private int[ , ] grades; // rectangular array of student grades
8
9     // auto-implemented property CourseName
10    public string CourseName { get; set; }
11
12    // two-parameter constructor initializes
13    // auto-implemented property CourseName and grades array
14    public GradeBook( string name, int[ , ] gradesArray )
15    {
16        CourseName = name; // set CourseName to name
17        grades = gradesArray; // initialize grades array
18    } // end two-parameter GradeBook constructor
19
20    // display a welcome message to the GradeBook user
21    public void DisplayMessage()
22    {
23        // auto-implemented property CourseName gets the name of course
24        Console.WriteLine( "Welcome to the grade book for\n{0}!\n",
25            CourseName );
26    } // end method DisplayMessage
27
28    // perform various operations on the data
29    public void ProcessGrades()
30    {

```

---

**Fig. 8.20** | Grade book using a rectangular array to store grades. (Part I of 4.)

```
31     // output grades array
32     OutputGrades();
33
34     // call methods GetMinimum and GetMaximum
35     Console.WriteLine( "\n{0} {1}\n{2} {3}\n",
36         "Lowest grade in the grade book is", GetMinimum(),
37         "Highest grade in the grade book is", GetMaximum() );
38
39     // output grade distribution chart of all grades on all tests
40     OutputBarChart();
41 } // end method ProcessGrades
42
43 // find minimum grade
44 public int GetMinimum()
45 {
46     // assume first element of grades array is smallest
47     int lowGrade = grades[ 0, 0 ];
48
49     // loop through elements of rectangular grades array
50     foreach ( int grade in grades )
51     {
52         // if grade less than lowGrade, assign it to lowGrade
53         if ( grade < lowGrade )
54             lowGrade = grade;
55     } // end foreach
56
57     return lowGrade; // return lowest grade
58 } // end method GetMinimum
59
60 // find maximum grade
61 public int GetMaximum()
62 {
63     // assume first element of grades array is largest
64     int highGrade = grades[ 0, 0 ];
65
66     // loop through elements of rectangular grades array
67     foreach ( int grade in grades )
68     {
69         // if grade greater than highGrade, assign it to highGrade
70         if ( grade > highGrade )
71             highGrade = grade;
72     } // end foreach
73
74     return highGrade; // return highest grade
75 } // end method GetMaximum
76
77 // determine average grade for particular student
78 public double GetAverage( int student )
79 {
80     // get the number of grades per student
81     int amount = grades.GetLength( 1 );
82     int total = 0; // initialize total
```

Fig. 8.20 | Grade book using a rectangular array to store grades. (Part 2 of 4.)

```
84     // sum grades for one student
85     for ( int exam = 0; exam < amount; ++exam )
86         total += grades[ student, exam ];
87
88     // return average of grades
89     return ( double ) total / amount;
90 } // end method GetAverage
91
92 // output bar chart displaying overall grade distribution
93 public void OutputBarChart()
94 {
95     Console.WriteLine( "Overall grade distribution:" );
96
97     // stores frequency of grades in each range of 10 grades
98     int[] frequency = new int[ 11 ];
99
100    // for each grade in GradeBook, increment the appropriate frequency
101    foreach ( int grade in grades )
102    {
103        ++frequency[ grade / 10 ];
104    } // end foreach
105
106    // for each grade frequency, display bar in chart
107    for ( int count = 0; count < frequency.Length; ++count )
108    {
109        // output bar label ( "00-09: ", ..., "90-99: ", "100: " )
110        if ( count == 10 )
111            Console.Write( " 100: " );
112        else
113            Console.Write( "{0:D2}-{1:D2}: ",
114                count * 10, count * 10 + 9 );
115
116        // display bar of asterisks
117        for ( int stars = 0; stars < frequency[ count ]; ++stars )
118            Console.Write( "*" );
119
120        Console.WriteLine(); // start a new line of output
121    } // end outer for
122 } // end method OutputBarChart
123
124 // output the contents of the grades array
125 public void OutputGrades()
126 {
127     Console.WriteLine( "The grades are:\n" );
128     Console.Write( " " ); // align column heads
129
130     // create a column heading for each of the tests
131     for ( int test = 0; test < grades.GetLength( 1 ); ++test )
132         Console.Write( "Test {0} ", test + 1 );
133
134     Console.WriteLine( "Average" ); // student average column heading
135 }
```

Fig. 8.20 | Grade book using a rectangular array to store grades. (Part 3 of 4.)

---

```

136     // create rows/columns of text representing array grades
137     for ( int student = 0; student < grades.GetLength( 0 ); ++student )
138     {
139         Console.WriteLine( "Student {0,2}", student + 1 );
140
141         // output student's grades
142         for ( int grade = 0; grade < grades.GetLength( 1 ); ++grade )
143             Console.WriteLine( "{0,8}", grades[ student, grade ] );
144
145         // call method GetAverage to calculate student's average grade;
146         // pass row number as the argument to GetAverage
147         Console.WriteLine( "{0,9:F}", GetAverage( student ) );
148     } // end outer for
149 } // end method OutputGrades
150 } // end class GradeBook

```

---

**Fig. 8.20** | Grade book using a rectangular array to store grades. (Part 4 of 4.)

### *Processing a Two-Dimensional Array with a foreach Statement*

Methods `GetMinimum`, `GetMaximum` and `OutputBarChart` each loop through array `grades` using the `foreach` statement—for example, the `foreach` statement from method `GetMinimum` (lines 50–55). To find the lowest overall grade, this `foreach` statement iterates through rectangular array `grades` and compares each element to variable `lowGrade`. If a grade is less than `lowGrade`, `lowGrade` is set to that grade.

When the `foreach` statement traverses the elements of array `grades`, it looks at each element of the first row in order by index, then each element of the second row in order by index and so on. The `foreach` statement in lines 50–55 traverses the elements of `grade` in the same order as the following equivalent code, expressed with nested `for` statements:

```

for ( int row = 0; row < grades.GetLength( 0 ); ++row )
    for ( int column = 0; column < grades.GetLength( 1 ); ++column )
    {
        if ( grades[ row, column ] < lowGrade )
            lowGrade = grades[ row, column ];
    }

```

When the `foreach` statement completes, `lowGrade` contains the lowest grade in the rectangular array. Method `GetMaximum` works similarly to method `GetMinimum`.

### *Method OutputBarChart*

Method `OutputBarChart` (lines 93–122) displays the grade distribution as a bar chart. The syntax of the `foreach` statement (lines 101–104) is identical for one-dimensional and two-dimensional arrays.

### *Method OutputGrades*

Method `OutputGrades` (lines 125–149) uses nested `for` statements to output values of the array `grades`, in addition to each student's semester average. The output in Fig. 8.21 shows the result, which resembles the tabular format of an instructor's physical grade book. Lines 131–132 (in Fig. 8.20) display the column headings for each test. We use the `for` statement rather than the `foreach` statement here so that we can identify each test with a number. Similarly, the `for` statement in lines 137–148 first outputs a row label using a counter vari-

able to identify each student (line 139). Although array indices start at 0, lines 132 and 139 output `test + 1` and `student + 1`, respectively, to produce test and student numbers starting at 1 (see Fig. 8.21). The inner for statement in lines 142–143 uses the outer for statement's counter variable `student` to loop through a specific row of array `grades` and output each student's test grade. Finally, line 147 obtains each student's semester average by passing the row index of `grades` (i.e., `student`) to method `GetAverage`.

### **Method `GetAverage`**

Method `GetAverage` (lines 78–90) takes one argument—the row index for a particular student. When line 147 calls `GetAverage`, the argument is `int` value `student`, which specifies the particular row of rectangular array `grades`. Method `GetAverage` calculates the sum of the array elements on this row, divides the total by the number of test results and returns the floating-point result as a `double` value (line 89).

### **Class `GradeBookTest` That Demonstrates Class `GradeBook`**

The app in Fig. 8.21 creates an object of class `GradeBook` (Fig. 8.20) using the two-dimensional array of `ints` that `gradesArray` references (Fig. 8.21, lines 9–18). Lines 20–21 pass a course name and `gradesArray` to the `GradeBook` constructor. Lines 22–23 then invoke `myGradeBook`'s `DisplayMessage` and `ProcessGrades` methods to display a welcome message and obtain a report summarizing the students' grades for the semester, respectively.

---

```

1 // Fig. 8.21: GradeBookTest.cs
2 // Create a GradeBook object using a rectangular array of grades.
3 public class GradeBookTest
4 {
5     // Main method begins app execution
6     public static void Main( string[] args )
7     {
8         // rectangular array of student grades
9         int[ , ] gradesArray = { { 87, 96, 70 },
10                             { 68, 87, 90 },
11                             { 94, 100, 90 },
12                             { 100, 81, 82 },
13                             { 83, 65, 85 },
14                             { 78, 87, 65 },
15                             { 85, 75, 83 },
16                             { 91, 94, 100 },
17                             { 76, 72, 84 },
18                             { 87, 93, 73 } };
19
20     GradeBook myGradeBook = new GradeBook(
21         "CS101 Introduction to C# Programming", gradesArray );
22     myGradeBook.DisplayMessage();
23     myGradeBook.ProcessGrades();
24 } // end Main
25 } // end class GradeBookTest

```

Welcome to the grade book for  
CS101 Introduction to C# Programming!

**Fig. 8.21** | Create a `GradeBook` object using a rectangular array of grades. (Part I of 2.)

The grades are:

|            | Test 1 | Test 2 | Test 3 | Average |
|------------|--------|--------|--------|---------|
| Student 1  | 87     | 96     | 70     | 84.33   |
| Student 2  | 68     | 87     | 90     | 81.67   |
| Student 3  | 94     | 100    | 90     | 94.67   |
| Student 4  | 100    | 81     | 82     | 87.67   |
| Student 5  | 83     | 65     | 85     | 77.67   |
| Student 6  | 78     | 87     | 65     | 76.67   |
| Student 7  | 85     | 75     | 83     | 81.00   |
| Student 8  | 91     | 94     | 100    | 95.00   |
| Student 9  | 76     | 72     | 84     | 77.33   |
| Student 10 | 87     | 93     | 73     | 84.33   |

Lowest grade in the grade book is 65

Highest grade in the grade book is 100

Overall grade distribution:

00-09:

10-19:

20-29:

30-39:

40-49:

50-59:

60-69: \*\*\*

70-79: \*\*\*\*\*

80-89: \*\*\*\*\*

90-99: \*\*\*\*\*

100: \*\*\*

**Fig. 8.21** | Create a GradeBook object using a rectangular array of grades. (Part 2 of 2.)

## 8.12 Variable-Length Argument Lists

Variable-length argument lists allow you to create methods that receive an arbitrary number of arguments. A one-dimensional array-type argument preceded by the keyword **params** in a method's parameter list indicates that the method receives a variable number of arguments with the type of the array's elements. This use of a **params** modifier can occur only in the last entry of the parameter list. While you can use method overloading and array passing to accomplish much of what is accomplished with variable-length argument lists, using the **params** modifier is more concise.

Figure 8.22 demonstrates method **Average** (lines 8–17), which receives a variable-length sequence of **doubles** (line 8). C# treats the variable-length argument list as a one-dimensional array whose elements are all of the same type. Hence, the method body can manipulate the parameter **numbers** as an array of **doubles**. Lines 13–14 use the **foreach** loop to walk through the array and calculate the total of the **doubles** in the array. Line 16 accesses **numbers.Length** to obtain the size of the **numbers** array for use in the averaging calculation. Lines 31, 33 and 35 in **Main** call method **Average** with two, three and four arguments, respectively. Method **Average** has a variable-length argument list, so it can average as many **double** arguments as the caller passes. The output reveals that each call to method **Average** returns the correct value.



### Common Programming Error 8.5

*The params modifier may be used only with the last parameter of the parameter list.*

```

1 // Fig. 8.22: ParamArrayTest.cs
2 // Using variable-length argument lists.
3 using System;
4
5 public class ParamArrayTest
6 {
7     // calculate average
8     public static double Average( params double[] numbers )
9     {
10         double total = 0.0; // initialize total
11
12         // calculate total using the foreach statement
13         foreach ( double d in numbers )
14             total += d;
15
16         return total / numbers.Length;
17     } // end method Average
18
19     public static void Main( string[] args )
20     {
21         double d1 = 10.0;
22         double d2 = 20.0;
23         double d3 = 30.0;
24         double d4 = 40.0;
25
26         Console.WriteLine(
27             "d1 = {0:F1}\nd2 = {1:F1}\nd3 = {2:F1}\nd4 = {3:F1}\n",
28             d1, d2, d3, d4 );
29
30         Console.WriteLine( "Average of d1 and d2 is {0:F1}",
31             Average( d1, d2 ) );
32         Console.WriteLine( "Average of d1, d2 and d3 is {0:F1}",
33             Average( d1, d2, d3 ) );
34         Console.WriteLine( "Average of d1, d2, d3 and d4 is {0:F1}",
35             Average( d1, d2, d3, d4 ) );
36     } // end Main
37 } // end class ParamArrayTest

```

```

d1 = 10.0
d2 = 20.0
d3 = 30.0
d4 = 40.0

Average of d1 and d2 is 15.0
Average of d1, d2 and d3 is 20.0
Average of d1, d2, d3 and d4 is 25.0

```

**Fig. 8.22** | Using variable-length argument lists.

## 8.13 Using Command-Line Arguments

On many systems, it's possible to pass arguments from the command line (these are known as **command-line arguments**) to an app by including a parameter of type `string[]` (i.e., an array of `strings`) in the parameter list of `Main`, exactly as we've done in every app in the book. By convention, this parameter is named `args` (Fig. 8.23, line 7). When an app is executed from the **Command Prompt**, the execution environment passes the command-line arguments that appear after the app name to the app's `Main` method as `strings` in the one-dimensional array `args`. The number of arguments passed from the command line is obtained by accessing the array's `Length` property. For example, the command "MyApp a b" passes two command-line arguments to app `MyApp`. Command-line arguments are separated by whitespace, not commas. When the preceding command executes, the `Main` method entry point receives the two-element array `args` (i.e., `args.Length` is 2) in which `args[0]` contains the `string` "a" and `args[1]` contains the `string` "b". Common uses of command-line arguments include passing options and file names to apps.

```

1 // Fig. 8.23: InitArray.cs
2 // Using command-line arguments to initialize an array.
3 using System;
4
5 public class InitArray
6 {
7     public static void Main( string[] args )
8     {
9         // check number of command-line arguments
10        if ( args.Length != 3 )
11            Console.WriteLine(
12                "Error: Please re-enter the entire command, including\n" +
13                "an array size, initial value and increment." );
14    else
15    {
16        // get array size from first command-line argument
17        int arrayLength = Convert.ToInt32( args[ 0 ] );
18        int[] array = new int[ arrayLength ]; // create array
19
20        // get initial value and increment from command-line argument
21        int initialValue = Convert.ToInt32( args[ 1 ] );
22        int increment = Convert.ToInt32( args[ 2 ] );
23
24        // calculate value for each array element
25        for ( int counter = 0; counter < array.Length; ++counter )
26            array[ counter ] = initialValue + increment * counter;
27
28        Console.WriteLine( "{0}{1,8}", "Index", "Value" );
29
30        // display array index and value
31        for ( int counter = 0; counter < array.Length; ++counter )
32            Console.WriteLine( "{0,5}{1,8}", counter, array[ counter ] );
33    } // end else
34 } // end Main
35 } // end class InitArray

```

**Fig. 8.23** | Using command-line arguments to initialize an array. (Part 1 of 2.)

```
C:\Examples\ch08\fig08_23>InitArray.exe
Error: Please re-enter the entire command, including
an array size, initial value and increment.
```

```
C:\Examples\ch08\fig08_23>InitArray.exe 5 0 4
Index    Value
 0        0
 1        4
 2        8
 3       12
 4       16
```

```
C:\Examples\ch08\fig08_23>InitArray.exe 10 1 2
Index    Value
 0        1
 1        3
 2        5
 3        7
 4        9
 5       11
 6       13
 7       15
 8       17
 9       19
```

**Fig. 8.23** | Using command-line arguments to initialize an array. (Part 2 of 2.)

Figure 8.23 uses three command-line arguments to initialize an array. When the app executes, if `args.Length` is not 3, the app displays an error message and terminates (lines 10–13). Otherwise, lines 16–32 initialize and display the array based on the values of the command-line arguments.

The command-line arguments become available to `Main` as `strings` in `args`. Line 17 gets `args[0]`—a `string` that specifies the array size—and converts it to an `int` value, which the app uses to create the array in line 18. The `static` method `ToInt32` of class `Convert` converts its `string` argument to an `int`.

Lines 21–22 convert the `args[1]` and `args[2]` command-line arguments to `int` values and store them in `initialValue` and `increment`, respectively. Lines 25–26 calculate the value for each array element.

The first sample execution indicates that the app received an insufficient number of command-line arguments. The second sample execution uses command-line arguments 5, 0 and 4 to specify the size of the array (5), the value of the first element (0) and the increment of each value in the array (4), respectively. The corresponding output indicates that these values create an array containing the integers 0, 4, 8, 12 and 16. The output from the third sample execution illustrates that the command-line arguments 10, 1 and 2 produce an array whose 10 elements are the nonnegative odd integers from 1 to 19.

### *Specifying Command-Line Arguments in Visual Studio*

We ran this example from a Command Prompt. You can also supply command-line arguments in the IDE. Right click the project's **Properties** node in the **Solution Explorer**, then

select **Open**. Select the **Debug** tab, then enter the arguments in the text box labeled **Command line arguments**.

## 8.14 Wrap-Up

This chapter began our introduction to data structures, exploring the use of arrays to store data in and retrieve data from lists and tables of values. The chapter examples demonstrated how to declare array variables, initialize arrays and refer to individual elements of arrays. The chapter introduced the `foreach` statement as an additional means (besides the `for` statement) for iterating through arrays. We showed how to pass arrays to methods and how to declare and manipulate multidimensional arrays. Finally, the chapter showed how to write methods that use variable-length argument lists and how to read arguments passed to an app from the command line.

We continue our coverage of data structures in Chapter 9, where we discuss the `List` collection, which is a dynamically resizable array-based collection. Chapter 18 discusses searching and sorting algorithms. Chapter 19 introduces dynamic data structures, such as lists, queues, stacks and trees, that can grow and shrink as apps execute. Chapter 20 presents generics, which provide the means to create general models of methods and classes that can be declared once, but used with many different data types. Chapter 21 introduces the data structure classes provided by the .NET Framework, some of which use generics to allow you to specify the exact types of objects that a particular data structure will store. You can use these predefined data structures instead of building your own. Chapter 21 discusses many data-structure classes that can grow and shrink in response to an app's changing storage requirements. The .NET Framework also provides class `Array`, which contains utility methods for array manipulation. Chapter 21 uses several `static` methods of class `Array` to perform such manipulations as sorting and searching the data in an array.

We've now introduced the basic concepts of classes, objects, control statements, methods and arrays. In Chapter 9 we introduce Language Integrated Query (LINQ), which enables you to write expressions that can retrieve information from a wide variety of data sources, such as arrays. You'll see how to search, sort and filter data using LINQ.

If you're in a course which either skips LINQ or defers coverage until later in the book when it's needed to support other more advanced C# features, you can proceed to Chapter 10, in which we take a deeper look at classes and objects.

---

## Summary

### Section 8.1 Introduction

- Arrays are data structures consisting of related data items of the same type. Arrays are fixed-length entities—they remain the same length once they're created.

### Section 8.2 Arrays

- Arrays are reference types. What we typically think of as an array is actually a reference to an array object. The elements of an array can be either value types or reference types (including other arrays).
- An app refers to an array element with an array-access expression that includes the name of the array, followed by the index of the particular element in square brackets (`[]`).
- The first element in every array has index zero and is sometimes called the zeroth element.
- An array's `Length` property returns the number of elements in the array.

### Section 8.3 Declaring and Creating Arrays

- To create an array instance, you specify the type and the number of array elements as part of an array-creation expression that uses keyword new. The following declaration and array-creation expression create an array object containing 12 int elements:

```
int[] a = new int[ 12 ];
```

- When an array is created, each element of the array receives a default value—0 for the numeric simple-type elements, false for bool elements and null for references.
- An app can declare variables that reference arrays of any type. Every element of a value-type array contains a value of the array's declared type. In an array of a reference type, every element is a reference to an object of the array's declared type or null.

### Section 8.4 Examples Using Arrays

- An app can create an array and initialize its elements with an array initializer, which is a comma-separated list of expressions (called an initializer list) enclosed in braces.
- Constants must be initialized when they're declared and cannot be modified thereafter.
- In a format item, a D format specifier indicates that the value should be formatted as an integer, and the number after the D indicates how many digits this formatted integer must contain.
- When a program is executed, array element indices are checked for validity—all indices must be greater than or equal to 0 and less than the length of the array. If an attempt is made to use an invalid index to access an element, an IndexOutOfRangeException exception occurs.
- An exception indicates a problem that occurs while a program executes. The name “exception” suggests that the problem occurs infrequently—if the “rule” is that a statement normally executes correctly, then the problem represents the “exception to the rule.”
- Exception handling enables you to create fault-tolerant programs that can resolve exceptions.
- To handle an exception, place any code that might throw an exception in a try statement.
- The try block contains the code that might throw an exception, and the catch block contains the code that handles the exception if one occurs.
- You can have many catch blocks to handle different types of exceptions that might be thrown in the corresponding try block.
- When a try block terminates any variables declared in the try block go out of scope.
- A catch block declares a type and an exception parameter. Inside the catch block, you can use the parameter's identifier to interact with a caught exception object.
- An exception object's Message property returns the exception's error message.

### Section 8.5 Case Study: Card Shuffling and Dealing Simulation

- The ToString method of an object is called implicitly in many cases when the object is used where a string is expected, such as concatenating an object to a string.

### Section 8.6 foreach Statement

- The foreach statement iterates through the elements of an entire array or collection. The syntax of a foreach statement is:

```
foreach ( type identifier in arrayName )
    statement
```

where *type* and *identifier* are the type and name of the iteration variable, and *arrayName* is the array through which to iterate.

- The foreach header can be read concisely as “for each iteration, assign the next element of the array to the iteration variable, then execute the following statement.”

- The `foreach` statement's iteration variable can be used only to access array elements, not to modify them. Any attempt to change the value of the iteration variable in the body of a `foreach` statement will cause a compilation error.

### **Section 8.7 Passing Arrays and Array Elements to Methods**

- When an argument to a method is an entire array or an individual array element of a reference type, the called method receives a copy of the reference. However, when an argument to a method is an individual array element of a value type, the called method receives a copy of the element's value.

### **Section 8.8 Passing Arrays by Value and by Reference**

- When a reference-type object is passed with `ref`, the called method actually gains control over the reference itself, allowing the called method to replace the original reference in the caller with a different object or even with `null`.
- If you encounter a situation where you truly want the called procedure to modify the caller's reference, pass the reference-type parameter using keyword `ref`—but such situations are rare.

### **Section 8.10 Multidimensional Arrays**

- Two-dimensional arrays are often used to represent tables of values consisting of information arranged in rows and columns. To identify a particular table element, we must specify two indices.
- C# supports two types of two-dimensional arrays—rectangular arrays and jagged arrays.
- Rectangular arrays are used to represent tables of information in the form of rows and columns, where each row has the same number of columns.
- Elements in rectangular array `a` are identified by an expression of the form `a[row, column]`.
- A rectangular array could be declared and initialized with array initializers of the form:

```
arrayType[ , ] arrayName = { {row0 initializer}, {row1 initializer}, ... };
```

provided that each row of the rectangular array must have the same length.

- A rectangular array can be created with an array-creation expression of the form

```
arrayType[ , ] arrayName = new arrayType[ numRows, numColumns ];
```

- A jagged array is maintained as a one-dimensional array in which each element refers to a one-dimensional array.
- The lengths of the rows in a jagged array need not be the same.
- We can access the elements in a jagged array `arrayName` by an array-access expression of the form `arrayName[ row ][ column ]`.
- A jagged array can be declared and initialized in the form:

```
arrayType[][] arrayName = { new arrayType[] {row0 initializer},  
                           new arrayType[] {row1 initializer}, ... };
```

### **Section 8.11 Case Study: Class `GradeBook` Using a Rectangular Array**

- When the `foreach` statement traverses a rectangular array's elements, it looks at each element of the first row in order by index, then each element of the second row in order by index and so on.

### **Section 8.12 Variable-Length Argument Lists**

- A one-dimensional array parameter preceded by `params` in a method's parameter list indicates that the method receives a variable number of arguments with the type of the array's elements.
- The `params` modifier can appear only in the last entry of the parameter list.
- C# treats a variable-length argument list as a one-dimensional array.

### Section 8.13 Using Command-Line Arguments

- When an app is executed from the **Command Prompt**, the execution environment passes the command-line arguments that appear after the app name to the app's **Main** method as strings in a one-dimensional array.

## Terminology

|                           |                                  |
|---------------------------|----------------------------------|
| array                     | leading 0                        |
| array-access expression   | Length property of an array      |
| array-creation expression | <i>m</i> -by- <i>n</i> array     |
| array initializer         | magic number                     |
| bounds checking           | Message property of an exception |
| catch block               | multidimensional array           |
| column index              | name of an array                 |
| column of an array        | named constant                   |
| command-line arguments    | nested array initializers        |
| const keyword             | params modifier                  |
| element of an array       | rectangular array                |
| exception                 | row index                        |
| exception handling        | row of an array                  |
| fault-tolerant program    | square brackets, []              |
| foreach statement         | table of values                  |
| index                     | test harness                     |
| index zero                | traverse an array                |
| IndexOutOfRangeException  | try statement                    |
| initializer list          | two-dimensional array            |
| iteration variable        | variable-length argument list    |
| jagged array              | zeroth element                   |

## Self-Review Exercises

- 8.1** Fill in the blank(s) in each of the following statements:
- Lists and tables of values can be stored in \_\_\_\_\_.
  - An array is a group of \_\_\_\_\_ (called elements) containing values that all have the same \_\_\_\_\_.
  - The \_\_\_\_\_ statement allows you to iterate through the elements in an array without using a counter.
  - The number that refers to a particular array element is called the element's \_\_\_\_\_.
  - An array that uses two indices is referred to as a(n) \_\_\_\_\_ array.
  - Use the **foreach** header \_\_\_\_\_ to iterate through double array numbers.
  - Command-line arguments are stored in \_\_\_\_\_.
  - Use the expression \_\_\_\_\_ to receive the total number of arguments in a command line. Assume that command-line arguments are stored in **string[] args**.
  - Given the command **MyApp test**, the first command-line argument is \_\_\_\_\_.
  - A(n) \_\_\_\_\_ in the parameter list of a method indicates that the method can receive a variable number of arguments.
- 8.2** Determine whether each of the following is *true* or *false*. If *false*, explain why.
- A single array can store values of many different types.
  - An array index should normally be of type **float**.
  - An individual array element that's passed to a method and modified in that method will contain the modified value when the called method completes execution.

d) Command-line arguments are separated by commas.

**8.3**

Perform the following tasks for an array called `fractions`:

- Declare constant `ARRAY_SIZE` initialized to 10.
- Declare variable `fractions` which will reference an array with `ARRAY_SIZE` elements of type `double`. Initialize the elements to 0.
- Name the element of the array with index 3.
- Assign the value 1.667 to the array element with index 9.
- Assign the value 3.333 to the array element with index 6.
- Sum all the elements of the array, using a `for` statement. Declare integer variable `x` as a control variable for the loop.

**8.4**

Perform the following tasks for an array called `table`:

- Declare the variable and initialize it with a rectangular integer array that has three rows and three columns. Assume that constant `ARRAY_SIZE` has been declared to be 3.
- How many elements does the array contain?
- Use a `for` statement to initialize each element of the array to the sum of its indices.

**8.5**

Find and correct the error in each of the following code segments:

- `const int ARRAY_SIZE = 5;`  
`ARRAY_SIZE = 10;`
- Assume `int[] b = new int[ 10 ];`  
`for ( int i = 0; i <= b.Length; ++i )`  
`b[ i ] = 1;`
- Assume `int[ , ] a = { { 1, 2 }, { 3, 4 } };`  
`a[ 1 ][ 1 ] = 5;`

## Answers to Self-Review Exercises

**8.1** a) arrays. b) variables, type. c) `foreach`. d) index (or position number). e) two-dimensional. f) `foreach ( double d in numbers )`. g) an array of strings, usually called `args`. h) `args.Length`. i) `test`. j) `params` modifier.

**8.2**

- False. An array can store only values of the same type.
- False. An array index must be an integer or an integer expression.
- For individual value-type elements of an array: False. A called method receives and manipulates a copy of the value of such an element, so modifications do not affect the original value. If the reference of an array is passed to a method, however, modifications to the array elements made in the called method are indeed reflected in the original. For individual elements of a reference type: True. A called method receives a copy of the reference of such an element, and changes to the referenced object will be reflected in the original array element.
- False. Command-line arguments are separated by whitespace.

**8.3**

- `const int ARRAY_SIZE = 10;`
- `double[] fractions = new double[ ARRAY_SIZE ];`
- `fractions[ 3 ]`
- `fractions[ 9 ] = 1.667;`
- `fractions[ 6 ] = 3.333;`
- `double total = 0.0;`  
`for ( int x = 0; x < fractions.Length; ++x )`  
`total += fractions[ x ];`

**8.4**

- `int[ , ] table = new int[ ARRAY_SIZE, ARRAY_SIZE ];`
- Nine.

```
c) for (int x = 0; x < table.GetLength( 0 ); ++x )
    for (int y = 0; y < table.GetLength( 1 ); ++y )
        table[ x, y ] = x + y;
```

- 8.5**
- Error:* Assigning a value to a constant after it's been initialized.  
*Correction:* Assign the correct value to the constant in the `const` declaration.
  - Error:* Referencing an array element outside the bounds of the array (`b[10]`).  
*Correction:* Change the `<=` operator to `<`.
  - Error:* Array indexing is performed incorrectly.  
*Correction:* Change the statement to `a[ 1, 1 ] = 5;`.

## Exercises

- 8.6** Fill in the blanks in each of the following statements:
- One-dimensional array `p` contains four elements. The names of those elements are \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.
  - Naming an array's variable, stating its type and specifying the number of dimensions in the array is called \_\_\_\_\_ the array.
  - In a two-dimensional array, the first index identifies the \_\_\_\_\_ of an element and the second index identifies the \_\_\_\_\_ of an element.
  - An  $m$ -by- $n$  array contains \_\_\_\_\_ rows, \_\_\_\_\_ columns and \_\_\_\_\_ elements.
  - The name of the element in row 3 and column 5 of jagged array `d` is \_\_\_\_\_.
- 8.7** Determine whether each of the following is *true* or *false*. If *false*, explain why.
- To refer to a particular location or element within an array, we specify the name of the array's variable and the value of the particular element.
  - The declaration of a variable that references an array reserves memory for the array.
  - To indicate that 100 locations should be reserved for integer array `p`, the programmer writes the declaration `p[ 100 ]`;
  - An app that initializes the elements of a 15-element array to 0 must contain at least one `for` statement.
  - To total the elements of a two-dimensional array you must use nested `for` statements.
- 8.8** Write C# statements to accomplish each of the following tasks:
- Display the value of the element of character array `f` with index 6.
  - Initialize each of the five elements of one-dimensional integer array `g` to 8.
  - Total the 100 elements of floating-point array `c`.
  - Copy 11-element array `a` into the first portion of array `b`, which contains 34 elements.
  - Determine and display the smallest and largest values contained in 99-element floating-point array `w`.
- 8.9** Consider the two-by-three rectangular integer array `t`.
- Write a statement that declares `t` and creates the array.
  - How many rows does `t` have?
  - How many columns does `t` have?
  - How many elements does `t` have?
  - Write the names of all the elements in row 1 of `t`.
  - Write the names of all the elements in column 2 of `t`.
  - Write a single statement that sets the element of `t` in row 0 and column 1 to zero.
  - Write a sequence of statements that initializes each element of `t` to 1. Do not use a repetition statement.
  - Write a nested `for` statement that initializes each element of `t` to 3.

- j) Write a nested `for` statement that inputs values for the elements of `t` from the user.
- k) Write a sequence of statements that determines and displays the smallest value in `t`.
- l) Write a statement that displays the elements of row 0 of `t`.
- m) Write a statement that totals the elements of column 2 of `t`.
- n) Write a sequence of statements that displays the contents of `t` in tabular format. List the column indices as headings across the top, and list the row indices at the left of each row.

**8.10** (*Sales Commissions*) Use a one-dimensional array to solve the following problem: A company pays its salespeople on a commission basis. The salespeople receive \$200 per week plus 9% of their gross sales for that week. For example, a salesperson who grosses \$5000 in sales in a week receives \$200 plus 9% of \$5000, or a total of \$650. Write an app (using an array of counters) that determines how many of the salespeople earned salaries in each of the following ranges (assume that each salesperson's salary is an integer). Summarize the results in tabular format.

- a) \$200–299
- b) \$300–399
- c) \$400–499
- d) \$500–599
- e) \$600–699
- f) \$700–799
- g) \$800–899
- h) \$900–999
- i) \$1000 and over

**8.11** (*Array Manipulations*) Write statements that perform the following one-dimensional-array operations:

- a) Set the three elements of integer array `counts` to 0.
- b) Add 1 to each of the four elements of integer array `bonus`.
- c) Display the five values of integer array `bestScores` in column format.

**8.12** (*Duplicate Elimination*) Use a one-dimensional array to solve the following problem: Write an app that inputs five numbers, each of which is between 10 and 100, inclusive. As each number is read, display it only if it's not a duplicate of a number already read. Provide for the “worst case,” in which all five numbers are different. Use the smallest possible array to solve this problem. Display the complete set of unique values input after the user inputs each new value.

**8.13** (*Jagged Arrays*) List the elements of the three-by-five jagged array `sales` in the order in which they're set to 0 by the following code segment:

```
for ( int row = 0; row < sales.Length; ++row )
{
    for ( int col = 0; col < sales[row].Length; ++col )
    {
        sales[ row ][ col ] = 0;
    }
}
```

**8.14** (*Variable-Length Argument List*) Write an app that calculates the product of a series of integers that are passed to method `product` using a variable-length argument list. Test your method with several calls, each with a different number of arguments.

**8.15** (*Command-Line Arguments*) Rewrite Fig. 8.2 so that the array's size is specified by the first command-line argument. If no command-line argument is supplied, use 10 as the default size.

**8.16** (*Using the foreach Statement*) Write an app that uses a `foreach` statement to sum the double values passed by the command-line arguments. [Hint: Use static method `ToDouble` of class `Convert` to convert a string to a double value.]

**8.17 (Dice Rolling)** Write an app to simulate the rolling of two dice. The app should use an object of class `Random` once to roll the first die and again to roll the second die. The sum of the two values should then be calculated. Each die can show an integer value from 1 to 6, so the sum of the values will vary from 2 to 12, with 7 being the most frequent sum and 2 and 12 the least frequent sums. Figure 8.24 shows the 36 possible combinations of the two dice. Your app should roll the dice 36,000 times. Use a one-dimensional array to tally the number of times each possible sum appears. Display the results in tabular format. Determine whether the totals are reasonable (e.g., there are six ways to roll a 7, so approximately one-sixth of the rolls should be 7).

|   | 1 | 2 | 3 | 4  | 5  | 6  |
|---|---|---|---|----|----|----|
| 1 | 2 | 3 | 4 | 5  | 6  | 7  |
| 2 | 3 | 4 | 5 | 6  | 7  | 8  |
| 3 | 4 | 5 | 6 | 7  | 8  | 9  |
| 4 | 5 | 6 | 7 | 8  | 9  | 10 |
| 5 | 6 | 7 | 8 | 9  | 10 | 11 |
| 6 | 7 | 8 | 9 | 10 | 11 | 12 |

**Fig. 8.24** | The 36 possible sums of two dice.

**8.18 (Game of Craps)** Write an app that runs 1000 games of craps (Fig. 7.8) and answers the following questions:

- How many games are won on the first roll, second roll, ..., twentieth roll and after the twentieth roll?
- How many games are lost on the first roll, second roll, ..., twentieth roll and after the twentieth roll?
- What are the chances of winning at craps? [Note: You should discover that craps is one of the fairest casino games.]
- What is the average length of a game of craps?

**8.19 (Airline Reservations System)** A small airline has just purchased a computer for its new automated reservations system. You have been asked to develop the new system. You're to write an app to assign seats on each flight of the airline's only plane (capacity: 10 seats).

Display the following alternatives: Please type 1 for First Class and Please type 2 for Economy. If the user types 1, your app should assign a seat in the first-class section (seats 1–5). If the user types 2, your app should assign a seat in the economy section (seats 6–10).

Use a one-dimensional array of type `bool` to represent the seating chart of the plane. Initialize all the elements of the array to `false` to indicate that all the seats are empty. As each seat is assigned, set the corresponding element of the array to `true` to indicate that the seat is no longer available.

Your app should never assign a seat that has already been assigned. When the economy section is full, your app should ask the person if it's acceptable to be placed in the first-class section (and vice versa). If yes, make the appropriate seat assignment. If no, display the message "Next flight leaves in 3 hours."

**8.20 (Total Sales)** Use a rectangular array to solve the following problem: A company has three salespeople (1 to 3) who sell five different products (1 to 5). Once a day, each salesperson passes in a slip for each type of product sold. Each slip contains the following:

- The salesperson number
- The product number
- The total dollar value of that product sold that day

Thus, each salesperson passes in between 0 and 5 sales slips per day. Assume that the information from all of the slips for last month is available. Write an app that will read all the information for last month's sales and summarize the total sales by salesperson and by product. All totals should be stored in rectangular array `sales`. After processing all the information for last month, display the results in tabular format, with each column representing a particular salesperson and each row representing a particular product. Cross-total each row to get the total sales of each product for last month. Cross-total each column to get the total sales by salesperson for last month. Your tabular output should include these cross-totals to the right of the totaled rows and below the totaled columns.

**8.21 (Turtle Graphics)** The Logo language made the concept of *turtle graphics* famous. Imagine a mechanical turtle that walks around the room under the control of a C# app. The turtle holds a pen in one of two positions—up or down. While the pen is down, the turtle traces out shapes as it moves, and while the pen is up, the turtle moves about freely without writing anything. In this problem, you'll simulate the operation of the turtle and create a computerized sketchpad.

Use a 20-by-20 rectangular array `floor` that's initialized to 0. Read commands from an array that contains them. Keep track at all times of the current position of the turtle and whether the pen is currently up or down. Assume that the turtle always starts at position (0, 0) of the floor with its pen up. The set of turtle commands your app must process are shown in Fig. 8.25.

Suppose that the turtle is somewhere near the center of the floor. The following “app” would draw and display a 12-by-12 square, leaving the pen in the up position:

```

2
5,12
3
5,12
3
5,12
3
5,12
1
6
9

```

As the turtle moves with the pen down, set the appropriate elements of array `floor` to 1s. When the 6 command (display the array) is given, wherever there's a 1 in the array, display an asterisk or any character you choose. Wherever there's a 0, display a blank.

Write an app to implement the turtle graphics capabilities discussed here. Write several turtle graphics apps to draw interesting shapes. Add other commands to increase the power of your turtle graphics language.

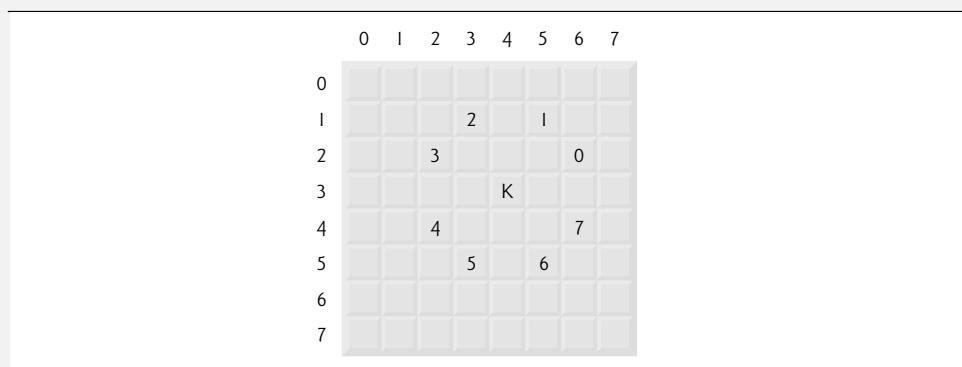
| Command | Meaning                                                              |
|---------|----------------------------------------------------------------------|
| 1       | Pen up                                                               |
| 2       | Pen down                                                             |
| 3       | Turn right                                                           |
| 4       | Turn left                                                            |
| 5,10    | Move forward 10 spaces (replace 10 for a different number of spaces) |
| 6       | Display the 20-by-20 array                                           |
| 9       | End of data (sentinel)                                               |

**Fig. 8.25** | Turtle graphics commands.

**8.22 (Knight's Tour)** One of the more interesting puzzlers for chess buffs is the Knight's Tour problem, originally proposed by the mathematician Euler. Can the chess piece called the knight move around an empty chessboard and touch each of the 64 squares once and only once? We study this intriguing problem in depth here.

The knight makes only L-shaped moves (two spaces in one direction and one space in a perpendicular direction). Thus, as shown in Fig. 8.26, from a square near the middle of an empty chessboard, the knight (labeled K) can make eight different moves (numbered 0 through 7).

- Draw an eight-by-eight chessboard on a sheet of paper, and attempt a Knight's Tour by hand. Put a 1 in the starting square, a 2 in the second square, a 3 in the third and so on. Before starting the tour, estimate how far you think you'll get, remembering that a full tour consists of 64 moves. How far did you get? Was this close to your estimate?
- Now let's develop an app that will move the knight around a chessboard. The board is represented by an eight-by-eight rectangular array `board`. Each square is initialized to zero. We describe each of the eight possible moves in terms of their horizontal and vertical components. For example, a move of type 0, as shown in Fig. 8.26, consists of moving two squares horizontally to the right and one square vertically upward. A move of type 2 consists of moving one square horizontally to the left and two squares vertically upward. Horizontal moves to the left and vertical moves upward are indicated with negative numbers. The eight moves may be described by two one-dimensional arrays, `horizontal` and `vertical`, as follows:



**Fig. 8.26** | The eight possible moves of the knight.

|                                   |                                 |
|-----------------------------------|---------------------------------|
| <code>horizontal[ 0 ] = 2</code>  | <code>vertical[ 0 ] = -1</code> |
| <code>horizontal[ 1 ] = 1</code>  | <code>vertical[ 1 ] = -2</code> |
| <code>horizontal[ 2 ] = -1</code> | <code>vertical[ 2 ] = -2</code> |
| <code>horizontal[ 3 ] = -2</code> | <code>vertical[ 3 ] = -1</code> |
| <code>horizontal[ 4 ] = -2</code> | <code>vertical[ 4 ] = 1</code>  |
| <code>horizontal[ 5 ] = -1</code> | <code>vertical[ 5 ] = 2</code>  |
| <code>horizontal[ 6 ] = 1</code>  | <code>vertical[ 6 ] = 2</code>  |
| <code>horizontal[ 7 ] = 2</code>  | <code>vertical[ 7 ] = 1</code>  |

Let variables `currentRow` and `currentColumn` indicate the row and column, respectively, of the knight's current position. To make a move of type `moveNumber`, where `moveNumber` is between 0 and 7, your app should use the statements

```
currentRow += vertical[ moveNumber ];
currentColumn += horizontal[ moveNumber ];
```

Write an app to move the knight around the chessboard. Keep a counter that varies from 1 to 64. Record the latest count in each square the knight moves to. Test each

- potential move to see if the knight has already visited that square. Test every potential move to ensure that the knight does not land off the chessboard. Run the app. How many moves did the knight make?
- c) After attempting to write and run a Knight's Tour app, you have probably developed some valuable insights. We'll use these insights to develop a *heuristic* for moving the knight. Heuristics do not guarantee success, but a carefully developed heuristic greatly improves the chance of success. You may have observed that the outer squares are more troublesome than the squares nearer the center of the board. In fact, the most troublesome and inaccessible squares are the four corners.

Intuition may suggest that you should attempt to move the knight to the most troublesome squares first and leave open those that are easiest to get to, so that when the board gets congested near the end of the tour, there will be a greater chance of success.

We could develop an “accessibility heuristic” by classifying each of the squares according to how accessible it is and always moving the knight (using the knight's L-shaped moves) to the most inaccessible square. We label two-dimensional array accessibility with numbers indicating from how many squares each particular square is accessible. On a blank chessboard, each of the 16 squares nearest the center is rated as 8, each corner square is rated as 2, and the other squares have accessibility numbers of 3, 4 or 6 as follows:

|   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 2 | 3 | 4 | 4 | 4 | 4 | 3 | 2 |
| 3 | 4 | 6 | 6 | 6 | 6 | 4 | 3 |
| 4 | 6 | 8 | 8 | 8 | 8 | 6 | 4 |
| 4 | 6 | 8 | 8 | 8 | 8 | 6 | 4 |
| 4 | 6 | 8 | 8 | 8 | 8 | 6 | 4 |
| 4 | 6 | 8 | 8 | 8 | 8 | 6 | 4 |
| 3 | 4 | 6 | 6 | 6 | 6 | 4 | 3 |
| 2 | 3 | 4 | 4 | 4 | 4 | 3 | 2 |

Write a new version of the Knight's Tour, using the accessibility heuristic. The knight should always move to the square with the lowest accessibility number. In case of a tie, the knight may move to any of the tied squares. Therefore, the tour may begin in any of the four corners. [Note: As the knight moves around the chessboard as more squares become occupied, your app should reduce the accessibility numbers. In this way, at any given time during the tour, each available square's accessibility number will remain equal to precisely the number of squares from which that square may be reached.] Run this version of your app. Did you get a full tour? Modify the app to run 64 tours, one starting from each square of the chessboard. How many full tours did you get?

- d) Write a version of the Knight's Tour app that, when encountering a tie between two or more squares, decides what square to choose by looking ahead to those squares reachable from the “tied” squares. Your app should move to the tied square for which the next move would arrive at the square with the lowest accessibility number.

**8.23 (Knight's Tour: Brute-Force Approaches)** In Part c of Exercise 8.22, we developed a solution to the Knight's Tour problem. The approach used, called the “accessibility heuristic,” generates many solutions and executes efficiently.

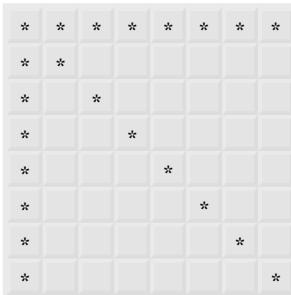
As computers continue to increase in power, we'll be able to solve more problems with sheer computer power and relatively unsophisticated algorithms. Let's call this approach “brute-force” problem solving.

- Use random-number generation to enable the knight to walk around the chessboard (in its legitimate L-shaped moves) at random. Your app should run one tour and display the final chessboard. How far did the knight get?
- Most likely, the app in Part a produced a relatively short tour. Now modify your app to attempt 1000 tours. Use a one-dimensional array to keep track of the number of

tours of each length. When your app finishes attempting the 1000 tours, it should display this information in neat tabular format. What was the best result?

- c) Most likely, the app in *Part b* gave you some “respectable” tours, but no full tours. Now let your app run until it produces a full tour. Once again, keep a table of the number of tours of each length, and display this table when the first full tour is found. How many tours did your app attempt before producing a full tour?
- d) Compare the brute-force version of the Knight’s Tour with the accessibility-heuristic version. Which required a more careful study of the problem? Which algorithm was more difficult to develop? Which required more computer power? Could we be certain (in advance) of obtaining a full tour with the accessibility-heuristic approach? Could we be certain (in advance) of obtaining a full tour with the brute-force approach? Argue the pros and cons of brute-force problem solving in general.

**8.24 (Eight Queens)** Another puzzler for chess buffs is the Eight Queens problem, which asks: Is it possible to place eight queens on an empty chessboard so that no queen is “attacking” any other (i.e., no two queens are in the same row, in the same column or along the same diagonal)? Use the thinking developed in Exercise 8.22 to formulate a heuristic for solving the Eight Queens problem. Run your app. [Hint: It’s possible to assign a value to each square of the chessboard to indicate how many squares of an empty chessboard are “eliminated” if a queen is placed in that square. Each of the corners would be assigned the value 22, as demonstrated by Fig. 8.27. Once these “elimination numbers” are placed in all 64 squares, an appropriate heuristic might be as follows: Place the next queen in the square with the smallest elimination number. Why is this strategy intuitively appealing?]



**Fig. 8.27** | The 22 squares eliminated by placing a queen in the upper left corner.

**8.25 (Eight Queens: Brute-Force Approaches)** In this exercise, you’ll develop several brute-force approaches to solving the Eight Queens problem introduced in Exercise 8.24.

- a) Use the random brute-force technique developed in Exercise 8.23 to solve the Eight Queens problem.
- b) Use an exhaustive technique (i.e., try all possible combinations of eight queens on the chessboard) to solve the Eight Queens problem.

**8.26 (Knight’s Tour: Closed-Tour Test)** In the Knight’s Tour (Exercise 8.22), a full tour occurs when the knight makes 64 moves, touching each square of the chessboard once and only once. A closed tour occurs when the 64th move is one move away from the square in which the tour started. Modify the app you wrote in Exercise 8.22 to test for a closed tour if a full tour has occurred.

**8.27 (Sieve of Eratosthenes)** A prime number is any integer greater than 1 that’s evenly divisible only by itself and 1. The Sieve of Eratosthenes finds prime numbers. It operates as follows:

- Create a simple type `bool` array with all elements initialized to `true`. Array elements with prime indices will remain `true`. All other array elements will eventually be set to `false`.
- Starting with array index 2, determine whether a given element is `true`. If so, loop through the remainder of the array and set to `false` every element whose index is a multiple of the index for the element with value `true`. Then continue the process with the next element with value `true`. For array index 2, all elements beyond element 2 in the array with indices that are multiples of 2 (indices 4, 6, 8, 10, etc.) will be set to `false`; for array index 3, all elements beyond element 3 in the array with indices that are multiples of 3 (indices 6, 9, 12, 15, etc.) will be set to `false`; and so on.

When this process completes, the array elements that are still `true` indicate that the index is a prime number. These indices can be displayed. Write an app that uses an array of 1000 elements to determine and display the prime numbers between 2 and 999. Ignore elements 0 and 1.

**8.28 (Simulation: The Tortoise and the Hare)** You'll now re-create the classic race of the tortoise and the hare. You'll use random-number generation to develop a simulation of this memorable event.

Our contenders begin the race at square 1 of 70 squares. Each square represents a possible position along the race course. The finish line is at square 70. The first contender to reach or pass square 70 is rewarded with a pail of fresh carrots and lettuce. The course weaves its way up the side of a slippery mountain, so occasionally the contenders lose ground.

A clock ticks once per second. With each tick of the clock, your app should adjust the position of the animals according to the rules in Fig. 8.28. Use variables to keep track of the positions of the animals (i.e., position numbers are 1–70). Start each animal at position 1 (the “starting gate”). If an animal slips left before square 1, move it back to square 1.

| Animal   | Move type  | Percentage of the time | Actual move            |
|----------|------------|------------------------|------------------------|
| Tortoise | Fast plod  | 50%                    | 3 squares to the right |
|          | Slip       | 20%                    | 6 squares to the left  |
|          | Slow plod  | 30%                    | 1 square to the right  |
| Hare     | Sleep      | 20%                    | No move at all         |
|          | Big hop    | 20%                    | 9 squares to the right |
|          | Big slip   | 10%                    | 12 squares to the left |
|          | Small hop  | 30%                    | 1 square to the right  |
|          | Small slip | 20%                    | 2 squares to the left  |

**Fig. 8.28** | Rules for adjusting the positions of the tortoise and the hare.

Generate the percentages in Fig. 8.28 by producing a random integer  $i$  in the range  $1 \leq i \leq 10$ . For the tortoise, perform a “fast plod” when  $1 \leq i \leq 5$ , a “slip” when  $6 \leq i \leq 7$  or a “slow plod” when  $8 \leq i \leq 10$ . Use a similar technique to move the hare.

Begin the race by displaying

```
ON YOUR MARK, GET SET
BANG !!!!!
AND THEY'RE OFF !!!!!
```

Then, for each tick of the clock (i.e., each repetition of a loop), display a 70-position line showing the letter `T` in the position of the tortoise and the letter `H` in the position of the hare. Occasionally, the contenders will land on the same square. In this case, the tortoise bites the hare, and your app

should display OUCH!!! beginning at that position. All output positions other than the T, the H or the OUCH!!! (in case of a tie) should be blank.

After each line is displayed, test for whether either animal has reached or passed square 70. If so, display the winner and terminate the simulation. If the tortoise wins, display TORTOISE WINS!!! YAY!!! If the hare wins, display Hare wins. Yuch. If both animals win on the same tick of the clock, you may want to favor the tortoise (the “underdog”), or you may want to display It's a tie. If neither animal wins, perform the loop again to simulate the next tick of the clock. When you're ready to run your app, assemble a group of fans to watch the race. You'll be amazed at how involved your audience gets!

**8.29** (*Card Shuffling and Dealing*) Modify the app of Fig. 8.11 to deal a five-card poker hand. Then modify class `DeckOfCards` of Fig. 8.10 to include methods that determine whether a hand contains

- a) a pair
- b) two pairs
- c) three of a kind (e.g., three jacks)
- d) four of a kind (e.g., four aces)
- e) a flush (i.e., all five cards of the same suit)
- f) a straight (i.e., five cards of consecutive face values)
- g) a full house (i.e., two cards of one face value and three cards of another face value)

[Hint: Add properties `Face` and `Suit` to class `Card` of Fig. 8.9.]

**8.30** (*Card Shuffling and Dealing*) Use the methods developed in Exercise 8.29 to write an app that deals two five-card poker hands, evaluates each hand and determines which is better.

## Special Section: Building Your Own Computer

In the next several problems, we take a temporary diversion from the world of high-level language programming to “peel open” a computer and look at its internal structure. We introduce machine-language programming and write several machine-language programs. To make this an especially valuable experience, we then build a computer (through the technique of software-based simulation) on which you can execute your machine-language programs.

**8.31** (*Machine-Language Programming*) Let's create a computer called the Simpletron. As its name implies, it's a simple machine, but powerful. The Simpletron runs programs written in the only language it directly understands: Simpletron Machine Language, or SML for short.

The Simpletron contains an *accumulator*—a special register into which information is put before the Simpletron uses it in calculations or examines it in various ways. All the information in the Simpletron is handled in terms of *words*. A word is a signed four-digit decimal number, such as +3364, -1293, +0007 and -0001. The Simpletron is equipped with a 100-word memory, and these words are referenced by their location numbers 00, 01, ..., 99.

Before running an SML program, we must *load*, or place, the code into memory. The first instruction (or statement) of every SML program is always placed in location 00. The simulator will start executing at this location.

Each instruction written in SML occupies one word of the Simpletron's memory (hence, instructions are signed four-digit decimal numbers). We shall assume that the sign of an SML instruction is always plus, but the sign of a data word may be either plus or minus. Each location in the Simpletron's memory may contain an instruction, a data value used by a program or an unused (and hence undefined) area of memory. The first two digits of each SML instruction are the *operation code* specifying the operation to be performed. SML operation codes are summarized in Fig. 8.29.

The last two digits of an SML instruction are the *operand*—the address of the memory location containing the word to which the operation applies. Let's consider several simple SML programs. The first SML program (Fig. 8.30) reads two numbers from the keyboard, then computes

| Operation code                          | Meaning                                                                                                                    |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| <i>Input/output operations:</i>         |                                                                                                                            |
| <code>const int READ = 10;</code>       | Read a word from the keyboard into a specific location in memory.                                                          |
| <code>const int WRITE = 11;</code>      | Write a word from a specific location in memory to the screen.                                                             |
| <i>Load/store operations:</i>           |                                                                                                                            |
| <code>const int LOAD = 20;</code>       | Load a word from a specific location in memory into the accumulator.                                                       |
| <code>const int STORE = 21;</code>      | Store a word from the accumulator into a specific location in memory.                                                      |
| <i>Arithmetic operations:</i>           |                                                                                                                            |
| <code>const int ADD = 30;</code>        | Add a word from a specific location in memory to the word in the accumulator (leave the result in the accumulator).        |
| <code>const int SUBTRACT = 31;</code>   | Subtract a word from a specific location in memory from the word in the accumulator (leave the result in the accumulator). |
| <code>const int DIVIDE = 32;</code>     | Divide a word from a specific location in memory into the word in the accumulator (leave result in the accumulator).       |
| <code>const int MULTIPLY = 33;</code>   | Multiply a word from a specific location in memory by the word in the accumulator (leave the result in the accumulator).   |
| <i>Transfer of control operations:</i>  |                                                                                                                            |
| <code>const int BRANCH = 40;</code>     | Branch to a specific location in memory.                                                                                   |
| <code>const int BRANCHNEG = 41;</code>  | Branch to a specific location in memory if the accumulator is negative.                                                    |
| <code>const int BRANCHZERO = 42;</code> | Branch to a specific location in memory if the accumulator is zero.                                                        |
| <code>const int HALT = 43;</code>       | Halt. The program has completed its task.                                                                                  |

**Fig. 8.29** | Simpletron Machine Language (SML) operation codes.

| Location | Number | Instruction |
|----------|--------|-------------|
| 00       | +1007  | (Read A)    |
| 01       | +1008  | (Read B)    |
| 02       | +2007  | (Load A)    |
| 03       | +3008  | (Add B)     |
| 04       | +2109  | (Store C)   |
| 05       | +1109  | (Write C)   |
| 06       | +4300  | (Halt)      |

**Fig. 8.30** | SML program that reads two integers and computes their sum. (Part 1 of 2.)

| Location | Number | Instruction  |
|----------|--------|--------------|
| 07       | +0000  | (Variable A) |
| 08       | +0000  | (Variable B) |
| 09       | +0000  | (Result C)   |

**Fig. 8.30** | SML program that reads two integers and computes their sum. (Part 2 of 2.)

and displays their sum. The instruction +1007 reads the first number from the keyboard and places it into location 07 (which has been initialized to 0). Then instruction +1008 reads the next number into location 08. The *load* instruction, +2007, puts the first number into the accumulator, and the *add* instruction, +3008, adds the second number to the number in the accumulator. *All SML arithmetic instructions leave their results in the accumulator.* The *store* instruction, +2109, places the result in memory location 09, from which the *write* instruction, +1109, takes the number and displays it (as a signed four-digit decimal number). The *halt* instruction, +4300, terminates execution.

The second SML program (Fig. 8.31) reads two numbers from the keyboard and determines and displays the larger value. Note the use of the instruction +4107 as a conditional transfer of control, much the same as C#'s *if* statement.

| Location | Number | Instruction             |
|----------|--------|-------------------------|
| 00       | +1009  | (Read A)                |
| 01       | +1010  | (Read B)                |
| 02       | +2009  | (Load A)                |
| 03       | +3110  | (Subtract B)            |
| 04       | +4107  | (Branch negative to 07) |
| 05       | +1109  | (Write A)               |
| 06       | +4300  | (Halt)                  |
| 07       | +1110  | (Write B)               |
| 08       | +4300  | (Halt)                  |
| 09       | +0000  | (Variable A)            |
| 10       | +0000  | (Variable B)            |

**Fig. 8.31** | SML program that reads two integers and determines the larger.

Now write SML programs to accomplish each of the following tasks:

- Use a sentinel-controlled loop to read positive numbers and compute and display their sum. Terminate input when a negative number is entered.
- Use a counter-controlled loop to read seven numbers, some positive and some negative, then compute and display their average.
- Read a series of numbers, then determine and display the largest number. The first number read indicates how many numbers should be processed.

**8.32** (*Computer Simulator*) In this problem, you're going to build your own computer. No, you'll not be soldering components together. Rather, you'll use the powerful technique of *software-based simulation* to create an object-oriented *software model* of the Simpletron of Exercise 8.31. Your

Simpletron simulator will turn the computer you're using into a Simpletron, and you'll actually be able to run, test and debug the SML programs you wrote in Exercise 8.31.

When you run your Simpletron simulator, it should begin by displaying:

```
*** Welcome to Simpletron! ***
*** Please enter your program one instruction ***
*** ( or data word ) at a time into the input ***
*** text field. I will display the location ***
*** number and a question mark (?). You then ***
*** type the word for that location. Enter ***
*** -99999 to stop entering your program. ***
```

Your app should simulate the memory of the Simpletron with a one-dimensional array `memory` of 100 elements. Now assume that the simulator is running, and let's examine the dialog as we enter the program of Fig. 8.31 (Exercise 8.31):

```
00 ? +1009
01 ? +1010
02 ? +2009
03 ? +3110
04 ? +4107
05 ? +1109
06 ? +4300
07 ? +1110
08 ? +4300
09 ? +0000
10 ? +0000
11 ? -99999
```

Your program should display the memory location followed by a question mark. Each of the values to the right of a question mark is input by the user. When the sentinel value -99999 is input, the program should display the following:

```
*** Program loading completed ***
*** Program execution begins ***
```

The SML program has now been placed (or loaded) in array `memory`. Now the Simpletron executes the SML program. Execution begins with the instruction in location 00 and, as in C#, continues sequentially, unless directed to some other part of the program by a transfer of control.

Use variable `accumulator` to represent the accumulator register. Use variable `instructionCounter` to keep track of the location in memory that contains the instruction being performed. Use variable `operationCode` to indicate the operation currently being performed (i.e., the left two digits of the instruction word). Use variable `operand` to indicate the memory location on which the current instruction operates. Thus, `operand` is the rightmost two digits of the instruction currently being performed. Do not execute instructions directly from memory. Rather, transfer the next instruction to be performed from memory to a variable called `instructionRegister`. Then "pick off" the left two digits and place them in `operationCode`, and "pick off" the right two digits and place them in `operand`. When the Simpletron begins execution, the special registers are all initialized to zero.

Now, let's "walk through" execution of the first SML instruction, +1009 in memory location 00. This procedure is called an *instruction execution cycle*.

The `instructionCounter` tells us the location of the next instruction to be performed. We *fetch* the contents of that location from `memory` by using the C# statement

```
instructionRegister = memory[ instructionCounter ];
```

The operation code and the operand are extracted from the instruction register by the statements

```
operationCode = instructionRegister / 100;
operand = instructionRegister % 100;
```

Now the Simpletron must determine that the operation code is actually a *read* (versus a *write*, a *load*, or whatever). A switch differentiates among the 12 operations of SML. In the switch statement, the behavior of various SML instructions is simulated as shown in Fig. 8.32. We discuss branch instructions shortly and leave the others to you.

| Instruction   | Description                                                                                                             |
|---------------|-------------------------------------------------------------------------------------------------------------------------|
| <i>read</i> : | Display the prompt "Enter an integer", then input the integer and store it in location <code>memory[ operand ]</code> . |
| <i>load</i> : | <code>accumulator = memory[ operand ];</code>                                                                           |
| <i>add</i> :  | <code>accumulator += memory[ operand ];</code>                                                                          |
| <i>halt</i> : | This instruction displays the message<br><code>*** Simpletron execution terminated ***</code>                           |

**Fig. 8.32** | Behavior of several SML instructions in the Simpletron.

When the SML program completes execution, the name and contents of each register, as well as the complete contents of memory, should be displayed. This is often called a memory dump. To help you program your dump method, a sample dump format is shown in Fig. 8.33. A dump after executing a Simpletron program would show the actual values of instructions and data values at the moment execution terminated.

```

REGISTERS:
accumulator      +0000
instructionCounter 00
instructionRegister +0000
operationCode      00
operand            00

MEMORY:
    0   1   2   3   4   5   6   7   8   9
0 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
10 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
20 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
30 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
40 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
50 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
60 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
70 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
80 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
90 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000

```

**Fig. 8.33** | A sample memory dump.

Let's proceed with the execution of our program's first instruction—namely, the +1009 in location 00. As we've indicated, the `switch` statement simulates this task by prompting the user to enter a value, reading the value and storing it in memory location `memory[ operand ]`. The value is then read into location 09.

At this point, simulation of the first instruction is completed. All that remains is to prepare the Simpletron to execute the next instruction. Since the instruction just performed was not a transfer of control, we need merely increment the `instructionCounter`.

This action completes the simulated execution of the first instruction. The entire process (i.e., the instruction execution cycle) begins anew with the fetch of the next instruction to execute.

Now let's consider how the branching instructions—the transfers of control—are simulated. All we need to do is adjust the value in the instruction counter appropriately. Therefore, the unconditional branch instruction (40) is simulated within the switch as

```
instructionCounter = operand;
```

The conditional “branch if accumulator is zero” instruction is simulated as

```
if ( accumulator == 0 )
    instructionCounter = operand;
```

At this point, you should implement your Simpletron simulator and run each of the SML programs you wrote in Exercise 8.31. If you desire, you may embellish SML with additional features and provide for these features in your simulator.

Your simulator should check for various types of errors. During the program-loading phase, for example, each number the user types into the Simpletron’s memory must be in the range -9999 to +9999. Your simulator should test that each number entered is in this range and, if not, keep prompting the user to re-enter the number until the user enters a correct number.

During the execution phase, your simulator should check for various serious errors, such as attempts to divide by zero, attempts to execute invalid operation codes and accumulator overflows (i.e., arithmetic operations resulting in values larger than +9999 or smaller than -9999). Such serious errors are called *fatal errors*. When a fatal error is detected, your simulator should display an error message, such as

```
*** Attempt to divide by zero ***
*** Simpletron execution abnormally terminated ***
```

and should display a full computer dump in the format we discussed previously. This treatment will help the user locate the error in the program.

**8.33 (Project: Simpletron Simulator Modifications)** In Exercise 8.32, you wrote a software simulation of a computer that executes programs written in Simpletron Machine Language (SML). In this exercise, we propose several modifications and enhancements to the Simpletron Simulator.

- a) Extend the Simpletron Simulator’s memory to contain 1000 memory locations to enable the Simpletron to handle larger programs.
- b) Allow the simulator to perform remainder calculations. This modification requires an additional SML instruction.
- c) Allow the simulator to perform exponentiation calculations. This modification requires an additional SML instruction.
- d) Modify the simulator to use hexadecimal values rather than integer values to represent SML instructions.
- e) Modify the simulator to allow output of a newline. This modification requires an additional SML instruction.
- f) Modify the simulator to process floating-point values in addition to integer values.
- g) Modify the simulator to handle string input. [Hint: Each Simpletron word can be divided into two groups, each holding a two-digit integer. Each two-digit integer represents the ASCII (see Appendix C) decimal equivalent of an uppercase character. Add a machine-language instruction that will input a string and store the string beginning at a specific Simpletron memory location. The first half of the word at that location will be a count of the number of characters in the string (i.e., the length of the string). Each succeeding half-word contains one ASCII character expressed as two decimal digits. The machine-language instruction converts each character into its ASCII equivalent and assigns it to a half-word.]

- h) Modify the simulator to handle output of uppercase strings stored in the format of *Part g.* [Hint: Add a machine-language instruction that will display a string beginning at a certain Simpletron memory location. The first half of the word at that location is a count of the number of characters in the string (i.e., the length of the string). Each succeeding half-word contains one ASCII character expressed as two decimal digits. The machine-language instruction checks the length and displays the string by translating each two-digit number into its equivalent character.]

## Making a Difference Exercise

**8.34 (Polling)** The Internet and the web are enabling more people to network, join a cause, voice opinions, and so on. The presidential candidates in 2012 used the Internet intensively to get out their messages and raise money for their campaigns. In this exercise, you'll write a simple polling program that allows users to rate five social-consciousness issues from 1 (least important) to 10 (most important). Pick five causes that are important to you (for example, political issues, global environmental issues). Use a one-dimensional array `topics` (of type `String`) to store the five causes. To summarize the survey responses, use a 5-row, 10-column two-dimensional array `responses` (of type `Integer`), each row corresponding to an element in the `topics` array. When the program runs, it should ask the user to rate each issue. Have your friends and family respond to the survey. Then have the program display a summary of the results, including:

- a) A tabular report with the five topics down the left side and the 10 ratings across the top, listing in each column the number of ratings received for each topic.
- b) To the right of each row, show the average of the ratings for that issue.
- c) Which issue received the highest point total? Display both the issue and the point total.
- d) Which issue received the lowest point total? Display both the issue and the point total.

# 9

# Introduction to LINQ and the `List` Collection



*To write it, it took three months; to conceive it three minutes; to collect the data in it—all my life.*

—F. Scott Fitzgerald

*You shall listen to all sides and filter them from your self.*

—Walt Whitman

*The portraitist can select one tiny aspect of everything shown at a moment to incorporate into the final painting.*

—Robert Nozick

*List, list, O, list!*

—William Shakespeare

## Objectives

In this chapter you'll:

- Learn basic LINQ concepts.
- Query an array using LINQ.
- Learn basic .NET collections concepts.
- Create and use a generic `List` collection.
- Query a generic `List` collection using LINQ.

# Outline

- |                                                                                                                                                                                                      |                                                                                                                                                                                                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <a href="#">9.1 Introduction</a><br><a href="#">9.2 Querying an Array of <code>int</code> Values Using LINQ</a><br><a href="#">9.3 Querying an Array of <code>Employee</code> Objects Using LINQ</a> | <a href="#">9.4 Introduction to Collections</a><br><a href="#">9.5 Querying a Generic Collection Using LINQ</a><br><a href="#">9.6 Wrap-Up</a><br><a href="#">9.7 Deitel LINQ Resource Center</a> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 9.1 Introduction

Chapter 8 introduced arrays—simple data structures used to store items of a specific type. Although commonly used, arrays have limited capabilities. For instance, you must specify an array’s size, and if at execution time, you wish to modify it, you must do so manually by creating a new array or by using class `Array`’s `Resize` method, which incurs the overhead of creating a new array and copying the existing elements into the new array for you.

In this chapter, we introduce a set of *prepackaged* data structures—the .NET Framework’s *collection* classes—that offer greater capabilities than traditional arrays. They’re reusable, reliable, powerful and efficient and have been carefully designed and tested to ensure correctness and good performance. This chapter focuses on the `List` collection. A `List` is similar to an array but provides additional functionality, such as **dynamic resizing**—a `List` can increase its size when items are added to it and decrease its size when items are removed. We use the `List` collection to implement several examples similar to those used in the preceding chapter.

Large amounts of data that need to persist beyond an app’s execution are typically stored in a *database*—an organized collection of data. (We discuss databases in detail in Chapter 22.) A *database management system (DBMS)* provides mechanisms for storing, organizing, retrieving and modifying data in the database. A language called SQL—pronounced “sequel”—is the international standard used to perform **queries** (i.e., to request information that satisfies given criteria) and to manipulate data. For years, programs accessing a relational database passed SQL queries to the database management system, then processed the results. This chapter introduces C#’s new **LINQ (Language Integrated Query)** capabilities. LINQ allows you to write **query expressions**, similar to SQL queries, that retrieve information from a *variety* of data sources, not just databases. We use **LINQ to Objects** in this chapter to query arrays and `Lists`, selecting elements that satisfy a set of conditions—this is known as **filtering**. Figure 9.1 shows where and how we use LINQ throughout the book.

| Chapter                                                              | Used to                                                                                    |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Chapter 9, Introduction to LINQ and the <code>List</code> Collection | Query arrays and <code>Lists</code> .                                                      |
| Chapter 16, Strings and Characters: A Deeper Look                    | Select GUI controls in a Windows Forms app (located in the online section of the chapter). |

**Fig. 9.1** | LINQ usage throughout the book. (Part 1 of 2.)

| Chapter                                      | Used to                                                             |
|----------------------------------------------|---------------------------------------------------------------------|
| Chapter 17, Files and Streams                | Search a directory and manipulate text files.                       |
| Chapter 22, Databases and LINQ               | Retrieve information from a database.                               |
| Chapter 23, Web App Development with ASP.NET | Retrieve information from a database to be used in a web-based app. |
| Chapter 24, XML and LINQ to XML              | Query an XML document.                                              |
| Chapter 30, Web Services                     | Query and update a database. Process XML returned by WCF services.  |

**Fig. 9.1** | LINQ usage throughout the book. (Part 2 of 2.)

### LINQ Providers

The syntax of LINQ is built into C#, but LINQ queries may be used in many different contexts because of libraries known as *providers*. A **LINQ provider** is a set of classes that implement LINQ operations and enable programs to interact with *data sources* to perform tasks such as *sorting*, *grouping* and *filtering* elements.

In this book, we discuss *LINQ to Entities* and *LINQ to XML*, which allow you to query databases and XML documents using LINQ. These providers, along with *LINQ to Objects*, mentioned above, are included with C# and the .NET Framework. There are many providers that are more specialized, allowing you to interact with a specific website or data format. Many LINQ providers are available. Be sure to check out the open source site [codeplex.com](http://codeplex.com). Simply search for “LINQ providers” on the site.

## 9.2 Querying an Array of int Values Using LINQ

Figure 9.2 demonstrates querying an array of integers using LINQ. Repetition statements that *filter* arrays focus on the process of getting the results—iterating through the elements and checking whether they satisfy the desired criteria. LINQ specifies the conditions that selected elements must satisfy. This is known as **declarative programming**—as opposed to **imperative programming** (which we’ve been doing so far) in which you specify the actual steps to perform a task. The query in lines 20–22 specifies that the results should consist of all the ints in the values array that are greater than 4. It *does not* specify *how* those results are obtained—the C# compiler generates all the necessary code, which is one of the great strengths of LINQ. To use *LINQ to Objects*, you must import the `System.Linq` namespace (line 4).

---

```

1 // Fig. 9.2: LINQWithSimpleTypeArray.cs
2 // LINQ to Objects using an int array.
3 using System;
4 using System.Linq;
5

```

**Fig. 9.2** | LINQ to Objects using an int array. (Part 1 of 3.)

```
6  class LINQWithSimpleTypeArray
7  {
8      public static void Main( string[] args )
9      {
10         // create an integer array
11         int[] values = { 2, 9, 5, 0, 3, 7, 1, 4, 8, 5 };
12
13         // display original values
14         Console.WriteLine( "Original array:" );
15         foreach ( var element in values )
16             Console.WriteLine( " {0}", element );
17
18         // LINQ query that obtains values greater than 4 from the array
19         var filtered =
20             from value in values
21             where value > 4
22             select value;
23
24         // display filtered results
25         Console.WriteLine( "\nArray values greater than 4:" );
26         foreach ( var element in filtered )
27             Console.WriteLine( " {0}", element );
28
29         // use orderby clause to original values in ascending order
30         var sorted =
31             from value in values
32             orderby value
33             select value;
34
35         // display sorted results
36         Console.WriteLine( "\nOriginal array, sorted:" );
37         foreach ( var element in sorted )
38             Console.WriteLine( " {0}", element );
39
40         // sort the filtered results into descending order
41         var sortFilteredResults =
42             from value in filtered
43             orderby value descending
44             select value;
45
46         // display the sorted results
47         Console.WriteLine(
48             "\nValues greater than 4, descending order (separately):" );
49         foreach ( var element in sortFilteredResults )
50             Console.WriteLine( " {0}", element );
51
52         // filter original array and sort results in descending order
53         var sortAndFilter =
54             from value in values
55             where value > 4
56             orderby value descending
57             select value;
58
```

---

Fig. 9.2 | LINQ to Objects using an int array. (Part 2 of 3.)

---

```

59     // display the filtered and sorted results
60     Console.WriteLine(
61         "\nValues greater than 4, descending order (one query):" );
62     foreach ( var element in sortAndFilter )
63         Console.WriteLine( " {0}" , element );
64
65     Console.WriteLine();
66 } // end Main
67 } // end class LINQWithSimpleTypeArray

```

```

Original array: 2 9 5 0 3 7 1 4 8 5
Array values greater than 4: 9 5 7 8 5
Original array, sorted: 0 1 2 3 4 5 5 7 8 9
Values greater than 4, descending order (separately): 9 8 7 5 5
Values greater than 4, descending order (one query): 9 8 7 5 5

```

**Fig. 9.2** | LINQ to Objects using an `int` array. (Part 3 of 3.)

### *The from Clause and Implicitly Typed Local Variables*

A LINQ query begins with a `from` clause (line 20), which specifies a **range variable** (`value`) and the data source to query (`values`). The range variable represents each item in the data source (one at a time), much like the control variable in a `foreach` statement. We do *not* specify the range variable's type. Since it's assigned one element at a time from the array `values`, which is an `int` array, the compiler determines that the range variable `value` should be of type `int`. This is a C# feature called **implicitly typed local variables**, which enables the compiler to *infer* a local variable's type based on the context in which it's used.

Introducing the range variable in the `from` clause at the beginning of the query allows the IDE to provide *IntelliSense* while you write the rest of the query. The IDE knows the range variable's type, so when you enter the range variable's name followed by a dot (.) in the code editor, the IDE can display the range variable's methods and properties.

### *The var Keyword and Implicitly Typed Local Variables*

You can also declare a local variable and let the compiler *infer* the variable's type based on the variable's *initializer*. To do so, the **var keyword** is used in place of the variable's type when declaring the variable. Consider the declaration

```
var x = 7;
```

Here, the compiler *infers* that the variable `x` should be of type `int`, because the compiler assumes that whole-number values, like 7, are of type `int`. Similarly, in the declaration

```
var y = -123.45;
```

the compiler *infers* that `y` should be of type `double`, because the compiler assumes that floating-point number values, like -123.45, are of type `double`. Typically, implicitly typed local variables are used for more complex types, such as the collections of data returned by LINQ queries. We use this feature in lines 19, 30, 41 and 53 to let the compiler determine the type of each variable that stores the results of a LINQ query. We also use this feature to declare the control variable in the `foreach` statements at lines 15–16, 26–27, 37–38, 49–50 and 62–63. In each case, the compiler infers that the control variable is of type `int` because the array `values` and the LINQ query results all contain `int` values.

### The **where** Clause

If the condition in the **where** clause (line 21) evaluates to `true`, the element is *selected*—i.e., it's included in the results. Here, the `ints` in the array are included only if they're greater than 4. An expression that takes an element of a collection and returns `true` or `false` by testing a condition on that element is known as a **predicate**.

### The **select** Clause

For each item in the data source, the **select** clause (line 22) determines what value appears in the results. In this case, it's the `int` that the `range` variable currently represents. A LINQ query typically ends with a **select** clause.

### Iterating Through the Results of the LINQ Query

Lines 26–27 use a `foreach` statement to display the query results. As you know, a `foreach` statement can iterate through the contents of an array, allowing you to process each element in the array. Actually, the `foreach` statement can iterate through the contents of arrays, collections and the results of LINQ queries. The `foreach` statement in lines 26–27 iterates over the query result `filtered`, displaying each of its items.

### LINQ vs. Repetition Statements

It would be simple to display the integers greater than 4 using a repetition statement that tests each value before displaying it. However, this would intertwine the code that selects elements and the code that displays them. With LINQ, these are kept separate, making the code easier to understand and maintain.

### The **orderby** Clause

The **orderby** clause (line 32) sorts the query results in *ascending* order. Lines 43 and 56 use the **descending** modifier in the **orderby** clause to sort the results in *descending* order. An **ascending** modifier also exists but isn't normally used, because it's the default. Any value that can be compared with other values of the same type may be used with the **orderby** clause. A value of a *simple type* (e.g., `int`) can always be compared to another value of the *same type*; we'll say more about comparing values of *reference types* in Chapter 12.

The queries in lines 42–44 and 54–57 generate the same results, but in different ways. The first query uses LINQ to sort the results of the query from lines 20–22. The second query uses both the **where** and **orderby** clauses. Because queries can operate on the results of other queries, it's possible to build a query one step at a time, and pass the results of queries between methods for further processing.

### More on Implicitly Typed Local Variables

Implicitly typed local variables can also be used to initialize arrays *without* explicitly giving their type. For example, the following statement creates an array of `int` values:

```
var array = new[] { 32, 27, 64, 18, 95, 14, 90, 70, 60, 37 };
```

Note that there are no square brackets on the left side of the assignment operator, and that `new[]` is used to specify that the variable is an array.

### An Aside: Interface **IEnumerable<T>**

As we mentioned, the `foreach` statement can iterate through the contents of *arrays*, *collections* and *LINQ query results*. Actually, `foreach` iterates over any so-called **IEnumerable<T>** object, which just happens to be what most LINQ queries return.

**IEnumerable<T>** is an **interface**. Interfaces define and standardize the ways in which people and systems can interact with one another. For example, the controls on a radio serve as an *interface* between radio users and the radio's internal components. The controls allow users to perform a limited set of *operations* (e.g., changing the station, adjusting the volume, and choosing between AM and FM), and different radios may implement the controls in different ways (e.g., using push buttons, dials or voice commands). The interface specifies *what* operations a radio permits users to perform but does not specify *how* the operations are implemented. Similarly, the interface between a driver and a car with a manual transmission includes the steering wheel, the gear shift, the clutch, the gas pedal and the brake pedal. This same interface is found in nearly all manual-transmission cars, enabling someone who knows how to drive one manual-transmission car to drive another.

Software objects also communicate via interfaces. A C# interface describes a set of members that can be called on an object—to tell the object, for example, to perform some task or return some piece of information. The **IEnumerable<T>** interface describes the functionality of any object that can be iterated over and thus offers members to access each element. A class that implements an interface must define each member in the interface with a signature identical to the one in the interface definition. Implementing an interface is like signing a contract with the compiler that states, “I will declare *all* the members specified by the interface.” Chapter 12 covers use of interfaces in more detail, as well as how to define your own interfaces.

Arrays are **IEnumerable<T>** objects, so a **foreach** statement can iterate over an array’s elements. Similarly, each LINQ query returns an **IEnumerable<T>** object. Therefore, you can use a **foreach** statement to iterate over the results of any LINQ query. The notation **<T>** indicates that the interface is a *generic* interface that can be used with any type of data (for example, **ints**, **strings** or **Employees**). You’ll learn more about the **<T>** notation in Section 9.4. You’ll learn more about interfaces in Section 12.7.

## 9.3 Querying an Array of Employee Objects Using LINQ

LINQ is not limited to querying arrays of simple types such as **ints**. It can be used with most data types, including **strings** and user-defined classes. It cannot be used when a query does not have a defined meaning—for example, you cannot use **orderby** on objects that are not *comparable*. Comparable types in .NET are those that implement the **IComparable** interface, which is discussed in Section 20.4. All built-in types, such as **string**, **int** and **double** implement **IComparable**. Figure 9.3 presents the **Employee** class. Figure 9.4 uses LINQ to query an array of **Employee** objects.

---

```

1 // Fig. 9.3: Employee.cs
2 // Employee class with FirstName, LastName and MonthlySalary properties.
3 public class Employee
4 {
5     private decimal monthlySalaryValue; // monthly salary of employee
6
7     // auto-implemented property FirstName
8     public string FirstName { get; set; }
9

```

---

**Fig. 9.3** | Employee class. (Part I of 2.)

```
10 // auto-implemented property LastName
11 public string LastName { get; set; }
12
13 // constructor initializes first name, last name and monthly salary
14 public Employee( string first, string last, decimal salary )
15 {
16     FirstName = first;
17     LastName = last;
18     MonthlySalary = salary;
19 } // end constructor
20
21 // property that gets and sets the employee's monthly salary
22 public decimal MonthlySalary
23 {
24     get
25     {
26         return monthlySalaryValue;
27     } // end get
28     set
29     {
30         if ( value >= 0M ) // if salary is nonnegative
31         {
32             monthlySalaryValue = value;
33         } // end if
34     } // end set
35 } // end property MonthlySalary
36
37 // return a string containing the employee's information
38 public override string ToString()
39 {
40     return string.Format( "{0,-10} {1,-10} {2,10:C}",
41                         FirstName, LastName, MonthlySalary );
42 } // end method ToString
43 } // end class Employee
```

---

**Fig. 9.3** | Employee class. (Part 2 of 2.)

```
1 // Fig. 9.4: LINQWithArrayOfObjects.cs
2 // LINQ to Objects using an array of Employee objects.
3 using System;
4 using System.Linq;
5
6 public class LINQWithArrayOfObjects
7 {
8     public static void Main( string[] args )
9     {
10         // initialize array of employees
11         Employee[] employees = {
12             new Employee( "Jason", "Red", 5000M ),
13             new Employee( "Ashley", "Green", 7600M ),
14             new Employee( "Matthew", "Indigo", 3587.5M ),
```

---

**Fig. 9.4** | LINQ to Objects using an array of Employee objects. (Part 1 of 3.)

```
15     new Employee( "James", "Indigo", 4700.77M ),
16     new Employee( "Luke", "Indigo", 6200M ),
17     new Employee( "Jason", "Blue", 3200M ),
18     new Employee( "Wendy", "Brown", 4236.4M ) };// end init list
19
20 // display all employees
21 Console.WriteLine( "Original array:" );
22 foreach ( var element in employees )
23     Console.WriteLine( element );
24
25 // filter a range of salaries using && in a LINQ query
26 var between4K6K =
27     from e in employees
28     where e.MonthlySalary >= 4000M && e.MonthlySalary <= 6000M
29     select e;
30
31 // display employees making between 4000 and 6000 per month
32 Console.WriteLine( string.Format(
33     "\nEmployees earning in the range {0:C}-{1:C} per month:",
34     4000, 6000 ) );
35 foreach ( var element in between4K6K )
36     Console.WriteLine( element );
37
38 // order the employees by last name, then first name with LINQ
39 var nameSorted =
40     from e in employees
41     orderby e.LastName, e.FirstName
42     select e;
43
44 // header
45 Console.WriteLine( "\nFirst employee when sorted by name:" );
46
47 // attempt to display the first result of the above LINQ query
48 if ( nameSorted.Any() )
49     Console.WriteLine( nameSorted.First() );
50 else
51     Console.WriteLine( "not found" );
52
53 // use LINQ to select employee last names
54 var lastNames =
55     from e in employees
56     select e.LastName;
57
58 // use method Distinct to select unique last names
59 Console.WriteLine( "\nUnique employee last names:" );
60 foreach ( var element in lastNames.Distinct() )
61     Console.WriteLine( element );
62
63 // use LINQ to select first and last names
64 var names =
65     from e in employees
66     select new { e.FirstName, Last = e.LastName };
```

**Fig. 9.4** | LINQ to Objects using an array of Employee objects. (Part 2 of 3.)

---

```

68     // display full names
69     Console.WriteLine( "\nNames only:" );
70     foreach ( var element in names )
71         Console.WriteLine( element );
72
73     Console.WriteLine();
74 } // end Main
75 } // end class LINQWithArrayOfObjects

```

Original array:

|         |        |            |
|---------|--------|------------|
| Jason   | Red    | \$5,000.00 |
| Ashley  | Green  | \$7,600.00 |
| Matthew | Indigo | \$3,587.50 |
| James   | Indigo | \$4,700.77 |
| Luke    | Indigo | \$6,200.00 |
| Jason   | Blue   | \$3,200.00 |
| Wendy   | Brown  | \$4,236.40 |

Employees earning in the range \$4,000.00–\$6,000.00 per month:

|       |        |            |
|-------|--------|------------|
| Jason | Red    | \$5,000.00 |
| James | Indigo | \$4,700.77 |
| Wendy | Brown  | \$4,236.40 |

First employee when sorted by name:

|       |      |            |
|-------|------|------------|
| Jason | Blue | \$3,200.00 |
|-------|------|------------|

Unique employee last names:

|        |
|--------|
| Red    |
| Green  |
| Indigo |
| Blue   |
| Brown  |

Names only:

|                                        |
|----------------------------------------|
| { FirstName = Jason, Last = Red }      |
| { FirstName = Ashley, Last = Green }   |
| { FirstName = Matthew, Last = Indigo } |
| { FirstName = James, Last = Indigo }   |
| { FirstName = Luke, Last = Indigo }    |
| { FirstName = Jason, Last = Blue }     |
| { FirstName = Wendy, Last = Brown }    |

**Fig. 9.4** | LINQ to Objects using an array of Employee objects. (Part 3 of 3.)

### Accessing the Properties of a LINQ Query's Range Variable

Line 28 of Fig. 9.4 shows a where clause that accesses the properties of the *range variable*. In this example, the compiler infers that the range variable is of type Employee based on its knowledge that employees was defined as an array of Employee objects (lines 11–18). Any bool expression can be used in a where clause. Line 28 uses the conditional AND (&&) operator to combine conditions. Here, only employees that have a salary between \$4,000 and \$6,000 per month, inclusive, are included in the query result, which is displayed in lines 35–36.

### Sorting a LINQ Query's Results By Multiple Properties

Line 41 uses an orderby clause to sort the results according to *multiple* properties—specified in a comma-separated list. In this query, the employees are sorted alphabetically by

last name. Each group of Employees that have the same last name is then sorted within the group by first name.

### **Any, First and Count Extension Methods**

Line 48 introduces the query result's **Any** method, which returns `true` if there's at least one element, and `false` if there are no elements. The query result's **First** method (line 49) returns the first element in the result. You should check that the query result is not empty (line 48) before calling **First**.

We've not specified the class that defines methods **First** and **Any**. Your intuition probably tells you they're methods declared in the `IEnumerable<T>` interface, but they aren't. They're actually *extension methods*—such methods can be used to enhance a class's capabilities without modifying the class's definition. The LINQ extension methods can be used as if they were methods of `IEnumerable<T>`.

LINQ defines many more extension methods, such as **Count**, which returns the number of elements in the results. Rather than using **Any**, we could have checked that **Count** was nonzero, but it's more efficient to determine whether there's at least one element than to count all the elements. The LINQ query syntax is actually transformed by the compiler into extension method calls, with the results of one method call used in the next. It's this design that allows queries to be run on the results of previous queries, as it simply involves passing the result of a method call to another method.

### **Selecting a Property of an Object**

Line 56 uses the `select` clause to select the range variable's `LastName` property rather than the range variable itself. This causes the results of the query to consist of only the last names (as strings), instead of complete `Employee` objects. Lines 60–61 display the unique last names. The **Distinct** extension method (line 60) removes duplicate elements, causing all elements in the result to be unique.

### **Creating New Types in the `select` Clause of a LINQ Query**

The last LINQ query in the example (lines 65–66) selects the properties `FirstName` and `LastName`. The syntax

```
new { e.FirstName, Last = e.LastName }
```

creates a new object of an **anonymous type** (a type with no name), which the compiler generates for you based on the properties listed in the curly braces `{}`. In this case, the anonymous type consists of properties for the first and last names of the selected `Employee`. The `LastName` property is assigned to the property `Last` in the `select` clause. This shows how you can specify a new name for the selected property. If you don't specify a new name, the property's original name is used—this is the case for `FirstName` in this example. The preceding query is an example of a **projection**—it performs a transformation on the data. In this case, the transformation creates new objects containing only the `FirstName` and `Last` properties. Transformations can also manipulate the data. For example, you could give all employees a 10% raise by multiplying their `MonthlySalary` properties by 1.1.

When creating a new anonymous type, you can select any number of properties by specifying them in a comma-separated list within the curly braces `{}` that delineate the anonymous type definition. In this example, the compiler automatically creates a new class having properties `FirstName` and `Last`, and the values are copied from the `Employee`

objects. These selected properties can then be accessed when iterating over the results. Implicitly typed local variables allow you to use *anonymous types* because you do not have to explicitly state the type when declaring such variables.

When the compiler creates an anonymous type, it automatically generates a `ToString` method that returns a `string` representation of the object. You can see this in the program's output—it consists of the property names and their values, enclosed in braces. Anonymous types are discussed in more detail in Chapter 22.

## 9.4 Introduction to Collections

The .NET Framework Class Library provides several classes, called *collections*, used to store groups of related objects. These classes provide efficient methods that organize, store and retrieve your data *without* requiring knowledge of how the data is being *stored*. This reduces app development time.

You've used arrays to store sequences of objects. Arrays do *not* automatically change their size at execution time to accommodate additional elements—you must do so manually by creating a new array or by using the `Array` class's `Resize` method.

The collection class `List<T>` (from namespace `System.Collections.Generic`) provides a convenient solution to this problem. The `T` is a placeholder—when declaring a new `List`, replace it with the type of elements that you want the `List` to hold. This is similar to specifying the type when declaring an array. For example,

```
List< int > list1;
```

declares `list1` as a `List` collection that can store only `int` values, and

```
List< string > list2;
```

declares `list2` as a `List` of `strings`. Classes with this kind of placeholder that can be used with any type are called **generic classes**. Generic classes and additional generic collection classes are discussed in Chapters 20 and 21, respectively. Figure 21.2 provides a table of collection classes. Figure 9.5 shows some common methods and properties of class `List<T>`.

| Method or property    | Description                                                                                                         |
|-----------------------|---------------------------------------------------------------------------------------------------------------------|
| <code>Add</code>      | Adds an element to the end of the <code>List</code> .                                                               |
| <code>Capacity</code> | Property that gets or sets the number of elements a <code>List</code> can store without resizing.                   |
| <code>Clear</code>    | Removes all the elements from the <code>List</code> .                                                               |
| <code>Contains</code> | Returns <code>true</code> if the <code>List</code> contains the specified element and <code>false</code> otherwise. |
| <code>Count</code>    | Property that returns the number of elements stored in the <code>List</code> .                                      |
| <code>IndexOf</code>  | Returns the index of the first occurrence of the specified value in the <code>List</code> .                         |
| <code>Insert</code>   | Inserts an element at the specified index.                                                                          |
| <code>Remove</code>   | Removes the first occurrence of the specified value.                                                                |

**Fig. 9.5** | Some methods and properties of class `List<T>`. (Part 1 of 2.)

| Method or property | Description                                                                                  |
|--------------------|----------------------------------------------------------------------------------------------|
| RemoveAt           | Removes the element at the specified index.                                                  |
| RemoveRange        | Removes a specified number of elements starting at a specified index.                        |
| Sort               | Sorts the List.                                                                              |
| TrimExcess         | Sets the Capacity of the List to the number of elements the List currently contains (Count). |

**Fig. 9.5** | Some methods and properties of class List<T>. (Part 2 of 2.)

Figure 9.6 demonstrates dynamically resizing a List object. The Add and Insert methods add elements to the List (lines 13–14). The Add method *appends* its argument to the end of the List. The Insert method inserts a new element at the specified position. The first argument is an index—as with arrays, collection indices start at zero. The second argument is the value that's to be inserted at the specified index. The indices of elements at the specified index and above *increase* by one. This is usually slower than adding an element to the end of the List.

```

1 // Fig. 9.6: ListCollection.cs
2 // Generic List<T> collection demonstration.
3 using System;
4 using System.Collections.Generic;
5
6 public class ListCollection
7 {
8     public static void Main( string[] args )
9     {
10         // create a new List of strings
11         List< string > items = new List< string >();
12
13         items.Add( "red" ); // append an item to the List
14         items.Insert( 0, "yellow" ); // insert the value at index 0
15
16         // display the colors in the list
17         Console.WriteLine(
18             "Display list contents with counter-controlled loop:" );
19         for ( int i = 0; i < items.Count; i++ )
20             Console.WriteLine( " {0}", items[ i ] );
21
22         // display colors using foreach
23         Console.WriteLine(
24             "\nDisplay list contents with foreach statement:" );
25         foreach ( var item in items )
26             Console.WriteLine( " {0}", item );
27
28         items.Add( "green" ); // add "green" to the end of the List
29         items.Add( "yellow" ); // add "yellow" to the end of the List
30

```

**Fig. 9.6** | Generic List<T> collection demonstration. (Part 1 of 2.)

```

31     // display the List
32     Console.WriteLine( "\nList with two new elements:" );
33     foreach ( var item in items )
34         Console.WriteLine( " {0}", item );
35
36     items.Remove( "yellow" ); // remove the first "yellow"
37
38     // display the List
39     Console.WriteLine( "\nRemove first instance of yellow:" );
40     foreach ( var item in items )
41         Console.WriteLine( " {0}", item );
42
43     items.RemoveAt( 1 ); // remove item at index 1
44
45     // display the List
46     Console.WriteLine( "\nRemove second list element (green):" );
47     foreach ( var item in items )
48         Console.WriteLine( " {0}", item );
49
50     // check if a value is in the List
51     Console.WriteLine( "\n\"red\" is {0} in the list",
52                     items.Contains( "red" ) ? string.Empty : "not " );
53
54     // display number of elements in the List
55     Console.WriteLine( "Count: {0}", items.Count );
56
57     // display the capacity of the List
58     Console.WriteLine( "Capacity: {0}", items.Capacity );
59 } // end Main
60 } // end class ListCollection

```

```

Display list contents with counter-controlled loop: yellow red
Display list contents with foreach statement: yellow red
List with two new elements: yellow red green yellow
Remove first instance of yellow: red green yellow
Remove second list element (green): red yellow
"red" is in the list
Count: 2
Capacity: 4

```

**Fig. 9.6** | Generic List<T> collection demonstration. (Part 2 of 2.)

Lines 19–20 display the items in the List. The **Count** property returns the number of elements currently in the List. Lists can be indexed like arrays by placing the index in square brackets after the List variable's name. The indexed List expression can be used to modify the element at the index. Lines 25–26 output the List by using a foreach statement. More elements are then added to the List, and it's displayed again (lines 28–34).

The **Remove** method is used to remove the *first* element with a specific value (line 36). If no such element is in the List, Remove does nothing. A similar method, **RemoveAt**, removes the element at the specified index (line 43). When an element is removed through

either of these methods, the indices of all elements above that index *decrease* by one—the opposite of the `Insert` method.

Line 52 uses the `Contains` method to check if an item is in the `List`. The `Contains` method returns `true` if the element is found in the `List`, and `false` otherwise. The method compares its argument to each element of the `List` in order until the item is found, so using `Contains` on a large `List` is *inefficient*.

Lines 55 and 58 display the `List`'s `Count` and `Capacity`. Recall that the `Count` property (line 55) indicates the number of items in the `List`. The `Capacity` property (line 58) indicates how many items the `List` can hold without having to grow. When the `List` grows, it must create a larger internal array and copy each element to the new array. This is a time-consuming operation. It would be inefficient for the `List` to grow each time an element is added. Instead, the `List` grows only when an element is added *and* the `Count` and `Capacity` properties are equal—there's no space for the new element.

## 9.5 Querying a Generic Collection Using LINQ

You can use LINQ to Objects to query `Lists` just as arrays. In Fig. 9.7, a `List` of `strings` is converted to uppercase and searched for those that begin with "R".

---

```

1 // Fig. 9.7: LINQWithListCollection.cs
2 // LINQ to Objects using a List< string >.
3 using System;
4 using System.Linq;
5 using System.Collections.Generic;
6
7 public class LINQWithListCollection
8 {
9     public static void Main( string[] args )
10    {
11        // populate a List of strings
12        List< string > items = new List< string >();
13        items.Add( "aQua" ); // add "aQua" to the end of the List
14        items.Add( "RusT" ); // add "RusT" to the end of the List
15        items.Add( "yElLow" ); // add "yElLow" to the end of the List
16        items.Add( "rEd" ); // add "rEd" to the end of the List
17
18        // convert all strings to uppercase; select those starting with "R"
19        var startsWithR =
20            from item in items
21            let uppercaseString = item.ToUpper()
22            where uppercaseString.StartsWith( "R" )
23            orderby uppercaseString
24            select uppercaseString;
25
26        // display query results
27        foreach ( var item in startsWithR )
28            Console.Write( "{0} ", item );
29
30        Console.WriteLine(); // output end of line

```

---

**Fig. 9.7** | LINQ to Objects using a `List<string>`. (Part I of 2.)

```

31     items.Add( "rUbY" ); // add "rUbY" to the end of the List
32     items.Add( "SaFfRon" ); // add "SaFfRon" to the end of the List
33
34     // display updated query results
35     foreach ( var item in startsWithR )
36         Console.WriteLine( "{0} ", item );
37
38     Console.WriteLine(); // output end of line
39 }
40 } // end Main
41 } // end class LINQWithListCollection

```

```

RED RUST
RED RUBY RUST

```

**Fig. 9.7** | LINQ to Objects using a `List<string>`. (Part 2 of 2.)

Line 21 uses LINQ's **let** clause to create a new range variable. This is useful if you need to store a temporary result for use later in the LINQ query. Typically, let declares a new range variable to which you assign the result of an expression that operates on the query's original range variable. In this case, we use `string` method **ToUpper** to convert each `item` to uppercase, then store the result in the new range variable `uppercaseString`. We then use the new range variable `uppercaseString` in the `where`, `orderby` and `select` clauses. The `where` clause (line 22) uses `string` method **StartsWith** to determine whether `uppercaseString` starts with the character "R". Method `StartsWith` performs a case-sensitive comparison to determine whether a `string` starts with the `string` received as an argument. If `uppercaseString` starts with "R", method `StartsWith` returns `true`, and the element is included in the query results. More powerful string matching can be done using the *regular-expression* capabilities introduced in Chapter 16, Strings and Characters: A Deeper Look.

The query is created only once (lines 20–24), yet iterating over the results (lines 27–28 and 36–37) gives two different lists of colors. This demonstrates LINQ's **deferred execution**—the query executes *only* when you access the results—such as iterating over them or using the `Count` method—not when you define the query. This allows you to create a query once and execute it many times. Any changes to the data source are reflected in the results each time the query executes.

There may be times when you do not want this behavior, and want to retrieve a collection of the results immediately. LINQ provides extension methods `ToArrayList` and `ToList` for this purpose. These methods execute the query on which they're called and give you the results as an array or `List<T>`, respectively. These methods can also improve efficiency if you'll be iterating over the same results multiple times, as you execute the query only once.

### Collection Initializers

C# has a feature called **collection initializers**, which provide a convenient syntax (similar to *array initializers*) for initializing a collection. For example, lines 12–16 of Fig. 9.7 could be replaced with the following statement:

```

List< string > items =
    new List< string > { "aQua", "RusT", "yEllow", "rEd" };

```

## 9.6 Wrap-Up

This chapter introduced LINQ (Language Integrated Query), a powerful feature for querying data. We showed how to filter an array or collection using LINQ's `where` clause, and how to sort the query results using the `orderby` clause. We used the `select` clause to select specific properties of an object, and the `let` clause to introduce a new range variable to make writing queries more convenient. The `StartsWith` method of class `string` was used to filter `strings` starting with a specified character or series of characters. We used several LINQ extension methods to perform operations not provided by the query syntax—the `Distinct` method to remove duplicates from the results, the `Any` method to determine if the results contain any items, and the `First` method to retrieve the first element in the results.

We introduced the `List<T>` generic collection, which provides all the functionality of arrays, along with other useful capabilities such as dynamic resizing. We used method `Add` to append new items to the end of the `List`, method `Insert` to insert new items into specified locations in the `List`, method `Remove` to remove the first occurrence of a specified item, method `RemoveAt` to remove an item at a specified index and method `Contains` to determine if an item was in the `List`. We used property `Count` to get the number of items in the `List`, and property `Capacity` to determine the size the `List` can hold without growing. We use more advanced features of LINQ in later chapters. In Chapter 10 we take a deeper look at classes and objects.

## 9.7 Deitel LINQ Resource Center

We've created a LINQ Resource Center ([www.deitel.com/LINQ/](http://www.deitel.com/LINQ/)) that contains many links to additional information, including blogs by Microsoft LINQ team members, books, sample chapters, FAQs, tutorials, videos, webcasts and more.

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## Summary

### *Section 9.1 Introduction*

- .NET's collection classes provide reusable data structures that are reliable, powerful and efficient.
- Lists automatically increase their size to accommodate additional elements.
- Large amounts of data are often stored in a database—an organized collection of data. Today's most popular database systems are relational databases. SQL is the international standard language used almost universally with relational databases to perform queries (i.e., to request information that satisfies given criteria).
- LINQ allows you to write query expressions (similar to SQL queries) that retrieve information from a wide variety of data sources. You can query arrays and Lists, selecting elements that satisfy a set of conditions—this is known as filtering.
- A LINQ provider is a set of classes that implement LINQ operations and enable programs to interact with data sources to perform tasks such as sorting, grouping and filtering elements.

### *Section 9.2 Querying an Array of int Values Using LINQ*

- Repetition statements focus on the process of iterating through elements. LINQ specifies the conditions that selected elements must satisfy, not the steps necessary to get the results.
- The `System.Linq` namespace contains the classes for LINQ to Objects.

- A `from` clause specifies a range variable and the data source to query. The range variable represents each item in the data source (one at a time), much like the control variable in a `foreach` statement.
- If the condition in the `where` clause evaluates to `true` for an element, it's included in the results.
- The `select` clause determines what value appears in the results.
- A C# interface describes members that can be used to interact with an object.
- The `IEnumerable<T>` interface describes the functionality of any object that's capable of being iterated over and thus offers methods to access each element in some order.
- A class that implements an interface must define each member in the interface.
- Arrays and generic collections implement the `IEnumerable<T>` interface.
- A `foreach` statement can iterate over any object that implements the `IEnumerable<T>` or `IEnumerable` interface.
- A LINQ query returns an object that implements the `IEnumerable<T>` interface.
- The `orderby` clause sorts query results in ascending order by default. Results can also be sorted in descending order using the `descending` modifier.
- C# provides implicitly typed local variables, which enable the compiler to infer a local variable's type based on the variable's initializer.
- To distinguish such an initialization from a simple assignment statement, the `var` keyword is used in place of the variable's type.
- You can use local type inference with control variables in the header of a `for` or `foreach` statement.
- Implicitly typed local variables can be used to initialize arrays without explicitly giving their type. To do so, use `new[]` to specify that the variable is an array.

### *Section 9.3 Querying an Array of Employee Objects Using LINQ*

- LINQ can be used with collections of most data types.
- Any `boolean` expression can be used in a `where` clause.
- An `orderby` clause can sort the results according to multiple properties specified in a comma-separated list.
- Method `Any` returns `true` if there's at least one element in the result; otherwise, it returns `false`.
- The `First` method returns the first element in the query result. You should check that the query result is not empty before calling `First`.
- The `Count` method returns the number of elements in the query result.
- The `Distinct` method removes duplicate values from query results.
- You can select any number of properties (a projection) in a `select` clause by specifying them in a comma-separated list in braces after the `new` keyword. The compiler automatically creates a new class having these properties—called an anonymous type.

### *Section 9.4 Introduction to Collections*

- The .NET collection classes provide efficient methods that organize, store and retrieve data without requiring knowledge of how the data is being stored.
- Class `List<T>` is similar to an array but provides richer functionality, such as dynamic resizing.
- The `Add` method appends an element to the end of a `List`.
- The `Insert` method inserts a new element at a specified position in the `List`.
- The `Count` property returns the number of elements currently in a `List`.
- `Lists` can be indexed like arrays by placing the index in square brackets after the `List` object's name.

- The `Remove` method is used to remove the first element with a specific value.
- The `RemoveAt` method removes the element at the specified index.
- The `Contains` method returns `true` if the element is found in the `List`, and `false` otherwise.
- The `Capacity` property indicates how many items a `List` can hold without growing.

### **Section 9.5 Querying a Generic Collection Using LINQ**

- LINQ to Objects can query `Lists`.
- LINQ's `let` clause creates a new range variable. This is useful if you need to store a temporary result for use later in the LINQ query.
- The `StartsWith` method of the `string` class determines whether a `string` starts with the `string` passed to it as an argument.
- A LINQ query uses deferred execution—it executes only when you access the results, not when you create the query.

## **Terminology**

Add method of class `List<T>`

anonymous type

Any extension method for `IEnumerable<T>`

ascending modifier of the `orderby` clause

Capacity property of class `List<T>`

collection initializer

Contains method of class `List<T>`

Count extension method for `IEnumerable<T>`

Count property of class `List<T>`

declarative programming

deferred execution

descending modifier of the `orderby` clause

Distinct extension method for `IEnumerable<T>`

dynamic resizing

filtering a collection with LINQ

First extension method for `IEnumerable<T>`

from clause of a LINQ query

`IEnumerable<T>` interface

imperative programming

implicitly typed local variable

Insert method of class `List<T>`

interface

`let` clause of a LINQ query

LINQ (Language Integrated Query)

LINQ provider

LINQ to Objects

`List<T>` collection class

`orderby` clause of a LINQ query

predicate

projection

query expression

query using LINQ

range variable

Remove method of class `List<T>`

RemoveAt method of class `List<T>`

`select` clause of a LINQ query

StartsWith method of class `string`

`ToUpper` method of class `string`

`var` keyword

`where` clause of a LINQ query

## **Self-Review Exercises**

**9.1** Fill in the blanks in each of the following statements:

- Use the \_\_\_\_\_ property of the `List` class to find the number of elements in the `List`.
- The LINQ \_\_\_\_\_ clause is used for filtering.
- \_\_\_\_\_ are classes specifically designed to store groups of objects and provide methods that organize, store and retrieve those objects.
- To add an element to the end of a `List`, use the \_\_\_\_\_ method.
- To get only unique results from a LINQ query, use the \_\_\_\_\_ method.

**9.2** State whether each of the following is *true* or *false*. If *false*, explain why.

- The `orderby` clause in a LINQ query can sort only in ascending order.
- LINQ queries can be used on both arrays and collections.
- The `Remove` method of the `List` class removes an element at a specific index.

## Answers to Self-Review Exercises

- 9.1** a) Count. b) where. c) Collections. d) Add. e) Distinct.
- 9.2** a) False. The `descending` modifier is used to make `orderby` sort in descending order.  
b) True. c) False. `Remove` removes the first element equal to its argument. `RemoveAt` removes the element at a specific index.

## Exercises

**9.3** (*Querying an Array of Invoice Objects*) Use the class `Invoice` provided in the `ex09_03` folder with this chapter's examples to create an array of `Invoice` objects. Use the sample data shown in Fig. 9.8. Class `Invoice` includes four properties—a `PartNumber` (type `int`), a `PartDescription` (type `string`), a `Quantity` of the item being purchased (type `int`) and a `Price` (type `decimal`). Perform the following queries on the array of `Invoice` objects and display the results:

- Use LINQ to sort the `Invoice` objects by `PartDescription`.
- Use LINQ to sort the `Invoice` objects by `Price`.
- Use LINQ to select the `PartDescription` and `Quantity` and sort the results by `Quantity`.
- Use LINQ to select from each `Invoice` the `PartDescription` and the value of the `Invoice` (i.e., `Quantity * Price`). Name the calculated column `InvoiceTotal`. Order the results by `Invoice` value. [Hint: Use `let` to store the result of `Quantity * Price` in a new range variable `total`.]
- Using the results of the LINQ query in *Part d*, select the `InvoiceTotals` in the range \$200 to \$500.

| Part number | Part description | Quantity | Price |
|-------------|------------------|----------|-------|
| 83          | Electric sander  | 7        | 57.98 |
| 24          | Power saw        | 18       | 99.99 |
| 7           | Sledge hammer    | 11       | 21.50 |
| 77          | Hammer           | 76       | 11.99 |
| 39          | Lawn mower       | 3        | 79.50 |
| 68          | Screwdriver      | 106      | 6.99  |
| 56          | Jig saw          | 21       | 11.00 |
| 3           | Wrench           | 34       | 7.50  |

**Fig. 9.8** | Sample data for Exercise 9.3.

**9.4** (*Duplicate Word Removal*) Write a console app that inputs a sentence from the user (assume no punctuation), then determines and displays the nonduplicate words in alphabetical order. Treat uppercase and lowercase letters the same. [Hint: You can use `string` method `Split` with no arguments, as in `sentence.Split()`, to break a sentence into an array of `strings` containing the individual words. By default, `Split` uses spaces as delimiters. Use `string` method `ToLower` in the `select` and `orderby` clauses of your LINQ query to obtain the lowercase version of each word.]

**9.5** (*Sorting Letters and Removing Duplicates*) Write a console app that inserts 30 random letters into a `List<char>`. Perform the following queries on the `List` and display your results: [Hint: Strings can be indexed like arrays to access a character at a specific index.]

- Use LINQ to sort the `List` in ascending order.
- Use LINQ to sort the `List` in descending order.
- Display the `List` in ascending order with duplicates removed.

# Classes and Objects: A Deeper Look

# 10



*But what, to serve  
our private ends,  
Forbids the cheating  
of our friends?*

—Charles Churchill

*This above all: to thine own self  
be true.*

—William Shakespeare.

## Objectives

In this chapter you'll:

- Understand encapsulation and data hiding.
- Use composition to allow a class to have references to objects of other classes as members.
- Throw an exception to indicate that an argument is out of range.
- Use keyword `this`.
- Use `static` variables and methods.
- Use `readonly` fields.
- Take advantage of C#'s memory-management features.
- Use the IDE's **Class View** and **Object Browser** windows.
- Use object initializers to create an object and initialize it in the same statement.

# Outline

- |                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>10.1</b> Introduction<br><b>10.2</b> Time Class Case Study<br><b>10.3</b> Controlling Access to Members<br><b>10.4</b> Referring to the Current Object's Members with the <code>this</code> Reference<br><b>10.5</b> Time Class Case Study: Overloaded Constructors<br><b>10.6</b> Default and Parameterless Constructors<br><b>10.7</b> Composition | <b>10.8</b> Garbage Collection and Destructors<br><b>10.9</b> <code>static</code> Class Members<br><b>10.10</b> <code>readonly</code> Instance Variables<br><b>10.11</b> Data Abstraction and Encapsulation<br><b>10.12</b> Class View and Object Browser<br><b>10.13</b> Object Initializers<br><b>10.14</b> Wrap-Up |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 10.1 Introduction

In this chapter, we take a deeper look at building classes, controlling access to members of a class and creating constructors. We discuss *composition*—a capability that allows a class to have references to objects of other classes as members. We reexamine the use of properties. The chapter also discusses `static` class members and `readonly` instance variables in detail. We investigate issues such as software reusability, data abstraction and encapsulation. We also discuss several miscellaneous topics related to defining classes.

## 10.2 Time Class Case Study

### Time1 Class Declaration

Our first example consists of classes `Time1` (Fig. 10.1) and `Time1Test` (Fig. 10.2). Class `Time1` represents the time of day. Class `Time1Test`'s `Main` method creates an object of class `Time1` and invokes its methods. The output of this app appears in Fig. 10.2. [Note: C# has the type `DateTime` for date and time manipulations. Our time examples are for *demonstration* purposes—you do not need to create your own types for dates and times.]

Class `Time1` contains three `private` instance variables of type `int` (Fig. 10.1, lines 7–9)—`hour`, `minute` and `second`—that represent the time in universal-time format (24-hour clock format, in which hours are in the range 0–23). Class `Time1` contains `public` methods `SetTime` (lines 13–25), `ToUniversalString` (lines 28–32) and `ToString` (lines 35–40). These are the `public` services or the `public` interface that this class provides to its clients.

---

```

1 // Fig. 10.1: Time1.cs
2 // Time1 class declaration maintains the time in 24-hour format.
3 using System; // namespace containing ArgumentOutOfRangeException
4
5 public class Time1
6 {
7     private int hour; // 0 - 23
8     private int minute; // 0 - 59
9     private int second; // 0 - 59

```

---

**Fig. 10.1** | `Time1` class declaration maintains the time in 24-hour format. (Part 1 of 2.)

```

10 // set a new time value using universal time; throw an
11 // exception if the hour, minute or second is invalid
12 public void SetTime( int h, int m, int s )
13 {
14     // validate hour, minute and second
15     if ( ( h >= 0 && h < 24 ) && ( m >= 0 && m < 60 ) &&
16         ( s >= 0 && s < 60 ) )
17     {
18         hour = h;
19         minute = m;
20         second = s;
21     } // end if
22     else
23         throw new ArgumentOutOfRangeException();
24 } // end method SetTime
25
26 // convert to string in universal-time format (HH:MM:SS)
27 public string ToUniversalString()
28 {
29     return string.Format( "{0:D2}:{1:D2}:{2:D2}",
30                         hour, minute, second );
31 } // end method ToUniversalString
32
33 // convert to string in standard-time format (H:MM:SS AM or PM)
34 public override string ToString()
35 {
36     return string.Format( "{0}:{1:D2}:{2:D2} {3}",
37                         ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 ),
38                         minute, second, ( hour < 12 ? "AM" : "PM" ) );
39 } // end method ToString
40 } // end class Time1

```

**Fig. 10.1** | Time1 class declaration maintains the time in 24-hour format. (Part 2 of 2.)

In this example, class Time1 does not declare a constructor, so the class has a default constructor that's supplied by the compiler. Each instance variable implicitly receives the default value 0 for an int. When instance variables are declared in the class body, they can be initialized using the same initialization syntax as a local variable.

#### *Method SetTime and Throwing Exceptions*

Method SetTime (lines 13–25) is a public method that declares three int parameters and uses them to set the time. Lines 16–17 test each argument to determine whether the value is in the proper range, and, if so, lines 19–21 assign the values to the hour, minute and second instance variables. The hour value (line 13) must be greater than or equal to 0 and less than 24, because universal-time format represents hours as integers from 0 to 23 (e.g., 1 PM is hour 13 and 11 PM is hour 23; midnight is hour 0 and noon is hour 12). Similarly, both minute and second values must be greater than or equal to 0 and less than 60. For values outside these ranges, SetTime throws an exception of type ArgumentOutOfRangeException (lines 23–24), which notifies the client code that an invalid argument was passed to the method. As you learned in Chapter 8, you can use try...catch to catch exceptions and attempt to recover from them, which we'll do in Fig. 10.2. The throw statement (line

24) creates a new object of type `ArgumentOutOfRangeException`. The parentheses following the class name indicate a call to the `ArgumentOutOfRangeException` constructor. After the exception object is created, the `throw` statement immediately terminates method `SetTime` and the exception is returned to the code that attempted to set the time.

### **Method `ToUniversalString`**

Method `ToUniversalString` (lines 28–32) takes no arguments and returns a `string` in universal-time format, consisting of six digits—two for the hour, two for the minute and two for the second. For example, if the time were 1:30:07 PM, method `ToUniversalString` would return `13:30:07`. The `return` statement (lines 30–31) uses `static` method `Format` of class `String` to return a `string` containing the formatted hour, minute and second values, each with two digits and, where needed, a leading 0 (specified with the `D2` format specifier—which pads the integer with *leading 0s* if it has less than two digits). Method `Format` is similar to the `String` formatting in method `Console.WriteLine`, except that `Format` returns a formatted `string` rather than displaying it in a console window. The formatted `string` is returned by method `ToUniversalString`.

### **Method `ToString`**

Method `ToString` (lines 35–40) takes no arguments and returns a `string` in standard-time format, consisting of the `hour`, `minute` and `second` values separated by colons and followed by an AM or PM indicator (e.g., `1:27:06 PM`). Like method `ToUniversalString`, method `ToString` uses `static string` method `Format` to format the `minute` and `second` as two-digit values with leading 0s, if necessary. Line 38 uses a conditional operator (`? :`) to determine the value for `hour` in the `string`—if the `hour` is 0 or 12 (AM or PM), it appears as 12—otherwise, it appears as a value from 1 to 11. The conditional operator in line 39 determines whether AM or PM will be returned as part of the `string`.

Recall from Section 7.4 that all objects in C# have a `ToString` method that returns a `string` representation of the object. We chose to return a `string` containing the time in standard-time format. Method `ToString` is called *implicitly* when an object's value is output with a format item in a call to `Console.WriteLine`. Remember that to enable objects to be converted to their `String` representations, we need to declare method `ToString` with keyword `override`—the reason for this will become clear when we discuss *inheritance* in Chapter 11.

### **Using Class `Time1`**

As you learned in Chapter 4, each class you declare represents a new *type* in C#. Therefore, after declaring class `Time1`, we can use it as a type in declarations such as

```
Time1 sunset; // sunset can hold a reference to a Time1 object
```

The `Time1Test` app class (Fig. 10.2) uses class `Time1`. Line 10 creates a `Time1` object and assigns it to local variable `time`. Operator `new` invokes class `Time1`'s *default constructor*, since `Time1` does not declare any constructors. Lines 13–17 output the time, first in universal-time format (by invoking `time`'s `ToUniversalString` method in line 14), then in standard-time format (by explicitly invoking `time`'s `ToString` method in line 16) to confirm that the `Time1` object was initialized properly. Line 20 invokes method `SetTime` of the `time` object to change the time. Then lines 21–25 output the time again in both formats to confirm that the time was set correctly.

```
1 // Fig. 10.2: Time1Test.cs
2 // Time1 object used in an app.
3 using System;
4
5 public class Time1Test
6 {
7     public static void Main( string[] args )
8     {
9         // create and initialize a Time1 object
10        Time1 time = new Time1(); // invokes Time1 constructor
11
12        // output string representations of the time
13        Console.WriteLine( "The initial universal time is: " );
14        Console.WriteLine( time.ToUniversalString() );
15        Console.WriteLine( "The initial standard time is: " );
16        Console.WriteLine( time.ToString() );
17        Console.WriteLine(); // output a blank line
18
19        // change time and output updated time
20        time.SetTime( 13, 27, 6 );
21        Console.WriteLine( "Universal time after SetTime is: " );
22        Console.WriteLine( time.ToUniversalString() );
23        Console.WriteLine( "Standard time after SetTime is: " );
24        Console.WriteLine( time.ToString() );
25        Console.WriteLine(); // output a blank line
26
27        // attempt to set time with invalid values
28        try
29        {
30            time.SetTime( 99, 99, 99 );
31        } // end try
32        catch ( ArgumentOutOfRangeException ex )
33        {
34            Console.WriteLine( ex.Message + "\n" );
35        } // end catch
36
37        // display time after attempt to set invalid values
38        Console.WriteLine( "After attempting invalid settings:" );
39        Console.WriteLine( "Universal time: " );
40        Console.WriteLine( time.ToUniversalString() );
41        Console.WriteLine( "Standard time: " );
42        Console.WriteLine( time.ToString() );
43    } // end Main
44 } // end class Time1Test
```

```
The initial universal time is: 00:00:00
The initial standard time is: 12:00:00 AM

Universal time after SetTime is: 13:27:06
Standard time after SetTime is: 1:27:06 PM

Specified argument was out of the range of valid values.
```

**Fig. 10.2** | Time1 object used in an app. (Part I of 2.)

```
After attempting invalid settings:  
Universal time: 13:27:06  
Standard time: 1:27:06 PM
```

**Fig. 10.2** | Time1 object used in an app. (Part 2 of 2.)

### *Calling Time Method SetTime with Invalid Values*

To illustrate that method `SetTime` validates its arguments, line 30 calls method `SetTime` with invalid arguments of 99 for the hour, minute and second. This statement is placed in a `try` block (lines 28–31) in case `SetTime` throws an `ArgumentOutOfRangeException`, which it will do since the arguments are all invalid. When this occurs, the exception is caught at lines 32–35 and the exception's `Message` property is displayed. Lines 38–42 output the time again in both formats to confirm that `SetTime` did not change the time when invalid arguments were supplied.

### *Notes on the Time1 Class Declaration*

Consider several issues of class design with respect to class `Time1`. The instance variables `hour`, `minute` and `second` are each declared `private`. The actual data representation used within the class is of no concern to the class's clients. For example, it would be perfectly reasonable for `Time1` to represent the time internally as the number of seconds since midnight or the number of minutes and seconds since midnight. Clients could use the same `public` methods and properties to get the same results without being aware of this. (Exercise 10.4 asks you to represent the time as the number of seconds since midnight and show that indeed no change is visible to the clients of the class.)



#### **Software Engineering Observation 10.1**

*Classes simplify programming because the client can use only the public members exposed by the class. Such members are usually client oriented rather than implementation oriented. Clients are neither aware of, nor involved in, a class's implementation. Clients generally care about what the class does but not how the class does it. Clients do, of course, care that the class operates correctly and efficiently.*



#### **Software Engineering Observation 10.2**

*Interfaces change less frequently than implementations. When an implementation changes, implementation-dependent code must change accordingly. Hiding the implementation reduces the possibility that other app parts become dependent on class-implementation details.*

## **10.3 Controlling Access to Members**

The access modifiers `public` and `private` control access to a class's variables, methods and properties. (In Chapter 11, we'll introduce the additional access modifier `protected`.) As we stated in Section 10.2, the primary purpose of `public` methods is to present to the class's clients a view of the services the class provides (that is, the class's public interface). Clients of the class need not be concerned with how the class accomplishes its tasks. For

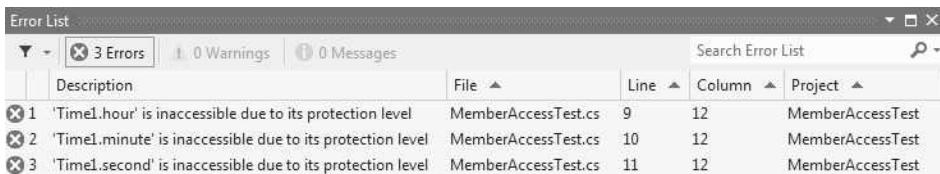
this reason, a class's private variables, properties and methods (i.e., the class's implementation details) are not directly accessible to the class's clients.

Figure 10.3 demonstrates that private class members are not directly accessible outside the class. Lines 9–11 attempt to directly access private instance variables `hour`, `minute` and `second` of `Time1` object `time`. When this app is compiled, the compiler generates error messages stating that these private members are not accessible. [Note: This app uses the `Time1` class from Fig. 10.1.]

```

1 // Fig. 10.3: MemberAccessTest.cs
2 // Private members of class Time1 are not accessible outside the class.
3 public class MemberAccessTest
4 {
5     public static void Main( string[] args )
6     {
7         Time1 time = new Time1(); // create and initialize Time1 object
8
9         time.hour = 7; // error: hour has private access in Time1
10        time.minute = 15; // error: minute has private access in Time1
11        time.second = 30; // error: second has private access in Time1
12    } // end Main
13 } // end class MemberAccessTest

```



**Fig. 10.3** | Private members of class `Time1` are not accessible outside the class.

Notice that members of a class—for instance, properties, methods and instance variables—do not need to be *explicitly* declared `private`. If a class member is not declared with an access modifier, it has `private` access *by default*. For clarity, we always explicitly declare `private` members.

## 10.4 Referring to the Current Object's Members with the **this** Reference

Every object can access a *reference to itself* with keyword `this` (also called the **this reference**). When a non-static method is called for a particular object, the method's body *implicitly* uses keyword `this` to refer to the object's instance variables and other methods. As you'll see in Fig. 10.4, you can also use keyword `this` *explicitly* in a non-static method's body. Section 10.5 shows a more interesting use of keyword `this`. Section 10.9 explains why keyword `this` *cannot* be used in a `static` method.

We now demonstrate implicit and explicit use of the `this` reference to enable class `ThisTest`'s `Main` method to display the `private` data of a class `SimpleTime` object (Fig. 10.4). For the sake of brevity, we declare two classes in one file—class `ThisTest` is declared in lines 5–12, and class `SimpleTime` is declared in lines 15–48.

```

1 // Fig. 10.4: ThisTest.cs
2 // this used implicitly and explicitly to refer to members of an object.
3 using System;
4
5 public class ThisTest
6 {
7     public static void Main( string[] args )
8     {
9         SimpleTime time = new SimpleTime( 15, 30, 19 );
10        Console.WriteLine( time.BuildString() );
11    } // end Main
12 } // end class ThisTest
13
14 // class SimpleTime demonstrates the "this" reference
15 public class SimpleTime
16 {
17     private int hour; // 0-23
18     private int minute; // 0-59
19     private int second; // 0-59
20
21     // if the constructor uses parameter names identical to
22     // instance-variable names, the "this" reference is
23     // required to distinguish between names
24     public SimpleTime( int hour, int minute, int second )
25     {
26         this.hour = hour; // set "this" object's hour instance variable
27         this.minute = minute; // set "this" object's minute
28         this.second = second; // set "this" object's second
29     } // end SimpleTime constructor
30
31     // use explicit and implicit "this" to call ToUniversalString
32     public string BuildString()
33     {
34         return string.Format( "{0,24}: {1}\n{2,24}: {3}",
35             "this.ToUniversalString()", this.ToUniversalString(),
36             "ToUniversalString()", ToUniversalString() );
37     } // end method BuildString
38
39     // convert to string in universal-time format (HH:MM:SS)
40     public string ToUniversalString()
41     {
42         // "this" is not required here to access instance variables,
43         // because method does not have local variables with same
44         // names as instance variables
45         return string.Format( "{0:D2}:{1:D2}:{2:D2}",
46             this.hour, this.minute, this.second );
47     } // end method ToUniversalString
48 } // end class SimpleTime

```

```

this.ToUniversalString(): 15:30:19
ToUniversalString(): 15:30:19

```

**Fig. 10.4** | this used implicitly and explicitly to refer to members of an object.

Class `SimpleTime` declares three private instance variables—`hour`, `minute` and `second` (lines 17–19). The constructor (lines 24–29) receives three `int` arguments to initialize a `SimpleTime` object. For the constructor we used parameter names that are identical to the class's instance-variable names (lines 17–19). We don't recommend this practice, but we intentionally did it here to hide the corresponding instance variables so that we could illustrate explicit use of the `this` reference. Recall from Section 7.11 that if a method contains a local variable with the *same* name as a field, within that method the name refers to the local variable rather than the field. In this case, the parameter *hides* the field in the method's scope. However, the method can use the `this` reference to refer to the hidden instance variable explicitly, as shown in lines 26–28 for `SimpleTime`'s hidden instance variables.

Method `BuildString` (lines 32–37) returns a `string` created by a statement that uses the `this` reference explicitly and implicitly. Line 35 uses the `this` reference *explicitly* to call method `ToUniversalString`. Line 36 uses the `this` reference *implicitly* to call the same method. Programmers typically do not use the `this` reference explicitly to reference other methods in the current object. Also, line 46 in method `ToUniversalString` explicitly uses the `this` reference to access each instance variable. This is not necessary here, because the method does *not* have any local variables that hide the instance variables of the class.



### Common Programming Error 10.1

*It's often a logic error when a method contains a parameter or local variable that has the same name as an instance variable of the class. In such a case, use reference `this` if you wish to access the instance variable of the class—otherwise, the method parameter or local variable will be referenced.*



### Error-Prevention Tip 10.1

*Avoid method-parameter names or local-variable names that conflict with field names. This helps prevent subtle, hard-to-locate bugs.*

Class `ThisTest` (lines 5–12) demonstrates class `SimpleTime`. Line 9 creates an instance of class `SimpleTime` and invokes its constructor. Line 10 invokes the object's `BuildString` method, then displays the results.



### Performance Tip 10.1

*C# conserves memory by maintaining only one copy of each method per class—this method is invoked by every object of the class. Each object, on the other hand, has its own copy of the class's instance variables (i.e., non-static variables). Each non-static method of the class implicitly uses the `this` reference to determine the specific object of the class to manipulate.*

## 10.5 Time Class Case Study: Overloaded Constructors

Next, we demonstrate a class with several **overloaded constructors** that enable objects of that class to be conveniently initialized in different ways. To overload constructors, simply provide multiple constructor declarations with different signatures.

### *Class `Time2` with Overloaded Constructors*

By default, instance variables `hour`, `minute` and `second` of class `Time1` (Fig. 10.1) are initialized to their default values of 0—midnight in universal time. Class `Time1` doesn't enable the class's clients to initialize the time with specific nonzero values. Class `Time2` (Fig. 10.5) con-

tains overloaded constructors. In this app, one constructor invokes the other constructor, which in turn calls `SetTime` to set the hour, minute and second. The compiler invokes the appropriate `Time2` constructor by matching the number and types of the arguments specified in the constructor call with the number and types of the parameters specified in each constructor declaration.

```
1 // Fig. 10.5: Time2.cs
2 // Time2 class declaration with overloaded constructors.
3 using System; // for class ArgumentOutOfRangeException
4
5 public class Time2
6 {
7     private int hour; // 0 - 23
8     private int minute; // 0 - 59
9     private int second; // 0 - 59
10
11    // constructor can be called with zero, one, two or three arguments
12    public Time2( int h = 0, int m = 0, int s = 0 )
13    {
14        SetTime( h, m, s ); // invoke SetTime to validate time
15    } // end Time2 three-argument constructor
16
17    // Time2 constructor: another Time2 object supplied as an argument
18    public Time2( Time2 time )
19        : this( time.Hour, time.Minute, time.Second ) { }
20
21    // set a new time value using universal time; ensure that
22    // the data remains consistent by setting invalid values to zero
23    public void SetTime( int h, int m, int s )
24    {
25        Hour = h; // set the Hour property
26        Minute = m; // set the Minute property
27        Second = s; // set the Second property
28    } // end method SetTime
29
30    // property that gets and sets the hour
31    public int Hour
32    {
33        get
34        {
35            return hour;
36        } // end get
37        set
38        {
39            if ( value >= 0 && value < 24 )
40                hour = value;
41            else
42                throw new ArgumentOutOfRangeException(
43                    "Hour", value, "Hour must be 0-23" );
44        } // end set
45    } // end property Hour
```

**Fig. 10.5** | Time2 class declaration with overloaded constructors. (Part I of 2.)

```
46 // property that gets and sets the minute
47 public int Minute
48 {
49     get
50     {
51         return minute;
52     } // end get
53     set
54     {
55         if ( value >= 0 && value < 60 )
56             minute = value;
57         else
58             throw new ArgumentOutOfRangeException(
59                 "Minute", value, "Minute must be 0-59" );
60     } // end set
61 } // end property Minute
62
63 // property that gets and sets the second
64 public int Second
65 {
66     get
67     {
68         return second;
69     } // end get
70     set
71     {
72         if ( value >= 0 && value < 60 )
73             second = value;
74         else
75             throw new ArgumentOutOfRangeException(
76                 "Second", value, "Second must be 0-59" );
77     } // end set
78 } // end property Second
79
80 // convert to string in universal-time format (HH:MM:SS)
81 public string ToUniversalString()
82 {
83     return string.Format(
84         "{0:D2}:{1:D2}:{2:D2}", Hour, Minute, Second );
85 } // end method ToUniversalString
86
87 // convert to string in standard-time format (H:MM:SS AM or PM)
88 public override string ToString()
89 {
90     return string.Format( "{0}:{1:D2}:{2:D2} {3}",
91         ( ( Hour == 0 || Hour == 12 ) ? 12 : Hour % 12 ),
92         Minute, Second, ( Hour < 12 ? "AM" : "PM" ) );
93 } // end method ToString
94 } // end class Time2
```

---

Fig. 10.5 | Time2 class declaration with overloaded constructors. (Part 2 of 2.)

### *Class Time2's Parameterless Constructor*

Lines 12–15 declare a constructor with three *default parameters*. This constructor is also considered to be the class's **parameterless constructor** because you can call the constructor without arguments and the compiler will automatically provide the default parameter values. This constructor can also be called with one argument for the hour, two arguments for the hour and minute, or three arguments for the hour, minute and second. This constructor calls `SetTime` to set the time.



### **Common Programming Error 10.2**

*A constructor can call methods of its class. Be aware that the instance variables might not yet be initialized, because the constructor is in the process of initializing the object. Using instance variables before they have been initialized properly is a logic error.*

### *Class Time2's Constructor That Receives a Reference to Another Time2 Object*

Lines 18–19 declare a `Time2` constructor that receives a reference to a `Time2` object. In this case, the values from the `Time2` argument are passed to the three-parameter constructor at lines 12–15 to initialize the hour, minute and second. In this constructor, we use `this` in a manner that's allowed *only* in the constructor's header. In line 19, the usual constructor header is followed by a colon (:), then the keyword `this`. The `this` reference is used in method-call syntax (along with the three `int` arguments) to invoke the `Time2` constructor that takes three `int` arguments (lines 12–15). The constructor passes the values of the `time` argument's `Hour`, `Minute` and `Second` properties to set the hour, minute and second of the `Time2` object being constructed. Additional initialization code can be placed in this constructor's body and it will execute after the other constructor is called.

### *Constructor Initializers*

The use of the `this` reference as shown in line 19 is called a **constructor initializer**. Constructor initializers are a popular way to reuse initialization code provided by one of the class's constructors rather than defining similar code in another constructor's body. This syntax makes the class easier to maintain, because one constructor *reuses* the other. If we needed to change how objects of class `Time2` are initialized, only the constructor at lines 12–15 would need to be modified. Even that constructor might not need modification—it simply calls the `SetTime` method to perform the actual initialization, so it's possible that the changes the class might require would be localized to this method.

Line 19 could have directly accessed instance variables `hour`, `minute` and `second` of the constructor's `time` argument with the expressions `time.hour`, `time.minute` and `time.second`—even though they're declared as `private` variables of class `Time2`.



### **Software Engineering Observation 10.3**

*When one object of a class has a reference to another object of the same class, the first object can access all the second object's data and methods (including those that are private).*

### *Class Time2's SetTime Method*

Method `SetTime` (lines 23–28) invokes the `set` accessors of the new properties `Hour` (lines 31–45), `Minute` (lines 48–62) and `Second` (lines 65–79), which ensure that the value supplied for `hour` is in the range 0 to 23 and that the values for `minute` and `second` are each in the range 0 to 59. If a value is out of range, each `set` accessor throws an `ArgumentOutOfRangeException`.

`RangeException` (lines 42–43, 59–60 and 76–77). In this example, we use the `ArgumentOutOfRangeException` constructor that receives three arguments—the name of the item that was out of range, the value that was supplied for that item and an error message.

### *Notes Regarding Class `Time2`'s Methods, Properties and Constructors*

`Time2`'s properties are accessed throughout the class's body. Method `SetTime` assigns values to properties `Hour`, `Minute` and `Second` in lines 25–27, and methods `ToUniversalString` and `ToString` use properties `Hour`, `Minute` and `Second` in line 85 and lines 92–93, respectively. These methods could have accessed the class's private data directly. However, consider changing the representation of the time from three `int` values (requiring 12 bytes of memory) to a single `int` value representing the total number of seconds that have elapsed since midnight (requiring only 4 bytes of memory). If we make such a change, only the bodies of the methods that access the private data directly would need to change—in particular, the individual properties `Hour`, `Minute` and `Second`. There would be no need to modify the bodies of methods `SetTime`, `ToUniversalString` or `ToString`, because they do not access the private data directly. Designing the class in this manner reduces the likelihood of programming errors when altering the class's implementation.

Similarly, each constructor could be written to include a copy of the appropriate statements from method `SetTime`. Doing so may be slightly more efficient, because the extra constructor call and the call to `SetTime` are eliminated. However, duplicating statements in multiple methods or constructors makes changing the class's internal data representation more difficult and error-prone. Having one constructor call the other or even call `SetTime` directly requires any changes to `SetTime`'s implementation to be made only once.



### **Software Engineering Observation 10.4**

*When implementing a method of a class, using the class's properties to access the class's private data simplifies code maintenance and reduces the likelihood of errors.*

### *Using Class `Time2`'s Overloaded Constructors*

Class `Time2Test` (Fig. 10.6) creates six `Time2` objects (lines 9–13 and 42) to invoke the overloaded `Time2` constructors. Lines 9–13 demonstrate passing arguments to the `Time2` constructors. C# invokes the appropriate overloaded constructor by matching the number and types of the arguments specified in the constructor call with the number and types of the parameters specified in each constructor declaration. Lines 9–12 each invoke the constructor at lines 12–15 of Fig. 10.5. Line 9 of Fig. 10.6 invokes the constructor with no arguments, which causes the compiler to supply the default value 0 for each of the three parameters. Line 10 invokes the constructor with one argument that represents the hour—the compiler supplies the default value 0 for the minute and second. Line 11 invokes the constructor with two arguments that represent the hour and minute—the compiler supplies the default value 0 for the second. Line 12 invoke the constructor with values for all three parameters. Line 13 invokes the constructor at lines 18–19 of Fig. 10.5. Lines 16–37 display the `string` representation of each initialized `Time2` object to confirm that each was initialized properly.

Line 42 attempts to initialize `t6` by creating a new `Time2` object and passing three invalid values to the constructor. When the constructor attempts to use the invalid hour value to initialize the object's `Hour` property, an `ArgumentOutOfRangeException` occurs. We catch this exception at line 44 and display its `Message` property, which results in the last three lines of the output in Fig. 10.6. Because we used the three-argument `Argument-`

`OutOfRangeException` constructor when the exception object was created, the exception's `Message` property also includes the *information about the out-of-range value*.

```

1 // Fig. 10.6: Time2Test.cs
2 // Overloaded constructors used to initialize Time2 objects.
3 using System;
4
5 public class Time2Test
6 {
7     public static void Main( string[] args )
8     {
9         Time2 t1 = new Time2(); // 00:00:00
10        Time2 t2 = new Time2( 2 ); // 02:00:00
11        Time2 t3 = new Time2( 21, 34 ); // 21:34:00
12        Time2 t4 = new Time2( 12, 25, 42 ); // 12:25:42
13        Time2 t5 = new Time2( t4 ); // 12:25:42
14        Time2 t6; // initialized later in the program
15
16        Console.WriteLine( "Constructed with:\n" );
17        Console.WriteLine( "t1: all arguments defaulted" );
18        Console.WriteLine( "    {0}", t1.ToUniversalString() ); // 00:00:00
19        Console.WriteLine( "    {0}\n", t1.ToString() ); // 12:00:00 AM
20
21        Console.WriteLine(
22             "t2: hour specified; minute and second defaulted" );
23        Console.WriteLine( "    {0}", t2.ToUniversalString() ); // 02:00:00
24        Console.WriteLine( "    {0}\n", t2.ToString() ); // 2:00:00 AM
25
26        Console.WriteLine(
27             "t3: hour and minute specified; second defaulted" );
28        Console.WriteLine( "    {0}", t3.ToUniversalString() ); // 21:34:00
29        Console.WriteLine( "    {0}\n", t3.ToString() ); // 9:34:00 PM
30
31        Console.WriteLine( "t4: hour, minute and second specified" );
32        Console.WriteLine( "    {0}", t4.ToUniversalString() ); // 12:25:42
33        Console.WriteLine( "    {0}\n", t4.ToString() ); // 12:25:42 PM
34
35        Console.WriteLine( "t5: Time2 object t4 specified" );
36        Console.WriteLine( "    {0}", t5.ToUniversalString() ); // 12:25:42
37        Console.WriteLine( "    {0}\n", t5.ToString() ); // 12:25:42 PM
38
39        // attempt to initialize t6 with invalid values
40        try
41        {
42            t6 = new Time2( 27, 74, 99 ); // invalid values
43        } // end try
44        catch ( ArgumentException ex )
45        {
46            Console.WriteLine( "\nException while initializing t6:" );
47            Console.WriteLine( ex.Message );
48        } // end catch
49    } // end Main
50 } // end class Time2Test

```

**Fig. 10.6** | Overloaded constructors used to initialize Time2 objects. (Part I of 2.)

Constructed with:

```
t1: all arguments defaulted  
00:00:00  
12:00:00 AM  
  
t2: hour specified; minute and second defaulted  
02:00:00  
2:00:00 AM  
  
t3: hour and minute specified; second defaulted  
21:34:00  
9:34:00 PM  
  
t4: hour, minute and second specified  
12:25:42  
12:25:42 PM  
  
t5: Time2 object t4 specified  
12:25:42  
12:25:42 PM
```

Exception while initializing t6:

```
hour must be 0-23  
Parameter name: hour  
Actual value was 27.
```

**Fig. 10.6** | Overloaded constructors used to initialize Time2 objects. (Part 2 of 2.)

## 10.6 Default and Parameterless Constructors

Every class *must* have at least one constructor. Recall from Section 4.10 that if you do not provide any constructors in a class's declaration, the compiler creates a *default constructor* that takes no arguments when it's invoked. In Section 11.4.1, you'll learn that the default constructor implicitly performs a special task.

The compiler will *not* create a default constructor for a class that *explicitly* declares at least one constructor. In this case, if you want to be able to invoke the constructor with no arguments, you must declare a *parameterless constructor*—as in line 12 of Fig. 10.5. Like a default constructor, a parameterless constructor is invoked with *empty parentheses*. The Time2 parameterless constructor explicitly initializes a Time2 object by passing to SetTime 0 for each parameter. If we omit the parameterless constructor, clients of this class would not be able to create a Time2 object with the expression new Time2().



### Common Programming Error 10.3

*If a class has constructors, but none of the public constructors are parameterless constructors, and an attempt is made to call a parameterless constructor to initialize an object of the class, a compilation error occurs. A constructor can be called with no arguments only if the class does not have any constructors (in which case the default constructor is called) or if the class has a parameterless constructor.*

## 10.7 Composition

A class can have references to objects of other classes as members. This is called **composition** and is sometimes referred to as a *has-a* relationship. For example, an object of class `AlarmClock` needs to know the current time *and* the time when it's supposed to sound its alarm, so it's reasonable to include *two* references to `Time` objects in an `AlarmClock` object.



### Software Engineering Observation 10.5

*One form of software reuse is composition, in which a class contains references to other objects. A class can have a property of its own type—for example, a Person class could have a Mom property of type Person.*

#### Class Date

Our example of composition contains three classes—`Date` (Fig. 10.7), `Employee` (Fig. 10.8) and `EmployeeTest` (Fig. 10.9). Class `Date` (Fig. 10.7) declares instance variables `month` and `day` (lines 7–8) and *auto-implemented property* `Year` (line 11) to represent a date. The constructor receives three `int` parameters. Line 17 invokes the `set` accessor of property `Month` (lines 24–38) to validate the month—if the value is out-of-range the accessor throws an exception. Line 18 uses property `Year` to set the year. Since `Year` is an *auto-implemented property*, we're assuming in this example that the value for `Year` is correct. Line 19 uses property `Day` (lines 41–63), which validates and assigns the value for day based on the current `month` and `Year` (by using properties `Month` and `Year` in turn to obtain the values of `month` and `Year`). The *order of initialization is important*, because the `set` accessor of property `Day` validates the value for day based on the assumption that `month` and `Year` are correct. Line 53 determines whether the day is correct based on the number of days in the particular `Month`. If the day is not correct, lines 56–57 determine whether the `Month` is February, the day is 29 and the `Year` is a leap year. Otherwise, if the parameter `value` does not contain a correct value for day, the `set` accessor throws an exception. Line 20 in the constructor outputs the `this` reference as a `string`. Since `this` is a reference to the current `Date` object, the object's `To-String` method (lines 66–69) is called *implicitly* to obtain the object's `string` representation.

```

1 // Fig. 10.7: Date.cs
2 // Date class declaration.
3 using System;
4
5 public class Date
6 {
7     private int month; // 1-12
8     private int day; // 1-31 based on month
9
10    // auto-implemented property Year
11    public int Year { get; private set; }
12
13    // constructor: use property Month to confirm proper value for month;
14    // use property Day to confirm proper value for day
15    public Date( int theMonth, int theDay, int theYear )
16    {
17        Month = theMonth; // validate month

```

**Fig. 10.7** | Date class declaration. (Part 1 of 2.)

```

18     Year = theYear; // could validate year
19     Day = theDay; // validate day
20     Console.WriteLine( "Date object constructor for date {0}", this );
21 } // end Date constructor
22
23 // property that gets and sets the month
24 public int Month
25 {
26     get
27     {
28         return month;
29     } // end get
30     private set // make writing inaccessible outside the class
31     {
32         if ( value > 0 && value <= 12 ) // validate month
33             month = value;
34         else // month is invalid
35             throw new ArgumentOutOfRangeException(
36                 "Month", value, "Month must be 1-12" );
37     } // end set
38 } // end property Month
39
40 // property that gets and sets the day
41 public int Day
42 {
43     get
44     {
45         return day;
46     } // end get
47     private set // make writing inaccessible outside the class
48     {
49         int[] daysPerMonth = { 0, 31, 28, 31, 30, 31, 30,
50                             31, 31, 30, 31, 30, 31 };
51
52         // check if day in range for month
53         if ( value > 0 && value <= daysPerMonth[ Month ] )
54             day = value;
55         // check for leap year
56         else if ( Month == 2 && value == 29 &&
57                 ( Year % 400 == 0 || ( Year % 4 == 0 && Year % 100 != 0 ) ) )
58             day = value;
59         else // day is invalid
60             throw new ArgumentOutOfRangeException(
61                 "Day", value, "Day out of range for current month/year" );
62     } // end set
63 } // end property Day
64
65 // return a string of the form month/day/year
66 public override string ToString()
67 {
68     return string.Format( "{0}/{1}/{2}", Month, Day, Year );
69 } // end method ToString
70 } // end class Date

```

**Fig. 10.7** | Date class declaration. (Part 2 of 2.)

***Class Date's private set Accessors***

Class Date uses access modifiers to ensure that *clients* of the class must use the appropriate methods and properties to access private data. In particular, the properties Year, Month and Day declare private set accessors (lines 11, 30 and 47, respectively) to restrict the use of the set accessors to members of the class. We declare these private for the same reasons that we declare the instance variables private—to simplify code maintenance and control access to the class’s data. Although the constructor, method and properties in class Date still have all the advantages of using the set accessors to perform validation, clients of the class must use the class’s constructor to initialize the data in a Date object. The get accessors of properties Year, Month and Day are *implicitly* declared public because their properties are declared public—when there’s no access modifier before a get or set accessor, the accessor inherits the access modifier preceding the property name.

***Class Employee***

Class Employee (Fig. 10.8) has public auto-implemented properties FirstName, LastName, BirthDate and HireDate. BirthDate and HireDate (lines 7–8) manipulate Date objects, demonstrating that *a class can have references to objects of other classes as members*. This, of course, is also true of the properties FirstName and LastName, which manipulate String objects. The Employee constructor (lines 11–18) takes four parameters—first, last, dateOfBirth and dateOfHire. The objects referenced by parameters dateOfBirth and dateOfHire are assigned to the Employee object’s BirthDate and HireDate properties, respectively. When class Employee’s ToString method is called, it returns a string containing the string representations of the two Date objects. Each of these strings is obtained with an *implicit* call to the Date class’s ToString method.

---

```

1 // Fig. 10.8: Employee.cs
2 // Employee class with references to other objects.
3 public class Employee
4 {
5     public string FirstName { get; private set; }
6     public string LastName { get; private set; }
7     public Date BirthDate { get; private set; }
8     public Date HireDate { get; private set; }
9
10    // constructor to initialize name, birth date and hire date
11    public Employee( string first, string last,
12                     Date dateOfBirth, Date dateOfHire )
13    {
14        firstName = first;
15        lastName = last;
16        birthDate = dateOfBirth;
17        hireDate = dateOfHire;
18    } // end Employee constructor
19
20    // convert Employee to string format
21    public override string ToString()
22    {

```

**Fig. 10.8** | Employee class with references to other objects. (Part I of 2.)

---

```

23     return string.Format( "{0}, {1} Hired: {2} Birthday: {3}",
24         lastName, firstName, hireDate, birthDate );
25     } // end method ToString
26 } // end class Employee

```

---

**Fig. 10.8** | Employee class with references to other objects. (Part 2 of 2.)

### Class EmployeeTest

Class EmployeeTest (Fig. 10.9) creates two Date objects (lines 9–10) to represent an Employee's birthday and hire date, respectively. Line 11 creates an Employee and initializes its instance variables by passing to the constructor two strings (representing the Employee's first and last names) and two Date objects (representing the birthday and hire date). Line 13 *implicitly* invokes the Employee's ToString method to display the values of its instance variables and demonstrate that the object was initialized properly.

---

```

1 // Fig. 10.9: EmployeeTest.cs
2 // Composition demonstration.
3 using System;
4
5 public class EmployeeTest
6 {
7     public static void Main( string[] args )
8     {
9         Date birth = new Date( 7, 24, 1949 );
10        Date hire = new Date( 3, 12, 1988 );
11        Employee employee = new Employee( "Bob", "Blue", birth, hire );
12
13        Console.WriteLine( employee );
14    } // end Main
15 } // end class EmployeeTest

```

```

Date object constructor for date 7/24/1949
Date object constructor for date 3/12/1988
Blue, Bob Hired: 3/12/1988 Birthday: 7/24/1949

```

**Fig. 10.9** | Composition demonstration.

## 10.8 Garbage Collection and Destructors

Every object you create uses various system resources, such as memory. In many programming languages, these system resources are reserved for the object's use until they're explicitly released by the programmer. If all the references to the object that manages the resource are lost before the resource is explicitly released, the app can no longer access the resource to release it. This is known as a **resource leak**.

We need a disciplined way to give resources back to the system when they're no longer needed, thus avoiding resource leaks. The Common Language Runtime (CLR) performs automatic memory management by using a **garbage collector** to *reclaim* the memory occupied by objects that are no longer in use, so the memory can be used for other objects. When there are no more references to an object, the object becomes **eligible for destruction**. Every

object has a special member, called a **destructor**, that's invoked by the garbage collector to perform **termination housekeeping** on an object before the garbage collector reclaims the object's memory. A destructor is declared like a parameterless constructor, except that its name is the class name, preceded by a tilde (~), and it has no access modifier in its header. After the garbage collector calls the object's destructor, the object becomes **eligible for garbage collection**. The memory for such an object can be reclaimed by the garbage collector.

Memory leaks, which are common in other languages such as C and C++ (because memory is *not* automatically reclaimed in those languages), are less likely in C# (but some can still happen in subtle ways). Other types of resource leaks can occur. For example, an app could open a file on disk to modify its contents. If the app does not close the file, no other app can modify (or possibly even use) the file until the app that opened it terminates.

A problem with the garbage collector is that it doesn't guarantee that it will perform its tasks at a specified time. Therefore, the garbage collector may call the destructor any time after the object becomes eligible for destruction, and may reclaim the memory any time after the destructor executes. In fact, it's possible that neither will happen before the app terminates. Thus, it's unclear whether, or when, the destructor will be called. For this reason, destructors are rarely used.



### Software Engineering Observation 10.6

*A class that uses resources, such as files on disk, should provide a method to eventually release the resources. Many Framework Class Library classes provide Close or Dispose methods for this purpose. Section 13.6 introduces the Dispose method, which is then used in many later examples. Close methods are typically used with objects that are associated with files (Chapter 17) and other types of so-called streams of data.*

## 10.9 static Class Members

Every object has its *own* copy of all the instance variables of the class. In certain cases, only one copy of a particular variable should be *shared* by all objects of a class. A **static** variable is used in such cases. A **static** variable represents **classwide information**—all objects of the class share the *same* piece of data. The declaration of a **static** variable begins with the keyword **static**.

Let's motivate **static** data with an example. Suppose that we have a video game with Martians and other space creatures. Each Martian tends to be brave and willing to attack other space creatures when it's aware that there are at least four other Martians present. If fewer than five Martians are present, each Martian becomes cowardly. Thus each Martian needs to know the **martianCount**. We could endow class **Martian** with **martianCount** as an instance variable. If we do this, every **Martian** will have a separate copy of the instance variable, and every time we create a new **Martian**, we'll have to update the instance variable **martianCount** in every **Martian**. This wastes space on redundant copies, wastes time updating the separate copies and is error prone. Instead, we declare **martianCount** to be **static**, making **martianCount** classwide data. Every **Martian** can access the **martianCount**, but only one copy of the **static martianCount** is maintained. This saves space. We save time by having the **Martian** constructor increment the **static martianCount**—there's *only one copy*, so we do not have to increment separate copies of **martianCount** for each **Martian** object.



### Software Engineering Observation 10.7

*Use a static variable when all objects of a class must share the same copy of the variable.*

The scope of a **static** variable is the body of its class. A class's **public static** members can be accessed by qualifying the member name with the class name and the member access (.) operator, as in `Math.PI`. A class's **private static** class members can be accessed *only* through the methods and properties of the class. Actually, **static** class members exist even when *no* objects of the class exist—they're available as soon as the class is loaded into memory at execution time. To access a **private static** member from outside its class, a **public static** method or property can be provided.



### Common Programming Error 10.4

*It's a compilation error to access or invoke a static member by referencing it through an instance of the class, like a non-static member.*



### Software Engineering Observation 10.8

*Static variables, methods and properties exist, and can be used, even if no objects of that class have been instantiated.*

## Class Employee

Our next app declares two classes—`Employee` (Fig. 10.10) and `EmployeeTest` (Fig. 10.11). Class `Employee` declares **private static** auto-implemented property `Count`. We declare `Count`'s set accessor **private**, because we don't want clients of the class to be able to modify the property's value. The compiler automatically creates a **private static** variable that property `Count` will manage. If a **static** variable is not initialized, the compiler assigns a default value to the variable—in this case, the **static** variable for the auto-implemented `Count` property is initialized to 0, the default value for type `int`. Property `Count` maintains a count of the number of objects of class `Employee` that have been created.

When `Employee` objects exist, `Count` can be used in any method of an `Employee` object—this example increments `Count` in the constructor (Fig. 10.10, line 22). Client code can access the `Count` with the expression `Employee.Count`, which evaluates to the number of `Employee` objects that have been created.

---

```

1 // Fig. 10.10: Employee.cs
2 // Static variable used to maintain a count of the number of
3 // Employee objects that have been created.
4 using System;
5
6 public class Employee
7 {
8     public static int Count { get; private set; } // objects in memory
9
10    // read-only auto-implemented property FirstName
11    public string FirstName { get; private set; }

```

---

**Fig. 10.10 |** static property used to maintain a count of the number of `Employee` objects that have been created. (Part 1 of 2.)

```
12 // read-only auto-implemented property LastName
13 public string LastName { get; private set; }
14
15
16 // initialize employee, add 1 to static Count and
17 // output string indicating that constructor was called
18 public Employee( string first, string last )
19 {
20     FirstName = first;
21     LastName = last;
22     ++Count; // increment static count of employees
23     Console.WriteLine( "Employee constructor: {0} {1}; Count = {2}",
24         FirstName, LastName, Count );
25 } // end Employee constructor
26 } // end class Employee
```

**Fig. 10.10** | static property used to maintain a count of the number of Employee objects that have been created. (Part 2 of 2.)

### Class EmployeeTest

EmployeeTest method Main (Fig. 10.11) instantiates two Employee objects (lines 14–15). When each object's constructor is invoked, lines 20–21 of Fig. 10.10 assign the Employee's first name and last name to properties FirstName and LastName. These two statements do *not* make copies of the original string arguments. Actually, string objects in C# are **immutable**—they *cannot* be modified after they're created. Therefore, it's safe to have many references to one string. This is *not* normally the case for objects of most other classes. If string objects are immutable, you might wonder why we're able to use operators + and += to concatenate string objects. String-concatenation operations actually result in a *new* string object containing the concatenated values. The original string objects are *not* modified.

```
1 // Fig. 10.11: EmployeeTest.cs
2 // Static member demonstration.
3 using System;
4
5 public class EmployeeTest
6 {
7     public static void Main( string[] args )
8     {
9         // show that Count is 0 before creating Employees
10        Console.WriteLine( "Employees before instantiation: {0}",
11            Employee.Count );
12
13        // create two Employees; Count should become 2
14        Employee e1 = new Employee( "Susan", "Baker" );
15        Employee e2 = new Employee( "Bob", "Blue" );
16
17        // show that Count is 2 after creating two Employees
18        Console.WriteLine( "\nEmployees after instantiation: {0}",
19            Employee.Count );
```

**Fig. 10.11** | static member demonstration. (Part 1 of 2.)

```

20      // get names of Employees
21      Console.WriteLine( "\nEmployee 1: {0} {1}\nEmployee 2: {2} {3}\n",
22          e1.FirstName, e1.LastName,
23          e2.FirstName, e2.LastName );
24
25      // in this example, there is only one reference to each Employee,
26      // so the following statements cause the CLR to mark each
27      // Employee object as being eligible for garbage collection
28      e1 = null; // mark object referenced by e1 as no longer needed
29      e2 = null; // mark object referenced by e2 as no longer needed
30
31  } // end Main
32 } // end class EmployeeTest

```

```

Employees before instantiation: 0
Employee constructor: Susan Baker; Count = 1
Employee constructor: Bob Blue; Count = 2

Employees after instantiation: 2

Employee 1: Susan Baker
Employee 2: Bob Blue

```

**Fig. 10.11 |** static member demonstration. (Part 2 of 2.)

Lines 18–19 of Fig. 10.11 display the updated Count. When Main has finished using the two Employee objects, references e1 and e2 are set to null at lines 29–30, so they no longer refer to the objects that were instantiated in lines 14–15. The objects become *eligible for destruction* because there are *no more references to them* in the app. After the objects' destructors are called, the objects become *eligible for garbage collection*.

Eventually, the garbage collector might reclaim the memory for these objects (or the operating system will reclaim the memory when the app terminates). C# does not guarantee when, or even whether, the garbage collector will execute. When the garbage collector does run, it's possible that no objects or only a subset of the eligible objects will be collected.

A method declared static cannot access non-static class members directly, because a static method can be called even when *no* objects of the class exist. For the same reason, the this reference cannot be used in a static method—the this reference must refer to a specific object of the class, and when a static method is called, there might *not* be any objects of its class in memory.

## 10.10 readonly Instance Variables

The principle of least privilege is fundamental to good software engineering. In the context of an app, the principle states that *code should be granted the amount of privilege and access needed to accomplish its designated task, but no more*. Let's see how this principle applies to instance variables.

Some instance variables need to be modifiable, and some do not. In Section 8.4, we used keyword const for declaring constants. These constants must be initialized to a constant value when they're declared. Suppose, however, we want to initialize in the object's

constructor a constant belonging to a specific object of the class. C# provides keyword **readonly** to specify that an instance variable of an object is *not* modifiable and that any attempt to modify it after the object is constructed is an error. For example,

```
private readonly int INCREMENT;
```

declares **readonly** instance variable **INCREMENT** of type **int**. Like constants, **readonly** variables are declared with all capital letters by convention. Although **readonly** instance variables can be initialized when they're declared, this isn't required. Readonly variables should be initialized *by each* of the class's constructors. Each constructor can assign values to a **readonly** instance variable multiple times—the variable doesn't become unmodifiable until *after* the constructor completes execution. If a constructor does not initialize the **readonly** variable, the variable receives the same default value as any other instance variable (0 for numeric simple types, **false** for **bool** type and **null** for reference types), and the compiler generates a warning.



### Software Engineering Observation 10.9

*Declaring an instance variable as **readonly** helps enforce the principle of least privilege. If an instance variable should not be modified after the object is constructed, declare it to be **readonly** to prevent modification.*

Members that are declared as **const** must be assigned values at compile time. Therefore, **const** members can be initialized *only* with other constant values, such as integers, **string** literals, characters and other **const** members. Constant members with values that cannot be determined at compile time must be declared with keyword **readonly**, so they can be initialized at *execution time*. Variables that are **readonly** can be initialized with more complex expressions, such as an array initializer or a method call that returns a value or a reference to an object.



### Common Programming Error 10.5

*Attempting to modify a **readonly** instance variable anywhere but in its declaration or the object's constructors is a compilation error.*



### Error-Prevention Tip 10.2

*Attempts to modify a **readonly** instance variable are caught at compilation time rather than causing execution-time errors. It's always preferable to get bugs out at compile time, if possible, rather than allowing them to slip through to execution time (where studies have found that repairing bugs is often much more costly).*



### Software Engineering Observation 10.10

*If a **readonly** instance variable is initialized to a constant only in its declaration, it's not necessary to have a separate copy of the instance variable for every object of the class. The variable should be declared **const** instead. Constants declared with **const** are implicitly **static**, so there will only be one copy for the entire class.*

## 10.11 Data Abstraction and Encapsulation

Classes normally *hide* the details of their implementation from their clients. This is called **information hiding**. As an example, let's consider the **stack** **data structure** introduced in

Section 7.6. Recall that a stack is a **last-in, first-out (LIFO)** data structure—the *last* item pushed (inserted) on the stack is the *first* item popped (removed) off the stack.

### Data Abstraction

Stacks can be implemented with arrays and with other data structures, such as linked lists. (We discuss stacks and linked lists in Chapters 19 and 21.) A client of a stack class need not be concerned with the stack’s implementation. The client knows only that when data items are placed in the stack, they’ll be recalled in last-in, first-out order. The client cares about *what* functionality a stack offers, not about *how* that functionality is implemented. This concept is referred to as **data abstraction**. Even if you know the details of a class’s implementation, you shouldn’t write code that depends on these details as they may later change. This enables a particular class (such as one that implements a stack and its *push* and *pop* operations) to be replaced with another version—perhaps one that runs faster or uses less memory—without affecting the rest of the system. As long as the **public** services of the class do not change (i.e., every original method still has the same name, return type and parameter list in the new class declaration), the rest of the system is not affected.

### Abstract Data Types (ADTs)

Earlier non-object-oriented programming languages like C emphasize actions. In these languages, data exists to support the actions that apps must take. Data is “less interesting” than actions. Data is “crude.” Only a few simple types exist, and it’s difficult for programmers to create their own types. C# and the object-oriented style of programming elevate the importance of data. The primary activities of object-oriented programming in C# are creating types (e.g., classes) and expressing the interactions among objects of those types. To create languages that emphasize data, the programming-languages community needed to formalize some notions about data. The formalization we consider here is the notion of **abstract data types (ADTs)**, which improve the app-development process.

Consider the type `int`, which most people associate with an integer in mathematics. Actually, an `int` is an *abstract representation of an integer*. Unlike mathematical integers, computer `ints` are *fixed* in size. Type `int` in C# is limited to the range  $-2,147,483,648$  to  $+2,147,483,647$ . If the result of a calculation falls *outside* this range, an error occurs, and the computer responds in some appropriate manner. It might produce an incorrect result, such as a value too large to fit in an `int` variable—commonly called **arithmetic overflow**. It also might throw an exception, called an `OverflowException`. (We show how to deal with arithmetic overflow in Section 13.8.) *Mathematical* integers do not have this problem. Therefore, the computer `int` is only an *approximation* of the real-world integer. Simple types like `int`, `double`, and `char` are all examples of abstract data types—*representations of real-world concepts to some satisfactory level of precision within a computer system*.

An ADT actually captures two notions: a **data representation** and the **operations** that can be performed on that data. For example, in C#, an `int` contains an integer value (data) and provides addition, subtraction, multiplication, division and remainder operations—division by zero is *undefined*.



#### Software Engineering Observation 10.11

Programmers create types through the class mechanism. Although the language is easy to extend via new types, you cannot alter the base language itself.

### *Queue Abstract Data Type*

Another ADT we discuss is a **queue**, which is similar to a “waiting line.” Computer systems use many queues internally. A queue offers well-understood behavior to its clients: Clients place items in a queue one at a time via an *enqueue* operation, then retrieve them one at a time via a *dequeue* operation. A queue returns items in **first-in, first-out (FIFO)** order—the first item inserted in a queue is the first removed. Conceptually, a queue can become infinitely long, but real queues are finite.

The queue hides an internal data representation that keeps track of the items currently waiting in line. The clients are not concerned about the implementation of the queue—they simply depend on the queue to operate “as advertised.” When a client enqueues an item, the queue should accept that item and place it in some kind of internal FIFO data structure. Similarly, when the client wants the next item from the front of the queue, the queue should remove the item from its internal representation and deliver it in FIFO order—the item that has been in the queue the *longest* should be returned by the next dequeue operation.

The queue ADT guarantees the integrity of its internal data structure. Clients cannot manipulate this data structure directly—only the queue ADT has access to its internal data. Clients are able to perform only allowable operations on the data representation—the ADT rejects operations that its public interface does not provide. We’ll discuss stacks and queues in greater depth in Chapter 19, Data Structures.

## 10.12 Class View and Object Browser

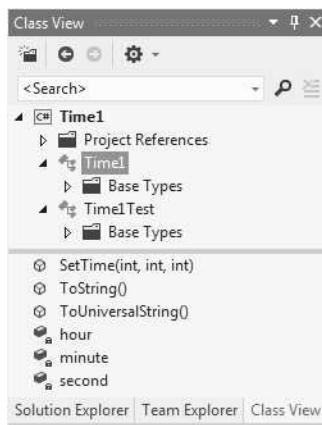
Now that we have introduced key concepts of object-oriented programming, we present two features that Visual Studio provides to facilitate the design of object-oriented apps—**Class View** and **Object Browser**.

### *Using the Class View Window*

The **Class View** displays the fields, methods and properties for all classes in a project. Select **VIEW > Class View** to display the **Class View** as a tab in the same position within the IDE as the **Solution Explorer**. Figure 10.12 shows the **Class View** for the **Time1** project of Fig. 10.1 (class **Time1**) and Fig. 10.2 (class **Time1Test**). The view follows a hierarchical structure, positioning the project name (**Time1**) as the *root* and including a series of nodes that represent the classes, variables, methods and properties in the project. If a appears to the left of a node, that node can be *expanded* to show other nodes. If a appears to the left of a node, that node can be *collapsed*. According to the **Class View**, project **Time1** contains class **Time1** and class **Time1Test** as children. When class **Time1** is selected, the class’s members appear in the lower half of the window. Class **Time1** contains methods **SetTime**, **ToString** and **ToUniversalString** (indicated by purple boxes, ) and instance variables **hour**, **minute** and **second** (indicated by blue boxes, ). The lock icons to the right of the blue box icons for the instance variables specify that the variables are **private**. Both class **Time1** and class **Time1Test** contain the **Base Types** node. If you expand this node, you’ll see class **Object** in each case, because each class *inherits* from class **System.Object** (discussed in Chapter 11).

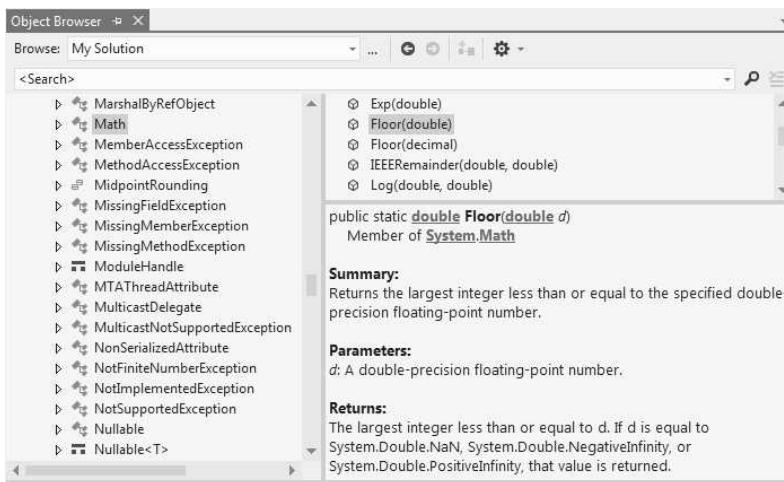
### *Using the Object Browser*

Visual Studio’s **Object Browser** lists all classes in the .NET library. You can use the **Object Browser** to learn about the functionality provided by a specific class. To open the **Object**



**Fig. 10.12** | Class View of class Time1 (Fig. 10.1) and class Time1Test (Fig. 10.2).

Browser, select **VIEW > Object Browser**. Figure 10.13 depicts the **Object Browser** when the user navigates to the **Math** class in namespace **System**. To do this, we expanded the node for **mscorlib** (Microsoft Core Library) in the upper-left pane of the **Object Browser**, then expanded its subnode for **System**. [Note: The most common classes from the **System** namespace, such as **System.Math**, are in **mscorlib**.]



**Fig. 10.13** | Object Browser for class Math.

The **Object Browser** lists all methods provided by class **Math** in the upper-right frame—this offers you “instant access” to information regarding the functionality of various objects. If you click the name of a member in the upper-right frame, a description of that member appears in the lower-right frame. The **Object Browser** can be a quick mechanism to learn about a class or one of its methods. You can also view the complete descrip-

tion of a class or a method in the online documentation by selecting the type or member in the **Object Browser** and pressing *F1*.

## 10.13 Object Initializers

Visual C# provides **object initializers** that allow you to create an object and initialize its **public** properties (and **public** instance variables, if any) in the same statement. This can be useful when a class does not provide an appropriate constructor to meet your needs, but does provide properties that you can use to manipulate the class's data. The following statements demonstrate object initializers using the class `Time2` from Fig. 10.5.

```
// create a Time2 object and initialize its properties
Time2 aTime = new Time2 { Hour = 14, Minute = 30, Second = 12 };

// create a Time2 object and initialize only its Minute property
Time2 anotherTime = new Time2 { Minute = 45 };
```

The first statement creates a `Time2` object (`aTime`), initializes it with class `Time2`'s constructor that can be called with no arguments, then uses an object initializer to set its `Hour`, `Minute` and `Second` properties. Notice that `new Time2` is immediately followed by an **object-initializer list**—a comma-separated list in curly braces (`{ }`) of properties and their values. Each property name can appear only *once* in the object-initializer list. The object initializer executes the property initializers in the order in which they appear.

The second statement creates a new `Time2` object (`anotherTime`), initializes it with class `Time2`'s constructor that can be called with no arguments, then sets only its `Minute` property using an object initializer. When the `Time2` constructor is called with no arguments, it initializes the time to midnight. The object initializer then sets each specified property to the supplied value. In this case, the `Minute` property is set to 45. The `Hour` and `Second` properties retain their default values, because no values are specified for them in the object initializer.

## 10.14 Wrap-Up

In this chapter, we discussed additional class concepts. The `Time` class case study presented a complete class declaration consisting of **private** data, overloaded **public** constructors for initialization flexibility, properties for manipulating the class's data and methods that returned **string** representations of a `Time` object in two different formats. You learned that every class can declare a `ToString` method that returns a **string** representation of an object of the class and that this method is invoked *implicitly* when an object of a class is output as a **string** or concatenated with a **string**.

You learned that the `this` reference is used implicitly in a class's non-**static** methods to access the class's instance variables and other non-**static** methods. You saw explicit uses of the `this` reference to access the class's members (including hidden fields) and learned how to use keyword `this` in a constructor to call another constructor of the class.

You saw that composition enables a class to have references to objects of other classes as members. You learned about C#'s garbage-collection capability and how it reclaims the memory of objects that are no longer used. We explained the motivation for **static** variables in a class and demonstrated how to declare and use **static** variables and methods in your own classes. You also learned how to declare and initialize **readonly** variables.

We also showed how to use Visual Studio's **Class View** and **Object Browser** windows to navigate the classes of the Framework Class Library and your own apps to discover

information about those classes. Finally, you learned how to initialize an object's properties as you create it with an object-initializer list.

In the next chapter, you'll learn about inheritance. You'll see that all classes in C# are related directly or indirectly to the `Object` class and begin to understand how inheritance enables you to build more powerful apps faster.

---

## Summary

### **Section 10.2 Time Class Case Study**

- The `public` methods of a class are part of the `public` services or the `public` interface that the class provides to its clients.
- Methods and properties that modify the values of `private` variables should verify that the intended new values are valid.
- A class's methods and properties can throw exceptions to indicate invalid data.
- The actual data representation used within the class is of no concern to the class's clients. This allows you to change the implementation of the class. Clients could use the same `public` methods and properties to get the same results without being aware of this change.
- Clients are neither aware of, nor involved in, a class's implementation. Clients generally care about *what* the class does but not *how* the class does it.

### **Section 10.3 Controlling Access to Members**

- Access modifiers `public` and `private` control access to a class's variables, methods and properties. A class's `private` variables, methods and properties are not directly accessible to the class's clients.
- If a client attempts to use the `private` members of another class, the compiler generates error messages stating that these `private` members are not accessible.
- If a class member is not declared with an access modifier, it has `private` access by default.

### **Section 10.4 Referring to the Current Object's Members with the `this` Reference**

- Every object can access a reference to itself with keyword `this`. When a non-static method is called for a particular object, the method's body implicitly uses keyword `this` to refer to the object's instance variables, other methods and properties.
- If a method contains a local variable with the same name as a field, that method will refer to the local variable rather than the field. However, a non-`static` method can use the `this` reference to refer to a hidden instance variable explicitly.
- Avoid method-parameter names or local-variable names that conflict with field names. This helps prevent subtle, hard-to-locate bugs.

### **Section 10.5 Time Class Case Study: Overloaded Constructors**

- To overload constructors, provide multiple constructor declarations with different signatures.
- Following the constructor header with the constructor initializer : `this ( args )` invokes the matching overloaded constructor in the same class.
- Constructor initializers are a popular way to reuse initialization code provided by one of the class's constructors rather than defining similar code in another constructor's body.
- When one object of a class has a reference to another object of the same class, the first object can access all the second object's data and methods (including those that are `private`).
- When implementing a method of a class, use the class's properties to access the class's `private` data. This simplifies code maintenance and reduces the likelihood of errors.

- The `ArgumentOutOfRangeException` constructor with three arguments lets you specify the name of the item that's out of range, the value that was out of range and an error message.

### **Section 10.6 Default and Parameterless Constructors**

- Every class must have at least one constructor. If there are no constructors in a class's declaration, the compiler creates a default constructor for the class.
- The compiler will not create a default constructor for a class that explicitly declares at least one constructor. In this case, if you want to be able to invoke the constructor with no arguments, you must declare a parameterless constructor.

### **Section 10.7 Composition**

- A class can have references to objects of other classes as members. Such a capability is called composition and is sometimes referred to as a *has-a* relationship.

### **Section 10.8 Garbage Collection and Destructors**

- Every object you create uses various system resources, such as memory. The CLR performs automatic memory management by using a garbage collector to reclaim the memory occupied by objects that are no longer in use.
- The destructor is invoked by the garbage collector to perform termination housekeeping on an object before the garbage collector reclaims the object's memory.
- Memory leaks, which are common in other languages like C and C++ (because memory is not automatically reclaimed in those languages), are less likely in C#.
- A problem with the garbage collector is that it's not guaranteed to perform its tasks at a specified time. Therefore, the garbage collector may call the destructor any time after the object becomes eligible for destruction, making it unclear when, or whether, the destructor will be called.

### **Section 10.9 static Class Members**

- A `static` variable represents classwide information—all objects of the class share the variable.
- The scope of a `static` variable is the body of its class. A class's `public static` members can be accessed by qualifying the member name with the class name and the member access (.) operator.
- Static class members exist even when no objects of the class exist—they're available as soon as the class is loaded into memory at execution time.
- String objects in C# are immutable—they cannot be modified after they're created. Therefore, it's safe to have many references to one `string` object.
- It's possible that no objects or only a subset of the eligible objects will be collected.
- A method declared `static` cannot access non-`static` class members directly, because a `static` method can be called even when no objects of the class exist. For the same reason, the `this` reference cannot be used in a `static` method.

### **Section 10.10 readonly Instance Variables**

- The principle of least privilege is fundamental to good software engineering. In the context of an app, the principle states that code should be granted only the amount of privilege and access needed to accomplish its designated task, but no more.
- Any attempt to modify a `readonly` instance variable after its object is constructed is an error.
- Although `readonly` instance variables can be initialized when they're declared, this is not required. A `readonly` variable can be initialized by each of the class's constructors.
- Members that are declared as `const` must be assigned values at compile time. Constant members with values that cannot be determined at compile time must be declared with keyword `readonly`, so they can be initialized at execution time.

**Section 10.11 Data Abstraction and Encapsulation**

- Classes use information hiding to hide the details of their implementation from their clients.
- The client cares about what functionality a class offers, not about how that functionality is implemented. This is referred to as data abstraction. Programmers should not write code that depends on these details as the details may later change.
- The primary activities of object-oriented programming in C# are the creation of types (e.g., classes) and the expression of the interactions among objects of those types.
- Types like `int`, `double`, and `char` are all examples of abstract data types. They're representations of real-world notions to some satisfactory level of precision within a computer system.
- An ADT actually captures two notions: a data representation and the operations that can be performed on that data.

**Section 10.12 Class View and Object Browser**

- The **Class View** displays the variables, methods and properties for all classes in a project. The view follows a hierarchical structure, positioning the project name as the root and including a series of nodes that represent the classes, variables, methods and properties in the project.
- The **Object Browser** lists all classes of the Framework Class Library. The **Object Browser** can be a quick mechanism to learn about a class or method of a class.

**Section 10.13 Object Initializers**

- Object initializers allow you to create an object and initialize its `public` properties (and `public` instance variables, if any) in the same statement.
- An object-initializer list is a comma-separated list in curly braces (`{}`) of properties and their values.
- Each property and instance variable name can appear only once in the object-initializer list.
- An object initializer first calls the class's constructor, then sets the value of each property and variable specified in the object-initializer list.

**Terminology**

|                                                         |                                         |
|---------------------------------------------------------|-----------------------------------------|
| abstract data type (ADT)                                | memory leak                             |
| <code>ArgumentOutOfRangeException</code> class          | <b>Object Browser</b>                   |
| arithmetic overflow                                     | object initializer                      |
| attribute (in the UML)                                  | object-initializer list                 |
| <b>Class View</b>                                       | overloaded constructors                 |
| classwide information                                   | parameterless constructor               |
| composition                                             | principle of least privilege            |
| constructor initializer                                 | <code>public</code> interface           |
| data abstraction                                        | <code>public</code> service             |
| data representation                                     | queue data structure                    |
| destructor                                              | <code>readonly</code> instance variable |
| eligible for destruction                                | resource leak                           |
| eligible for garbage collection                         | service of a class                      |
| first-in, first-out (FIFO) data structure               | simple name of a class, field or method |
| <code>Format</code> method of class <code>string</code> | <code>static</code> variable            |
| garbage collector                                       | stack data structure                    |
| <i>has-a</i> relationship                               | termination housekeeping                |
| immutable                                               | <code>this</code> keyword               |
| information hiding                                      | throw an exception                      |
| last-in, first-out (LIFO) data structure                | unmodifiable variable                   |

## Self-Review Exercises

- 10.1** Fill in the blanks in each of the following statements:
- string class static method \_\_\_\_\_ is similar to method `Console.WriteLine`, but returns a formatted string rather than displaying a string in a console window.
  - If a method contains a local variable with the same name as one of its class's fields, the local variable \_\_\_\_\_ the field in that method's scope.
  - The \_\_\_\_\_ is called by the garbage collector before it reclaims an object's memory.
  - If a class declares constructors, the compiler will not create a(n) \_\_\_\_\_.
  - An object's \_\_\_\_\_ method can be called implicitly when an object appears in code where a string is needed.
  - Composition is sometimes referred to as a(n) \_\_\_\_\_ relationship.
  - A(n) \_\_\_\_\_ variable represents classwide information that's shared by all the objects of the class.
  - The \_\_\_\_\_ states that code should be granted only the amount of access needed to accomplish its designated task.
  - Declaring an instance variable with keyword \_\_\_\_\_ specifies that the variable is not modifiable.
  - A(n) \_\_\_\_\_ consists of a data representation and the operations that can be performed on the data.
  - The public members of a class are also known as the class's \_\_\_\_\_ or \_\_\_\_\_.

- 10.2** Suppose class Book defines properties Title, Author and Year. Use an object initializer to create an object of class Book and initialize its properties.

## Answers to Self-Review Exercises

- 10.1** a) Format. b) hides. c) destructor. d) default constructor. e) `ToString`. f) *has-a*. g) static. h) principle of least privilege. i) `readonly`. j) abstract data type (ADT). k) public services, public interface.

**10.2** `new Book { Title = "Visual C# 2012 HTP",  
Author = "Deitel", Year = 2013 }`

## Exercises

- 10.3** (*Rectangle Class*) Create class Rectangle. The class has attributes length and width, each of which defaults to 1. It has read-only properties that calculate the Perimeter and the Area of the rectangle. It has properties for both length and width. The set accessors should verify that length and width are each floating-point numbers greater than 0.0 and less than 20.0. Write an app to test class Rectangle.

- 10.4** (*Modifying the Internal Data Representation of a Class*) It would be perfectly reasonable for the Time2 class of Fig. 10.5 to represent the time internally as the number of seconds since midnight rather than the three integer values hour, minute and second. Clients could use the same public methods and properties to get the same results. Modify the Time2 class of Fig. 10.5 to implement the Time2 as the number of seconds since midnight and show that no change is visible to the clients of the class by using the same test app from Fig. 10.6.

- 10.5** (*Savings-Account Class*) Create the class SavingsAccount. Use the static variable annualInterestRate to store the annual interest rate for all account holders. Each object of the class contains a private instance variable savingsBalance, indicating the amount the saver currently has on deposit. Provide method CalculateMonthlyInterest to calculate the monthly interest by multiplying the savingsBalance by annualInterestRate divided by 12—this interest should be added to savingsBal-

ance. Provide static method `ModifyInterestRate` to set the `annualInterestRate` to a new value. Write an app to test class `SavingsAccount`. Create two `savingsAccount` objects, `saver1` and `saver2`, with balances of \$2000.00 and \$3000.00, respectively. Set `annualInterestRate` to 4%, then calculate the monthly interest and display the new balances for both savers. Then set the `annualInterestRate` to 5%, calculate the next month's interest and display the new balances for both savers.

**10.6 (Enhancing Class Date)** Modify class `Date` of Fig. 10.7 to perform error checking on the initializer values for instance variables `month`, `day` and `year` (class `Date` currently validates only the month and day). You'll need to convert the auto-implemented property `Year` into instance variable `year` with an associated `Year` property. Provide method `NextDay` to increment the day by 1. The `Date` object should always maintain valid data and throw exceptions when attempts are made to set invalid values. Write an app that tests the `NextDay` method in a loop that displays the date during each iteration of the loop to illustrate that the `NextDay` method works correctly. Test the following cases:

- incrementing to the next month and
- incrementing to the next year.

**10.7 (Complex Numbers)** Create a class called `Complex` for performing arithmetic with complex numbers. Complex numbers have the form  $realPart + imaginaryPart * i$  where  $i$  is  $\sqrt{-1}$ . Write an app to test your class. Use floating-point variables to represent the private data of the class. Provide a constructor that enables an object of this class to be initialized when it's declared. Provide a parameterless constructor with default values in case no initializers are provided. Provide public methods that perform the following operations:

- Add two `Complex` numbers: The real parts are added together and the imaginary parts are added together.
- Subtract two `Complex` numbers: The real part of the right operand is subtracted from the real part of the left operand, and the imaginary part of the right operand is subtracted from the imaginary part of the left operand.
- Return a `string` representation of a `Complex` number in the form  $(a, b)$ , where  $a$  is the real part and  $b$  is the imaginary part.

**10.8 (Set of Integers)** Create class `IntegerSet`. Each `IntegerSet` object can hold integers in the range 0–100. The set is represented by an array of `bool`s. Array element `a[i]` is `true` if integer  $i$  is in the set. Array element `a[j]` is `false` if integer  $j$  is not in the set. The parameterless constructor initializes the array to the “empty set” (i.e., a set whose array representation contains all `false` values).

Provide the following methods:

- Method `Union` creates a third set that's the set-theoretic union of two existing sets (i.e., an element of the third set's array is set to `true` if that element is `true` in either or both of the existing sets—otherwise, the element of the third set is set to `false`).
- Method `Intersection` creates a third set which is the set-theoretic intersection of two existing sets (i.e., an element of the third set's array is set to `false` if that element is `false` in either or both of the existing sets—otherwise, the element of the third set is set to `true`).
- Method `InsertElement` inserts a new integer  $k$  into a set (by setting `a[k]` to `true`).
- Method `DeleteElement` deletes integer  $m$  (by setting `a[m]` to `false`).
- Method `ToString` returns a string containing a set as a list of numbers separated by spaces. Include only those elements that are present in the set. Use `---` to represent an empty set.
- Method `IsEqualTo` determines whether two sets are equal.

Write an app to test class `IntegerSet`. Instantiate several `IntegerSet` objects. Test that all your methods work properly.

**10.9 (Rational Numbers)** Create a class called `Rational` for performing arithmetic with fractions. Write an app to test your class. Use integer variables to represent the private instance variables of the class—the numerator and the denominator. Provide a constructor that enables an object of this

class to be initialized when it's declared. The constructor should store the fraction in reduced form. The fraction

2/4

is equivalent to 1/2 and would be stored in the object as 1 in the numerator and 2 in the denominator. Provide a parameterless constructor with default values in case no initializers are provided. Provide `public` methods that perform each of the following operations (all calculation results should be stored in a reduced form):

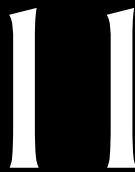
- a) Add two Rational numbers.
- b) Subtract two Rational numbers.
- c) Multiply two Rational numbers.
- d) Divide two Rational numbers.
- e) Display Rational numbers in the form a/b, where a is the numerator and b is the denominator.
- f) Display Rational numbers in floating-point format. (Consider providing formatting capabilities that enable the user of the class to specify the number of digits of precision to the right of the decimal point.)

**10.10 (*HugeInteger Class*)** Create a class `HugeInteger` which uses a 40-element array of digits to store integers as large as 40 digits each. Provide methods `Input`, `ToString`, `Add` and `Subtract`. For comparing `HugeInteger` objects, provide the following methods: `IsEqualTo`, `IsNotEqualTo`, `IsGreaterThan`, `IsLessThan`, `IsGreaterThanOrEqualTo` and `IsLessThanOrEqualTo`. Each of these is a method that returns true if the relationship holds between the two `HugeInteger` objects and returns false if the relationship does not hold. Provide method `IsZero`. If you feel ambitious, also provide methods `Multiply`, `Divide` and `Remainder`. In the `Input` method, use the `string` method `ToCharArray` to convert the input string into an array of characters, then iterate through these characters to create your `HugeInteger`. [Note: The .NET Framework Class Library includes type `BigInteger` for arbitrary sized integer values.]

**10.11 (*Tic-Tac-Toe*)** Create class `TicTacToe` that will enable you to write a complete app to play the game of Tic-Tac-Toe. The class contains a private 3-by-3 rectangular array of integers. The constructor should initialize the empty board to all 0s. Allow two human players. Wherever the first player moves, place a 1 in the specified square, and place a 2 wherever the second player moves. Each move must be to an empty square. After each move, determine whether the game has been won and whether it's a draw. If you feel ambitious, modify your app so that the computer makes the moves for one of the players. Also, allow the player to specify whether he or she wants to go first or second. If you feel exceptionally ambitious, develop an app that will play three-dimensional Tic-Tac-Toe on a 4-by-4-by-4 board.

**10.12** What happens when a return type, even `void`, is specified for a constructor?

# Object-Oriented Programming: Inheritance



*Say not you know another entirely, till you have divided an inheritance with him.*

—Johann Kaspar Lavater

*This method is to define as the number of a class the class of all classes similar to the given class.*

—Bertrand Russell

## Objectives

In this chapter you'll learn:

- How inheritance promotes software reusability.
- To create a derived class that inherits attributes and behaviors from a base class.
- To use access modifier `protected` to give derived-class methods access to base-class members.
- To access base-class members with `base`.
- How constructors are used in inheritance hierarchies.
- The methods of class `object`, the direct or indirect base class of all classes.

# Outline

|             |                                                                                       |               |                                                                                                                         |
|-------------|---------------------------------------------------------------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------|
| <b>11.1</b> | Introduction                                                                          | <b>11.4.4</b> | CommissionEmployee–<br>BasePlusCommissionEmployee<br>Inheritance Hierarchy Using<br><i>protected</i> Instance Variables |
| <b>11.2</b> | Base Classes and Derived Classes                                                      | <b>11.4.5</b> | CommissionEmployee–<br>BasePlusCommissionEmployee<br>Inheritance Hierarchy Using <i>private</i><br>Instance Variables   |
| <b>11.3</b> | <b>protected</b> Members                                                              | <b>11.5</b>   | Constructors in Derived Classes                                                                                         |
| <b>11.4</b> | Relationship between Base Classes<br>and Derived Classes                              | <b>11.6</b>   | Software Engineering with<br>Inheritance                                                                                |
| 11.4.1      | Creating and Using a<br>CommissionEmployee Class                                      | <b>11.7</b>   | Class <b>object</b>                                                                                                     |
| 11.4.2      | Creating a<br>BasePlusCommissionEmployee<br>Class without Using Inheritance           | <b>11.8</b>   | Wrap-Up                                                                                                                 |
| 11.4.3      | Creating a CommissionEmployee–<br>BasePlusCommissionEmployee<br>Inheritance Hierarchy |               |                                                                                                                         |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 11.1 Introduction

This chapter continues our discussion of object-oriented programming (OOP) by introducing one of its primary features—**inheritance**, a form of *software reuse* in which a new class is created by absorbing an existing class’s members and enhancing them with new or modified capabilities. Inheritance lets you save time during app development by reusing proven and debugged high-quality software. This also increases the likelihood that a system will be implemented effectively.

The existing class from which a new class inherits members is called the **base class**, and the new class is the **derived class**. Each derived class can become the base class for future derived classes.

A derived class normally adds its own fields and methods. Therefore, it’s more *specific* than its base class and represents a more specialized group of objects. Typically, the derived class exhibits the behaviors of its base class and additional ones that are specific to itself.

The **direct base class** is the base class from which the derived class explicitly inherits. An **indirect base class** is any class above the direct base class in the **class hierarchy**, which defines the inheritance relationships among classes. The class hierarchy begins with class **object** (which is the C# alias for `System.Object` in the Framework Class Library), which *every* class directly or indirectly **extends** (or “inherits from”). Section 11.7 lists the methods of class **object**, which *every* other class inherits. In the case of **single inheritance**, a class is derived from one *direct* base class. C# supports only single inheritance. In Chapter 12, OOP: Polymorphism, Interfaces and Operator Overloading, we explain how you can use interfaces to realize many of the benefits of multiple inheritance while avoiding the associated problems.

Experience in building software systems indicates that significant amounts of code deal with closely related special cases. When you’re preoccupied with special cases, the details can obscure the big picture. With object-oriented programming, you can, when appropriate, focus on the commonalities among objects in the system rather than the special cases.

We distinguish between the *is-a* relationship and the *has-a* relationship. *Is-a* represents inheritance. In an *is-a* relationship, an object of a derived class can also be treated as

an object of its base class. For example, a car *is a* vehicle, and a truck *is a* vehicle. By contrast, *has-a* represents composition (see Chapter 10). In a *has-a* relationship, an object contains references to other objects. For example, a car *has a* steering wheel, and a car object *has a* reference to a steering-wheel object.

New classes can inherit from classes in **class libraries**. Organizations develop their own class libraries and can take advantage of others available worldwide. Some day, most new software likely will be constructed from **standardized reusable components**, just as automobiles and most computer hardware are constructed today. This will facilitate the development of more powerful, abundant and economical software.

## 11.2 Base Classes and Derived Classes

Often, an object of one class *is an* object of another class as well. For example, in geometry, a rectangle *is a* quadrilateral (as are squares, parallelograms and trapezoids). Thus, class `Rectangle` can be said to inherit from class `Quadrilateral`. In this context, class `Quadrilateral` is a *base class* and class `Rectangle` is a *derived class*. A rectangle *is a* specific type of quadrilateral, but it's incorrect to claim that every quadrilateral *is a* rectangle—the quadrilateral could be a parallelogram or some other shape. Figure 11.1 lists several simple examples of base classes and derived classes—base classes tend to be more *general*, and derived classes tend to be more *specific*.

| Base class               | Derived classes                                                                                       |
|--------------------------|-------------------------------------------------------------------------------------------------------|
| <code>Student</code>     | <code>GraduateStudent</code> , <code>UndergraduateStudent</code>                                      |
| <code>Shape</code>       | <code>Circle</code> , <code>Triangle</code> , <code>Rectangle</code>                                  |
| <code>Loan</code>        | <code>CarLoan</code> , <code>HomeImprovementLoan</code> , <code>MortgageLoan</code>                   |
| <code>Employee</code>    | <code>Faculty</code> , <code>Staff</code> , <code>HourlyWorker</code> , <code>CommissionWorker</code> |
| <code>BankAccount</code> | <code>CheckingAccount</code> , <code>SavingsAccount</code>                                            |

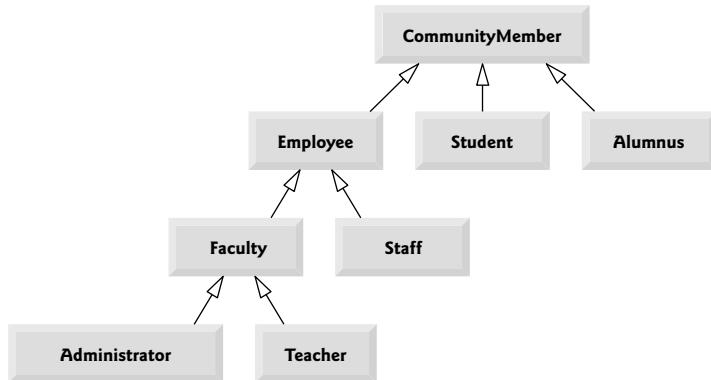
**Fig. 11.1** | Inheritance examples.

Because every derived-class object *is an* object of its base class, and one base class can have *many* derived classes, the set of objects represented by a base class is typically larger than the set of objects represented by any of its derived classes. For example, the base class `Vehicle` represents all vehicles—cars, trucks, boats, bicycles and so on. By contrast, derived class `Car` represents a smaller, more specific subset of vehicles.

Inheritance relationships form treelike hierarchical structures (Figs. 11.2 and 11.3). A base class exists in a hierarchical relationship with its derived classes. When classes participate in inheritance relationships, they become “affiliated” with other classes. A class becomes either a base class, supplying members to other classes, or a derived class, inheriting its members from another class. Sometimes, a class is *both* a base and a derived class.

Let us develop a sample class hierarchy, also called an **inheritance hierarchy** (Fig. 11.2). The UML class diagram of Fig. 11.2 shows a university community that has many types of members, including employees, students and alumni. Employees are either faculty members or staff members. Faculty members are either administrators (such as deans and department chairpersons) or teachers. The hierarchy could contain many other

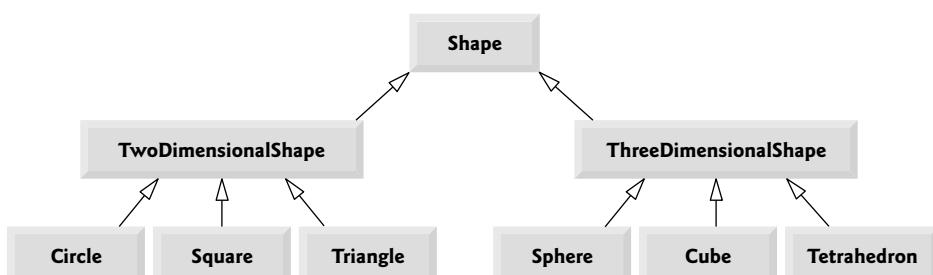
classes. For example, students can be graduate or undergraduate students. Undergraduate students can be freshmen, sophomores, juniors or seniors.



**Fig. 11.2** | UML class diagram showing an inheritance hierarchy for university CommunityMembers.

Each arrow with a *hollow triangular arrowhead* in the hierarchy diagram represents an *is-a* relationship. As we follow the arrows, we can state, for instance, that “an **Employee** is a **CommunityMember**” and “a **Teacher** is a **Faculty** member.” **CommunityMember** is the *direct* base class of **Employee**, **Student** and **Alumnus** and is an *indirect* base class of all the other classes in the diagram. Starting from the bottom, you can follow the arrows and apply the *is-a* relationship up to the topmost base class. For example, an **Administrator** is a **Faculty** member, is an **Employee** and is a **CommunityMember**.

Now consider the Shape hierarchy in Fig. 11.3, which begins with base class **Shape**. This class is extended by derived classes **TwoDimensionalShape** and **ThreeDimensionalShape**—a **Shape** is either a **TwoDimensionalShape** or a **ThreeDimensionalShape**. The third level of this hierarchy contains specific **TwoDimensionalShapes** and **ThreeDimensionalShapes**. We can follow the arrows from the bottom to the topmost base class in this hierarchy to identify the *is-a* relationships. For instance, a **Triangle** is a **TwoDimensionalShape** and is a **Shape**, while a **Sphere** is a **ThreeDimensionalShape** and is a **Shape**. This hierarchy could contain many other classes. For example, ellipses and trapezoids also are **TwoDimensionalShapes**.



**Fig. 11.3** | UML class diagram showing an inheritance hierarchy for Shapes.

Not every class relationship is an inheritance relationship. In Chapter 10 we discussed the *has-a* relationship, in which classes have members that are references to objects of other classes. Such relationships create classes by *composition* of existing classes. For example, given the classes `Employee`, `BirthDate` and `TelephoneNumber`, it's improper to say that an `Employee` *is a* `BirthDate` or that an `Employee` *is a* `TelephoneNumber`. However, an `Employee` *has a* `BirthDate`, and an `Employee` *has a* `TelephoneNumber`.

It's possible to treat base-class objects and derived-class objects similarly—their commonalities are expressed in the base class's members. Objects of all classes that extend a common base class can be treated as objects of that base class—such objects have an *is-a* relationship with the base class. However, *base-class objects cannot be treated as objects of their derived classes*. For example, all cars are vehicles, but not all vehicles are cars (other vehicles could be trucks, planes, bicycles, etc.). This chapter and Chapter 12 consider many examples of *is-a* relationships.

A derived class can customize methods it inherits from its base class. In such cases, the derived class can **override** (redefine) the base-class method with an appropriate implementation, as we'll see often in the chapter's code examples.

## 11.3 protected Members

Chapter 10 discussed access modifiers `public` and `private`. A class's `public` members are accessible wherever the app has a reference to an object of that class or one of its derived classes. A class's `private` members are accessible *only* within the class itself. A base class's `private` members *are inherited* by its derived classes, but are *not* directly accessible by derived-class methods and properties. In this section, we introduce access modifier `protected`. Using `protected` access offers an intermediate level of access between `public` and `private`. A base class's `protected` members can be accessed by members of that base class *and* by members of its derived classes.

All non-`private` base-class members retain their original access modifier when they become members of the derived class—`public` members of the base class become `public` members of the derived class, and `protected` members of the base class become `protected` members of the derived class.

Derived-class methods can refer to `public` and `protected` members inherited from the base class simply by using the member names. When a derived-class method overrides a base-class method, the base-class version can be accessed from the derived class by preceding the base-class method name with the keyword `base` and the member access `(.)` operator. We discuss accessing overridden members of the base class in Section 11.4.



### Software Engineering Observation 11.1

*Properties and methods of a derived class cannot directly access private members of the base class. A derived class can change the state of private base-class fields only through non-private methods and properties provided in the base class.*



### Software Engineering Observation 11.2

*Declaring private fields in a base class helps you test, debug and correctly modify systems. If a derived class could access its base class's private fields, classes that inherit from that derived class could access the fields as well. This would propagate access to what should be private fields, and the benefits of information hiding would be lost.*

## 11.4 Relationship between Base Classes and Derived Classes

In this section, we use an inheritance hierarchy containing types of employees in a company's payroll app to discuss the relationship between a base class and its derived classes. In this company, *commission employees* (who will be represented as objects of a base class) are paid a percentage of their sales, while *base-salaried commission employees* (who will be represented as objects of a derived class) receive a base salary *plus* a percentage of their sales.

We divide our discussion of the relationship between commission employees and base-salaried commission employees into five examples:

1. The first creates class `CommissionEmployee`, which directly inherits from class `object` and declares as private instance variables a first name, last name, social security number, commission rate and gross (i.e., total) sales amount.
2. The second declares class `BasePlusCommissionEmployee`, which also directly inherits from `object` and declares as private instance variables a first name, last name, social security number, commission rate, gross sales amount *and* base salary. We create the class by writing *every* line of code the class requires—we'll soon see that it's more efficient to create this class by inheriting from `CommissionEmployee`.
3. The third declares a separate `BasePlusCommissionEmployee` class that extends class `CommissionEmployee` (i.e., a `BasePlusCommissionEmployee` is a `CommissionEmployee` who also has a base salary). We show that base-class methods must be explicitly declared `virtual` if they're to be overridden by methods in derived classes. `BasePlusCommissionEmployee` attempts to access class `CommissionEmployee`'s private members, but this results in compilation errors because a derived class *cannot* access its base class's private instance variables.
4. The fourth shows that if base class `CommissionEmployee`'s instance variables are declared as `protected`, a `BasePlusCommissionEmployee` class that inherits from class `CommissionEmployee` can access that data directly. For this purpose, we declare class `CommissionEmployee` with `protected` instance variables.
5. The fifth example demonstrates *best practice* by setting the `CommissionEmployee` instance variables back to `private` in class `CommissionEmployee` to enforce good software engineering. Then we show how a separate `BasePlusCommissionEmployee` class, which inherits from class `CommissionEmployee`, can use `CommissionEmployee`'s public methods to manipulate `CommissionEmployee`'s private instance variables.

### 11.4.1 Creating and Using a `CommissionEmployee` Class

We begin by declaring class `CommissionEmployee` (Fig. 11.4). Line 5 begins the class declaration. The colon (:) followed by class name `object` at the end of the declaration header indicates that class `CommissionEmployee` *extends* (i.e., *inherits from*) class `object` (`System.Object` in the Framework Class Library). C# programmers use inheritance to create classes from existing classes. In fact, *every* class in C# (except `object`) extends an existing class. Because class `CommissionEmployee` extends class `object`, class `CommissionEmployee` inherits the methods of class `object`—class `object` has no fields. Every C# class directly or indirectly inherits `object`'s methods. If a class does not specify that it inherits from another

class, the new class *implicitly* inherits from `object`. For this reason, you typically do *not* include “`: object`” in your code—we do so in this example for demonstration purposes.

```
1 // Fig. 11.4: CommissionEmployee.cs
2 // CommissionEmployee class represents a commission employee.
3 using System;
4
5 public class CommissionEmployee : object
6 {
7     private string firstName;
8     private string lastName;
9     private string socialSecurityNumber;
10    private decimal grossSales; // gross weekly sales
11    private decimal commissionRate; // commission percentage
12
13    // five-parameter constructor
14    public CommissionEmployee( string first, string last, string ssn,
15        decimal sales, decimal rate )
16    {
17        // implicit call to object constructor occurs here
18        firstName = first;
19        lastName = last;
20        socialSecurityNumber = ssn;
21        GrossSales = sales; // validate gross sales via property
22        CommissionRate = rate; // validate commission rate via property
23    } // end five-parameter CommissionEmployee constructor
24
25    // read-only property that gets commission employee's first name
26    public string FirstName
27    {
28        get
29        {
30            return firstName;
31        } // end get
32    } // end property FirstName
33
34    // read-only property that gets commission employee's last name
35    public string LastName
36    {
37        get
38        {
39            return lastName;
40        } // end get
41    } // end property LastName
42
43    // read-only property that gets
44    // commission employee's social security number
45    public string SocialSecurityNumber
46    {
47        get
48        {
49            return socialSecurityNumber;
```

**Fig. 11.4** | CommissionEmployee class represents a commission employee. (Part 1 of 2.)

```
50 } // end get
51 } // end property SocialSecurityNumber
52
53 // property that gets and sets commission employee's gross sales
54 public decimal GrossSales
55 {
56     get
57     {
58         return grossSales;
59     } // end get
60     set
61     {
62         if ( value >= 0 )
63             grossSales = value;
64         else
65             throw new ArgumentOutOfRangeException(
66                 "GrossSales", value, "GrossSales must be >= 0" );
67     } // end set
68 } // end property GrossSales
69
70 // property that gets and sets commission employee's commission rate
71 public decimal CommissionRate
72 {
73     get
74     {
75         return commissionRate;
76     } // end get
77     set
78     {
79         if ( value > 0 && value < 1 )
80             commissionRate = value;
81         else
82             throw new ArgumentOutOfRangeException( "CommissionRate",
83                 value, "CommissionRate must be > 0 and < 1" );
84     } // end set
85 } // end property CommissionRate
86
87 // calculate commission employee's pay
88 public decimal Earnings()
89 {
90     return commissionRate * grossSales;
91 } // end method Earnings
92
93 // return string representation of CommissionEmployee object
94 public override string ToString()
95 {
96     return string.Format(
97         "{0}: {1} {2}\n{3}: {4}\n{5}: {6:C}\n{7}: {8:F2}",
98         "commission employee", FirstName, LastName,
99         "social security number", SocialSecurityNumber,
100        "gross sales", GrossSales, "commission rate", CommissionRate );
101    } // end method ToString
102 } // end class CommissionEmployee
```

---

**Fig. 11.4** | CommissionEmployee class represents a commission employee. (Part 2 of 2.)

### ***CommissionEmployee Class Overview***

CommissionEmployee's public services include a constructor (lines 14–23), methods `Earnings` (lines 88–91) and `ToString` (lines 94–101), and the public properties (lines 26–85) for manipulating the class's instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate` (declared in lines 7–11). Each of its instance variable is `private`, so objects of other classes cannot directly access these variables. Declaring instance variables as `private` and providing `public` properties to manipulate and validate them helps enforce good software engineering. The set accessors of properties `GrossSales` and `CommissionRate`, for example, *validate* their arguments before assigning the values to instance variables `grossSales` and `commissionRate`, respectively.

### ***CommissionEmployee Constructor***

Constructors are *not* inherited, so class CommissionEmployee does not inherit class `object`'s constructor. However, class CommissionEmployee's constructor calls class `object`'s constructor *implicitly*. In fact, before executing the code in its own body, the derived class's constructor calls its direct base class's constructor, either explicitly or implicitly (if no constructor call is specified), to ensure that the instance variables inherited from the base class are initialized properly. The syntax for calling a base-class constructor *explicitly* is discussed in Section 11.4.3. If the code does not include an *explicit* call to the base-class constructor, the compiler generates an *implicit* call to the base class's *default* or *parameterless* constructor. The comment in line 17 indicates where the implicit call to the base class `object`'s default constructor is made (you do not write the code for this call). Class `object`'s default (empty) constructor does nothing. Even if a class does not have constructors, the default constructor that the compiler implicitly declares for the class will call the base class's default or parameterless constructor. Class `object` is the *only* class that does not have a base class.

After the implicit call to `object`'s constructor occurs, lines 18–22 in the constructor assign values to the class's instance variables. We do *not* validate the values of arguments `first`, `last` and `ssn` before assigning them to the corresponding instance variables. We certainly could validate the first and last names—perhaps by ensuring that they're of a reasonable length. Similarly, a social security number could be validated to ensure that it contains nine digits, with or without dashes (e.g., 123-45-6789 or 123456789).

### ***CommissionEmployee Method Earnings***

Method `Earnings` (lines 88–91) calculates a CommissionEmployee's earnings. Line 90 multiplies the `commissionRate` by the `grossSales` and returns the result.

### ***CommissionEmployee Method ToString***

Method `ToString` (lines 94–101) is special—it's one of the methods that *every* class inherits directly or indirectly from class `object`, which is the *root* of the C# class hierarchy. Section 11.7 summarizes class `object`'s methods. Method `ToString` returns a `string` representing an object. It's called *implicitly* by an app whenever an object must be converted to a `string` representation, such as in `Console`'s `Write` method or `string` method `Format` using a format item. Class `object`'s `ToString` method returns a `string` that includes the name of the object's class. It's primarily a placeholder that can be (and typically should be) *overridden* by a derived class to specify an appropriate `string` representation of the data in a derived class object. Method `ToString` of class CommissionEmployee overrides (redefines) class `object`'s `ToString` method. When invoked, CommissionEmployee's `ToString` method uses

string method Format to return a string containing information about the CommissionEmployee. Line 97 uses the format specifier C (in "{6:C}") to format grossSales as currency and the format specifier F2 (in "{8:F2}") to format the commissionRate with two digits of precision to the right of the decimal point. To override a base-class method, a derived class must declare a method with keyword **override** and with the *same signature* (method name, number of parameters and parameter types) *and* return type as the base-class method—object's ToString method takes *no* parameters and returns type **string**, so CommissionEmployee declares ToString with the same parameter list and return type.



### Common Programming Error 11.1

*It's a compilation error to override a method with one that has a different access modifier. Overriding a method with a more restrictive access modifier would break the is-a relationship. If a public method could be overridden as a protected or private method, the derived-class objects would not be able to respond to the same method calls as base-class objects. Once a method is declared in a base class, the method must have the same access modifier for all that class's direct and indirect derived classes.*

#### Class CommissionEmployeeTest

Figure 11.5 tests class CommissionEmployee. Lines 10–11 create a CommissionEmployee object and invoke its constructor (lines 14–23 of Fig. 11.4) to initialize it. We append the M suffix to the gross sales amount and the commission rate to indicate that the compiler should treat these as decimal literals, rather than doubles. Lines 16–22 use CommissionEmployee's properties to retrieve the object's instance-variable values for output. Line 23 outputs the amount calculated by the Earnings method. Lines 25–26 invoke the set accessors of the object's GrossSales and CommissionRate properties to change the values of instance variables grossSales and commissionRate. Lines 28–29 output the string representation of the updated CommissionEmployee. When an object is output using a format item, the object's ToString method is invoked *implicitly* to obtain the object's string representation. Line 30 outputs the earnings again.

---

```

1 // Fig. 11.5: CommissionEmployeeTest.cs
2 // Testing class CommissionEmployee.
3 using System;
4
5 public class CommissionEmployeeTest
6 {
7     public static void Main( string[] args )
8     {
9         // instantiate CommissionEmployee object
10        CommissionEmployee employee = new CommissionEmployee( "Sue",
11            "Jones", "222-22-2222", 10000.00M, .06M );
12
13        // display CommissionEmployee data
14        Console.WriteLine(
15            "Employee information obtained by properties and methods: \n" );
16        Console.WriteLine( "First name is {0}", employee.FirstName );
17        Console.WriteLine( "Last name is {0}", employee.LastName );

```

---

Fig. 11.5 | Testing class CommissionEmployee. (Part 1 of 2.)

```

18     Console.WriteLine( "Social security number is {0}",
19         employee.SocialSecurityNumber );
20     Console.WriteLine( "Gross sales are {0:C}", employee.GrossSales );
21     Console.WriteLine( "Commission rate is {0:F2}",
22         employee.CommissionRate );
23     Console.WriteLine( "Earnings are {0:C}", employee.Earnings() );
24
25     employee.GrossSales = 5000.00M; // set gross sales
26     employee.CommissionRate = .1M; // set commission rate
27
28     Console.WriteLine( "\n{0}:\n{1}",
29         "Updated employee information obtained by ToString", employee );
30     Console.WriteLine( "earnings: {0:C}", employee.Earnings() );
31 } // end Main
32 } // end class CommissionEmployeeTest

```

Employee information obtained by properties and methods:

```

First name is Sue
Last name is Jones
Social security number is 222-22-2222
Gross sales are $10,000.00
Commission rate is 0.06
Earnings are $600.00

```

Updated employee information obtained by ToString:

```

commission employee: Sue Jones
social security number: 222-22-2222
gross sales: $5,000.00
commission rate: 0.10
earnings: $500.00

```

**Fig. 11.5** | Testing class CommissionEmployee. (Part 2 of 2.)

## 11.4.2 Creating a BasePlusCommissionEmployee Class without Using Inheritance

We now discuss the second part of our introduction to inheritance by declaring and testing the (completely new and independent) class `BasePlusCommissionEmployee` (Fig. 11.6), which contains a first name, last name, social security number, gross sales amount, commission rate *and* base salary—“Base” in the class name stands for “base salary” not base class. Class `BasePlusCommissionEmployee`’s public services include a `BasePlusCommissionEmployee` constructor (lines 16–26), methods `Earnings` (lines 113–116) and `ToString` (lines 119–127), and public properties (lines 30–110) for the class’s private instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales`, `commissionRate` and `baseSalary` (declared in lines 8–13). These variables, properties and methods encapsulate all the necessary features of a base-salaried commission employee. Note the similarity between this class and class `CommissionEmployee` (Fig. 11.4)—in this example, *we do not yet exploit that similarity*.

Class `BasePlusCommissionEmployee` does *not* specify that it extends `object` with the syntax “`: object`” in line 6, so the class *implicitly* extends `object`. Also, like class `CommissionEmployee`’s constructor (lines 14–23 of Fig. 11.4), class `BasePlusCommissionEm-`

ployee's constructor invokes class object's default constructor *implicitly*, as noted in the comment in line 19 of Fig. 11.6.

```
1 // Fig. 11.6: BasePlusCommissionEmployee.cs
2 // BasePlusCommissionEmployee class represents an employee that receives
3 // a base salary in addition to a commission.
4 using System;
5
6 public class BasePlusCommissionEmployee
7 {
8     private string firstName;
9     private string lastName;
10    private string socialSecurityNumber;
11    private decimal grossSales; // gross weekly sales
12    private decimal commissionRate; // commission percentage
13    private decimal baseSalary; // base salary per week
14
15    // six-parameter constructor
16    public BasePlusCommissionEmployee( string first, string last,
17        string ssn, decimal sales, decimal rate, decimal salary )
18    {
19        // implicit call to object constructor occurs here
20        firstName = first;
21        lastName = last;
22        socialSecurityNumber = ssn;
23        GrossSales = sales; // validate gross sales via property
24        CommissionRate = rate; // validate commission rate via property
25        BaseSalary = salary; // validate base salary via property
26    } // end six-parameter BasePlusCommissionEmployee constructor
27
28    // read-only property that gets
29    // BasePlusCommissionEmployee's first name
30    public string FirstName
31    {
32        get
33        {
34            return firstName;
35        } // end get
36    } // end property FirstName
37
38    // read-only property that gets
39    // BasePlusCommissionEmployee's last name
40    public string LastName
41    {
42        get
43        {
44            return lastName;
45        } // end get
46    } // end property LastName
47
```

**Fig. 11.6** | BasePlusCommissionEmployee class represents an employee that receives a base salary in addition to a commission. (Part I of 3.)

```
48 // read-only property that gets
49 // BasePlusCommissionEmployee's social security number
50 public string SocialSecurityNumber
51 {
52     get
53     {
54         return socialSecurityNumber;
55     } // end get
56 } // end property SocialSecurityNumber
57
58 // property that gets and sets
59 // BasePlusCommissionEmployee's gross sales
60 public decimal GrossSales
61 {
62     get
63     {
64         return grossSales;
65     } // end get
66     set
67     {
68         if ( value >= 0 )
69             grossSales = value;
70         else
71             throw new ArgumentOutOfRangeException(
72                 "GrossSales", value, "GrossSales must be >= 0" );
73     } // end set
74 } // end property GrossSales
75
76 // property that gets and sets
77 // BasePlusCommissionEmployee's commission rate
78 public decimal CommissionRate
79 {
80     get
81     {
82         return commissionRate;
83     } // end get
84     set
85     {
86         if ( value > 0 && value < 1 )
87             commissionRate = value;
88         else
89             throw new ArgumentOutOfRangeException( "CommissionRate",
90                 value, "CommissionRate must be > 0 and < 1" );
91     } // end set
92 } // end property CommissionRate
93
94 // property that gets and sets
95 // BasePlusCommissionEmployee's base salary
96 public decimal BaseSalary
97 {
98     get
99     {
```

**Fig. 11.6** | BasePlusCommissionEmployee class represents an employee that receives a base salary in addition to a commission. (Part 2 of 3.)

```
100         return baseSalary;
101     } // end get
102     set
103     {
104         if ( value >= 0 )
105             baseSalary = value;
106         else
107             throw new ArgumentException( "BaseSalary",
108                                         value, "BaseSalary must be >= 0" );
109     } // end set
110 } // end property BaseSalary
111
112 // calculate earnings
113 public decimal Earnings()
114 {
115     return baseSalary + ( commissionRate * grossSales );
116 } // end method Earnings
117
118 // return string representation of BasePlusCommissionEmployee
119 public override string ToString()
120 {
121     return string.Format(
122         "{0}: {1} {2}\n{3}: {4}\n{5}: {6:C}\n{7}: {8:F2}\n{9}: {10:C}",
123         "base-salaried commission employee", firstName, lastName,
124         "social security number", socialSecurityNumber,
125         "gross sales", grossSales, "commission rate", commissionRate,
126         "base salary", baseSalary );
127 } // end method ToString
128 } // end class BasePlusCommissionEmployee
```

---

**Fig. 11.6** | BasePlusCommissionEmployee class represents an employee that receives a base salary in addition to a commission. (Part 3 of 3.)

Class `BasePlusCommissionEmployee`'s `Earnings` method (lines 113–116) computes the earnings of a base-salaried commission employee. Line 115 adds the employee's base salary to the product of the commission rate and the gross sales, and returns the result.

Class `BasePlusCommissionEmployee` overrides `object` method `ToString` to return a `string` containing the `BasePlusCommissionEmployee`'s information (lines 119–127). Once again, we use format specifier `C` to format the gross sales and base salary as currency and format specifier `F2` to format the commission rate with two digits of precision to the right of the decimal point (line 122).

#### *Class `BasePlusCommissionEmployeeTest`*

Figure 11.7 tests class `BasePlusCommissionEmployee`. Lines 10–12 instantiate a `BasePlusCommissionEmployee` object and pass "Bob", "Lewis", "333-33-3333", 5000.00M, .04M and 300.00M to the constructor as the first name, last name, social security number, gross sales, commission rate and base salary, respectively. Lines 17–25 use `BasePlusCommissionEmployee`'s properties and methods to retrieve the values of the object's instance variables and calculate the earnings for output. Line 27 invokes the object's `BaseSalary` property to *change* the base salary. Property `BaseSalary`'s `set` accessor (Fig. 11.6, lines 102–109) ensures that instance variable `baseSalary` is not assigned a negative value, be-

cause an employee's base salary cannot be negative. Lines 29–30 of Fig. 11.7 invoke the object's `ToString` method *implicitly* to get the object's string representation.

```

1 // Fig. 11.7: BasePlusCommissionEmployeeTest.cs
2 // Testing class BasePlusCommissionEmployee.
3 using System;
4
5 public class BasePlusCommissionEmployeeTest
6 {
7     public static void Main( string[] args )
8     {
9         // instantiate BasePlusCommissionEmployee object
10        BasePlusCommissionEmployee employee =
11            new BasePlusCommissionEmployee( "Bob", "Lewis",
12                "333-33-3333", 5000.00M, .04M, 300.00M );
13
14        // display BasePlusCommissionEmployee's data
15        Console.WriteLine(
16            "Employee information obtained by properties and methods: \n" );
17        Console.WriteLine( "First name is {0}", employee.FirstName );
18        Console.WriteLine( "Last name is {0}", employee.LastName );
19        Console.WriteLine( "Social security number is {0}",
20            employee.SocialSecurityNumber );
21        Console.WriteLine( "Gross sales are {0:C}", employee.GrossSales );
22        Console.WriteLine( "Commission rate is {0:F2}",
23            employee.CommissionRate );
24        Console.WriteLine( "Earnings are {0:C}", employee.Earnings() );
25        Console.WriteLine( "Base salary is {0:C}", employee.BaseSalary );
26
27        employee.BaseSalary = 1000.00M; // set base salary
28
29        Console.WriteLine( "\n{0}:\n{1}",
30            "Updated employee information obtained by ToString", employee );
31        Console.WriteLine( "earnings: {0:C}", employee.Earnings() );
32    } // end Main
33 } // end class BasePlusCommissionEmployeeTest

```

Employee information obtained by properties and methods:

First name is Bob  
 Last name is Lewis  
 Social security number is 333-33-3333  
 Gross sales are \$5,000.00  
 Commission rate is 0.04  
 Earnings are \$500.00  
 Base salary is \$300.00

Updated employee information obtained by `ToString`:

base-salaried commission employee: Bob Lewis  
 social security number: 333-33-3333  
 gross sales: \$5,000.00  
 commission rate: 0.04  
 base salary: \$1,000.00  
 earnings: \$1,200.00

**Fig. 11.7** | Testing class `BasePlusCommissionEmployee`.

Much of the code for class `BasePlusCommissionEmployee` (Fig. 11.6) is similar, if not identical, to the code for class `CommissionEmployee` (Fig. 11.4). For example, in class `BasePlusCommissionEmployee`, private instance variables `firstName` and `lastName` and properties `FirstName` and `LastName` are identical to those of class `CommissionEmployee`. Classes `CommissionEmployee` and `BasePlusCommissionEmployee` also both contain private instance variables `socialSecurityNumber`, `commissionRate` and `grossSales`, as well as properties to manipulate these variables. In addition, the `BasePlusCommissionEmployee` constructor is almost identical to that of class `CommissionEmployee`, except that `BasePlusCommissionEmployee`'s constructor also sets the `baseSalary`. The other additions to class `BasePlusCommissionEmployee` are private instance variable `baseSalary` and property `BaseSalary`. Class `BasePlusCommissionEmployee`'s `Earnings` method is nearly identical to that of class `CommissionEmployee`, except that `BasePlusCommissionEmployee`'s also adds the `baseSalary`. Similarly, class `BasePlusCommissionEmployee`'s `ToString` method is nearly identical to that of class `CommissionEmployee`, except that `BasePlusCommissionEmployee`'s `ToString` also formats the value of instance variable `baseSalary` as currency.

We literally *copied* the code from class `CommissionEmployee` and *pasted* it into class `BasePlusCommissionEmployee`, then modified class `BasePlusCommissionEmployee` to include a base salary and methods and properties that manipulate the base salary. This “copy-and-paste” approach is often error prone and time consuming. Worse yet, it can spread many physical copies of the same code throughout a system, creating a code-maintenance nightmare. Is there a way to “absorb” the members of one class in a way that makes them part of other classes without copying code? In the next several examples we answer this question, using a more elegant approach to building classes—namely, *inheritance*.



### Error-Prevention Tip 11.1

*Copying and pasting code from one class to another can spread errors across multiple source-code files. To avoid duplicating code (and possibly errors) in situations where you want one class to “absorb” the members of another class, use inheritance rather than the “copy-and-paste” approach.*



### Software Engineering Observation 11.3

*With inheritance, the common members of all the classes in the hierarchy are declared in a base class. When changes are required for these common features, you need to make the changes only in the base class—derived classes then inherit the changes. Without inheritance, changes would need to be made to all the source-code files that contain a copy of the code in question.*

### 11.4.3 Creating a `CommissionEmployee-BasePlusCommissionEmployee` Inheritance Hierarchy

Now we declare class `BasePlusCommissionEmployee` (Fig. 11.8), which extends class `CommissionEmployee` (Fig. 11.4). A `BasePlusCommissionEmployee` object is a `CommissionEmployee` (because inheritance passes on the capabilities of class `CommissionEmployee`), but class `BasePlusCommissionEmployee` also has instance variable `baseSalary` (Fig. 11.8, line 7). The colon (:) in line 5 of the class declaration indicates inheritance. As a derived class, `BasePlusCommissionEmployee` inherits the members of class `CommissionEmployee` and can access those members that are non-private. The constructor of class `CommissionEmployee`

is *not* inherited. Thus, the public services of `BasePlusCommissionEmployee` include its constructor (lines 11–16), public methods and properties inherited from class `CommissionEmployee`, property `BaseSalary` (lines 20–34), method `Earnings` (lines 37–41) and method `ToString` (lines 44–53).

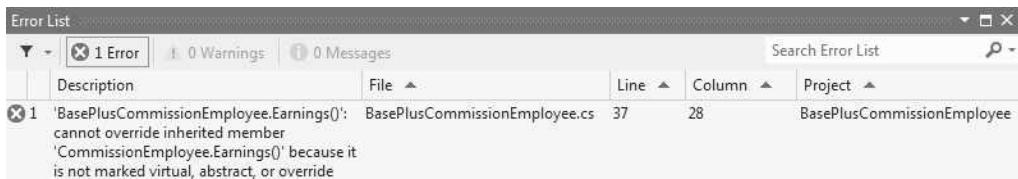
```
1 // Fig. 11.8: BasePlusCommissionEmployee.cs
2 // BasePlusCommissionEmployee inherits from class CommissionEmployee.
3 using System;
4
5 public class BasePlusCommissionEmployee : CommissionEmployee
6 {
7     private decimal baseSalary; // base salary per week
8
9     // six-parameter derived-class constructor
10    // with call to base class CommissionEmployee constructor
11    public BasePlusCommissionEmployee( string first, string last,
12        string ssn, decimal sales, decimal rate, decimal salary )
13        : base( first, last, ssn, sales, rate )
14    {
15        BaseSalary = salary; // validate base salary via property
16    } // end six-parameter BasePlusCommissionEmployee constructor
17
18    // property that gets and sets
19    // BasePlusCommissionEmployee's base salary
20    public decimal BaseSalary
21    {
22        get
23        {
24            return baseSalary;
25        } // end get
26        set
27        {
28            if ( value >= 0 )
29                baseSalary = value;
30            else
31                throw new ArgumentException( "BaseSalary",
32                    value, "BaseSalary must be >= 0" );
33        } // end set
34    } // end property BaseSalary
35
36    // calculate earnings
37    public override decimal Earnings()
38    {
39        // not allowed: commissionRate and grossSales private in base class
40        return baseSalary + ( commissionRate * grossSales );
41    } // end method Earnings
42
43    // return string representation of BasePlusCommissionEmployee
44    public override string ToString()
45    {
```

**Fig. 11.8** | `BasePlusCommissionEmployee` inherits from class `CommissionEmployee`. (Part 1 of 2.)

```

46      // not allowed: attempts to access private base-class members
47      return string.Format(
48          "{0}: {1} {2}\n{3}: {4}\n{5}: {6:C}\n{7}: {8:F2}\n{9}: {10:C}",
49          "base-salaried commission employee", firstName, lastName,
50          "social security number", socialSecurityNumber,
51          "gross sales", grossSales, "commission rate", commissionRate,
52          "base salary", baseSalary );
53    } // end method ToString
54 } // end class BasePlusCommissionEmployee

```



**Fig. 11.8** | BasePlusCommissionEmployee inherits from class CommissionEmployee. (Part 2 of 2.)

### A Derived Class's Constructor Must Call Its Base Class's Constructor

Each derived-class constructor *must* implicitly or explicitly call its base-class constructor to ensure that the instance variables inherited from the base class are initialized properly. BasePlusCommissionEmployee's six-parameter constructor explicitly calls class CommissionEmployee's five-parameter constructor to initialize the CommissionEmployee portion of a BasePlusCommissionEmployee object—that is, the instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`. Line 13 in the header of BasePlusCommissionEmployee's six-parameter constructor invokes the CommissionEmployee's five-parameter constructor (declared at lines 14–23 of Fig. 11.4) by using a *constructor initializer*. In Section 10.5, we used constructor initializers with keyword `this` to call overloaded constructors in the *same* class. In line 13 of Fig. 11.8, we use a constructor initializer with keyword `base` to invoke the base-class constructor. The arguments `first`, `last`, `ssn`, `sales` and `rate` are used to initialize base-class members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`, respectively. If BasePlusCommissionEmployee's constructor did not invoke CommissionEmployee's constructor explicitly, C# would attempt to invoke class CommissionEmployee's parameterless or default constructor *implicitly*—but the class does *not* have such a constructor, so the compiler would issue an error. When a base class contains a parameterless constructor, you can use `base()` in the constructor initializer to call that constructor explicitly, but this is rarely done.



### Common Programming Error 11.2

*A compilation error occurs if a derived-class constructor calls one of its base-class constructors with arguments that do not match the number and types of parameters specified in one of the base-class constructor declarations.*

### BasePlusCommissionEmployee Method Earnings

Lines 37–41 of Fig. 11.8 declare method `Earnings` using keyword `override` to override the `CommissionEmployee`'s `Earnings` method, as we did with method `ToString` in previ-

ous examples. Line 37 causes a compilation error indicating that we cannot override the base class's `Earnings` method because it was not explicitly "marked virtual, abstract, or override." The `virtual` and `abstract` keywords indicate that a base-class method can be overridden in derived classes. (As you'll learn in Section 12.4, `abstract` methods are *implicitly virtual*.) The `override` modifier declares that a derived-class method overrides a `virtual` or `abstract` base-class method. This modifier also *implicitly* declares the derived-class method `virtual` and allows it to be overridden in derived classes further down the inheritance hierarchy.

If we add the keyword `virtual` to method `Earnings`' declaration in Fig. 11.4 and recompile, other compilation errors appear (Fig. 11.9). The compiler generates additional errors for line 40 of Fig. 11.8 because base class `CommissionEmployee`'s instance variables `commissionRate` and `grossSales` are `private`—derived class `BasePlusCommissionEmployee`'s methods are not allowed to access base class `CommissionEmployee`'s `private` instance variables. The compiler issues additional errors at lines 49–51 of `BasePlusCommissionEmployee`'s `ToString` method for the same reason. The errors in `BasePlusCommissionEmployee` could have been prevented by using the `public` properties inherited from class `CommissionEmployee`. For example, line 40 could have invoked the get accessors of properties `CommissionRate` and `GrossSales` to access `CommissionEmployee`'s `private` instance variables `commissionRate` and `grossSales`, respectively. Lines 49–51 also could have used appropriate properties to retrieve the values of the base class's instance variables.

| Error List |                                                                                       |                               |            |            |                            |
|------------|---------------------------------------------------------------------------------------|-------------------------------|------------|------------|----------------------------|
|            |                                                                                       | 7 Errors                      | 0 Warnings | 0 Messages | Search Error List          |
|            | Description                                                                           | File                          | Line       | Column     | Project                    |
| ☒ 1        | 'CommissionEmployee.commissionRate' is inaccessible due to its protection level       | BasePlusCommissionEmployee.cs | 40         | 29         | BasePlusCommissionEmployee |
| ☒ 2        | 'CommissionEmployee.grossSales' is inaccessible due to its protection level           | BasePlusCommissionEmployee.cs | 40         | 46         | BasePlusCommissionEmployee |
| ☒ 3        | 'CommissionEmployee.firstName' is inaccessible due to its protection level            | BasePlusCommissionEmployee.cs | 49         | 47         | BasePlusCommissionEmployee |
| ☒ 4        | 'CommissionEmployee.lastName' is inaccessible due to its protection level             | BasePlusCommissionEmployee.cs | 49         | 58         | BasePlusCommissionEmployee |
| ☒ 5        | 'CommissionEmployee.socialSecurityNumber' is inaccessible due to its protection level | BasePlusCommissionEmployee.cs | 50         | 36         | BasePlusCommissionEmployee |
| ☒ 6        | 'CommissionEmployee.grossSales' is inaccessible due to its protection level           | BasePlusCommissionEmployee.cs | 51         | 25         | BasePlusCommissionEmployee |
| ☒ 7        | 'CommissionEmployee.commissionRate' is inaccessible due to its protection level       | BasePlusCommissionEmployee.cs | 51         | 56         | BasePlusCommissionEmployee |

**Fig. 11.9** | Compilation errors generated by `BasePlusCommissionEmployee` (Fig. 11.8) after declaring the `Earnings` method in Fig. 11.4 with keyword `virtual`.

#### 11.4.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Instance Variables

To enable class `BasePlusCommissionEmployee` to directly access base-class instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`, we can declare those members as `protected` in the base class. As we discussed in Section 11.3, a base class's `protected` members *are* inherited by all derived classes of that

base class. Class `CommissionEmployee` in this example is a modification of the version from Fig. 11.4 that declares its instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate` as `protected` rather than `private`. We also declare the `Earnings` method `virtual` as in

```
public virtual decimal Earnings()
```

so that `BasePlusCommissionEmployee` can override the method. The rest of the class declaration in this example is identical to that of Fig. 11.4. The complete source code for class `CommissionEmployee` is included in this example's project.

#### ***public vs. protected Data***

We could have declared base class `CommissionEmployee`'s instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate` as `public` to enable derived class `BasePlusCommissionEmployee` to access the base-class instance variables. However, declaring `public` instance variables is poor software engineering, because it allows unrestricted access to the instance variables, greatly increasing the chance of errors. With `protected` instance variables, the derived class gets access to the instance variables, but classes that are not derived from the base class cannot access its variables directly.

#### ***Class BasePlusCommissionEmployee***

Class `BasePlusCommissionEmployee` (Fig. 11.10) in this example extends the version of class `CommissionEmployee` with `protected` data rather than the one with `private` data in Fig. 11.4. Each `BasePlusCommissionEmployee` object inherits `CommissionEmployee`'s `protected` instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`—all these variables are now `protected` members of `BasePlusCommissionEmployee`. As a result, the compiler does *not* generate errors when compiling line 40 of method `Earnings` and lines 48–50 of method `ToString`. If another class extends `BasePlusCommissionEmployee`, the new derived class also inherits the `protected` members.

Class `BasePlusCommissionEmployee` does *not* inherit class `CommissionEmployee`'s constructor. However, class `BasePlusCommissionEmployee`'s six-parameter constructor (lines 12–17) calls class `CommissionEmployee`'s five-parameter constructor with a constructor initializer. `BasePlusCommissionEmployee`'s six-parameter constructor must *explicitly* call the five-parameter constructor of class `CommissionEmployee`, because `CommissionEmployee` does *not* provide a parameterless constructor that could be invoked implicitly.

---

```

1 // Fig. 11.10: BasePlusCommissionEmployee.cs
2 // BasePlusCommissionEmployee inherits from CommissionEmployee and has
3 // access to CommissionEmployee's protected members.
4 using System;
5
6 public class BasePlusCommissionEmployee : CommissionEmployee
7 {
8     private decimal baseSalary; // base salary per week
9 }
```

---

**Fig. 11.10 |** `BasePlusCommissionEmployee` inherits from `CommissionEmployee` and has access to `CommissionEmployee`'s `protected` members. (Part 1 of 2.)

```

10 // six-parameter derived-class constructor
11 // with call to base class CommissionEmployee constructor
12 public BasePlusCommissionEmployee( string first, string last,
13     string ssn, decimal sales, decimal rate, decimal salary )
14     : base( first, last, ssn, sales, rate )
15 {
16     BaseSalary = salary; // validate base salary via property
17 } // end six-parameter BasePlusCommissionEmployee constructor
18
19 // property that gets and sets
20 // BasePlusCommissionEmployee's base salary
21 public decimal BaseSalary
22 {
23     get
24     {
25         return baseSalary;
26     } // end get
27     set
28     {
29         if ( value >= 0 )
30             baseSalary = value;
31         else
32             throw new ArgumentException( "BaseSalary",
33                                         value, "BaseSalary must be >= 0" );
34     } // end set
35 } // end property BaseSalary
36
37 // calculate earnings
38 public override decimal Earnings()
39 {
40     return baseSalary + ( commissionRate * grossSales );
41 } // end method Earnings
42
43 // return string representation of BasePlusCommissionEmployee
44 public override string ToString()
45 {
46     return string.Format(
47         "{0}: {1} {2}\n{3}: {4}\n{5}: {6:C}\n{7}: {8:F2}\n{9}: {10:C}",
48         "base-salaried commission employee", firstName, lastName,
49         "social security number", socialSecurityNumber,
50         "gross sales", grossSales, "commission rate", commissionRate,
51         "base salary", baseSalary );
52 } // end method ToString
53 } // end class BasePlusCommissionEmployee

```

**Fig. 11.10** | BasePlusCommissionEmployee inherits from CommissionEmployee and has access to CommissionEmployee's protected members. (Part 2 of 2.)

#### Class **BasePlusCommissionEmployeeTest**

Figure 11.11 uses a BasePlusCommissionEmployee object to perform the *same* tasks that Fig. 11.7 performed on the version of the class from Fig. 11.6. The outputs of the two apps are identical. Although we declared the version of the class in Fig. 11.6 without using

inheritance and declared the version in Fig. 11.10 using inheritance, both classes provide the same functionality. The source code in Fig. 11.10 (which is 53 lines) is considerably *shorter* than the version in Fig. 11.6 (which is 128 lines), because the new class inherits most of its functionality from `CommissionEmployee`, whereas the version in Fig. 11.6 inherits only class `object`'s functionality. Also, there's now only *one* copy of the commission-employee functionality declared in class `CommissionEmployee`. This makes the code easier to maintain, modify and debug, because the code related to a commission employee exists *only* in class `CommissionEmployee`.

---

```

1 // Fig. 11.11: BasePlusCommissionEmployee.cs
2 // Testing class BasePlusCommissionEmployee.
3 using System;
4
5 public class BasePlusCommissionEmployeeTest
6 {
7     public static void Main( string[] args )
8     {
9         // instantiate BasePlusCommissionEmployee object
10        BasePlusCommissionEmployee basePlusCommissionEmployee =
11            new BasePlusCommissionEmployee( "Bob", "Lewis",
12                "333-33-3333", 5000.00M, .04M, 300.00M );
13
14        // display BasePlusCommissionEmployee's data
15        Console.WriteLine(
16            "Employee information obtained by properties and methods: \n" );
17        Console.WriteLine( "First name is {0}",
18            basePlusCommissionEmployee.FirstName );
19        Console.WriteLine( "Last name is {0}",
20            basePlusCommissionEmployee.LastName );
21        Console.WriteLine( "Social security number is {0}",
22            basePlusCommissionEmployee.SocialSecurityNumber );
23        Console.WriteLine( "Gross sales are {0:C}",
24            basePlusCommissionEmployee.GrossSales );
25        Console.WriteLine( "Commission rate is {0:F2}",
26            basePlusCommissionEmployee.CommissionRate );
27        Console.WriteLine( "Earnings are {0:C}",
28            basePlusCommissionEmployee.Earnings() );
29        Console.WriteLine( "Base salary is {0:C}",
30            basePlusCommissionEmployee.BaseSalary );
31
32        basePlusCommissionEmployee.BaseSalary = 1000.00M; // set base salary
33
34        Console.WriteLine( "\n{0}:\n{1}",
35            "Updated employee information obtained by ToString",
36            basePlusCommissionEmployee );
37        Console.WriteLine( "earnings: {0:C}",
38            basePlusCommissionEmployee.Earnings() );
39    } // end Main
40 } // end class BasePlusCommissionEmployeeTest

```

---

**Fig. 11.11** | Testing class `BasePlusCommissionEmployee`. (Part 1 of 2.)

Employee information obtained by properties and methods:

```
First name is Bob
Last name is Lewis
Social security number is 333-33-3333
Gross sales are $5,000.00
Commission rate is 0.04
Earnings are $500.00
Base salary is $300.00
```

Updated employee information obtained by ToString:

```
base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: $5,000.00
commission rate: 0.04
base salary: $1,000.00
earnings: $1,200.00
```

**Fig. 11.11** | Testing class BasePlusCommissionEmployee. (Part 2 of 2.)

### Problems with **protected** Instance Variables

In this example, we declared base-class instance variables as **protected** so that derived classes could access them. Inheriting **protected** instance variables enables you to directly access the variables in the derived class *without* invoking the set or get accessors of the corresponding property, thus violating encapsulation. In most cases, it's better to use **private** instance variables to encourage proper software engineering. Your code will be easier to maintain, modify and debug.

Using **protected** instance variables creates several potential problems. First, since the derived-class object can set an inherited variable's value directly *without* using a property's **set** accessor, a derived-class object can assign an *invalid* value to the variable. For example, if we were to declare **CommissionEmployee**'s instance variable **grossSales** as **protected**, a derived-class object (e.g., **BasePlusCommissionEmployee**) could then assign a *negative* value to **grossSales**. The second problem with using **protected** instance variables is that derived-class methods are more likely to be written to *depend* on the base class's data implementation. In practice, derived classes should depend only on the base-class *services* (i.e., non-private methods and properties) and *not* on the base-class data implementation. With **protected** instance variables in the base class, we may need to modify all the derived classes of the base class if the base-class implementation changes. For example, if for some reason we were to change the names of instance variables **firstName** and **lastName** to **first** and **last**, then we would have to do so for all occurrences in which a derived class directly references base-class instance variables **firstName** and **lastName**. In such a case, the software is said to be **fragile** or **brittle**, because a small change in the base class can "break" derived-class implementation. You should be able to *change* the base-class *implementation* while still providing the *same services* to the derived classes. Of course, if the base-class *services* change, we must reimplement our derived classes.



### Software Engineering Observation 11.4

*Declaring base-class instance variables **private** (as opposed to **protected**) enables the base-class implementation of these instance variables to change without affecting derived-class implementations.*

### 11.4.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Instance Variables

We now reexamine our hierarchy once more, this time using the best software engineering practices. Class `CommissionEmployee` (Fig. 11.12) declares instance variables `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate` as `private` (lines 7–11) and provides public properties `FirstName`, `LastName`, `SocialSecurityNumber`, `GrossSales` and `CommissionRate` for manipulating these values. Methods `Earnings` (lines 88–91) and `ToString` (lines 94–101) use the class's *properties* to obtain the values of its instance variables. If we decide to change the instance-variable names, the `Earnings` and `ToString` declarations will *not* require modification—only the bodies of the properties that directly manipulate the instance variables will need to change. These changes occur solely within the base class—no changes to the derived class are needed. Localizing the effects of changes like this is a good software engineering practice. Derived class `BasePlusCommissionEmployee` (Fig. 11.13) inherits from `CommissionEmployee`'s and can access the `private` base-class members via the inherited `public` properties.

---

```

1 // Fig. 11.12: CommissionEmployee.cs
2 // CommissionEmployee class represents a commission employee.
3 using System;
4
5 public class CommissionEmployee
6 {
7     private string firstName;
8     private string lastName;
9     private string socialSecurityNumber;
10    private decimal grossSales; // gross weekly sales
11    private decimal commissionRate; // commission percentage
12
13    // five-parameter constructor
14    public CommissionEmployee( string first, string last, string ssn,
15        decimal sales, decimal rate )
16    {
17        // implicit call to object constructor occurs here
18        firstName = first;
19        lastName = last;
20        socialSecurityNumber = ssn;
21        GrossSales = sales; // validate gross sales via property
22        CommissionRate = rate; // validate commission rate via property
23    } // end five-parameter CommissionEmployee constructor
24
25    // read-only property that gets commission employee's first name
26    public string FirstName
27    {
28        get
29        {
30            return firstName;
31        } // end get
32    } // end property FirstName
33

```

---

**Fig. 11.12** | `CommissionEmployee` class represents a commission employee. (Part I of 3.)

```
34 // read-only property that gets commission employee's last name
35 public string LastName
36 {
37     get
38     {
39         return LastName;
40     } // end get
41 } // end property LastName
42
43 // read-only property that gets
44 // commission employee's social security number
45 public string SocialSecurityNumber
46 {
47     get
48     {
49         return socialSecurityNumber;
50     } // end get
51 } // end property SocialSecurityNumber
52
53 // property that gets and sets commission employee's gross sales
54 public decimal GrossSales
55 {
56     get
57     {
58         return grossSales;
59     } // end get
60     set
61     {
62         if ( value >= 0 )
63             grossSales = value;
64         else
65             throw new ArgumentException(
66                 "GrossSales", value, "GrossSales must be >= 0" );
67     } // end set
68 } // end property GrossSales
69
70 // property that gets and sets commission employee's commission rate
71 public decimal CommissionRate
72 {
73     get
74     {
75         return commissionRate;
76     } // end get
77     set
78     {
79         if ( value > 0 && value < 1 )
80             commissionRate = value;
81         else
82             throw new ArgumentException( "CommissionRate",
83                 value, "CommissionRate must be > 0 and < 1" );
84     } // end set
85 } // end property CommissionRate
86
```

**Fig. 11.12** | CommissionEmployee class represents a commission employee. (Part 2 of 3.)

```
87 // calculate commission employee's pay
88 public virtual decimal Earnings()
89 {
90     return CommissionRate * GrossSales;
91 } // end method Earnings
92
93 // return string representation of CommissionEmployee object
94 public override string ToString()
95 {
96     return string.Format(
97         "{0}: {1} {2}\n{3}: {4}\n{5}: {6:C}\n{7}: {8:F2}",
98         "commission employee", FirstName, LastName,
99         "social security number", SocialSecurityNumber,
100        "gross sales", GrossSales, "commission rate", CommissionRate );
101    } // end method ToString
102 } // end class CommissionEmployee
```

**Fig. 11.12** | CommissionEmployee class represents a commission employee. (Part 3 of 3.)

Class BasePlusCommissionEmployee (Fig. 11.13) has several changes to its method implementations that distinguish it from the version in Fig. 11.10. Methods Earnings (Fig. 11.13, lines 39–42) and ToString (lines 45–49) each invoke property BaseSalary’s get accessor to obtain the base-salary value, rather than accessing baseSalary directly. If we decide to rename instance variable baseSalary, only the body of property BaseSalary will need to change.

```
1 // Fig. 11.13: BasePlusCommissionEmployee.cs
2 // BasePlusCommissionEmployee inherits from CommissionEmployee and has
3 // access to CommissionEmployee's private data via
4 // its public properties.
5 using System;
6
7 public class BasePlusCommissionEmployee : CommissionEmployee
8 {
9     private decimal baseSalary; // base salary per week
10
11    // six-parameter derived class constructor
12    // with call to base class CommissionEmployee constructor
13    public BasePlusCommissionEmployee( string first, string last,
14        string ssn, decimal sales, decimal rate, decimal salary )
15        : base( first, last, ssn, sales, rate )
16    {
17        BaseSalary = salary; // validate base salary via property
18    } // end six-parameter BasePlusCommissionEmployee constructor
19
20    // property that gets and sets
21    // BasePlusCommissionEmployee's base salary
22    public decimal BaseSalary
23    {
```

**Fig. 11.13** | BasePlusCommissionEmployee inherits from CommissionEmployee and has access to CommissionEmployee’s private data via its public properties. (Part 1 of 2.)

```
24     get
25     {
26         return baseSalary;
27     } // end get
28     set
29     {
30         if ( value >= 0 )
31             baseSalary = value;
32         else
33             throw new ArgumentException( "BaseSalary" ,
34                                         value, "BaseSalary must be >= 0" );
35     } // end set
36 } // end property BaseSalary
37
38 // calculate earnings
39 public override decimal Earnings()
40 {
41     return BaseSalary + base.Earnings();
42 } // end method Earnings
43
44 // return string representation of BasePlusCommissionEmployee
45 public override string ToString()
46 {
47     return string.Format( "base-salaried {0}\nbase salary: {1:C}" ,
48                           base.ToString(), BaseSalary );
49 } // end method ToString
50 } // end class BasePlusCommissionEmployee
```

**Fig. 11.13** | BasePlusCommissionEmployee inherits from CommissionEmployee and has access to CommissionEmployee's private data via its public properties. (Part 2 of 2.)

#### **BasePlusCommissionEmployee Method Earnings**

Class BasePlusCommissionEmployee's Earnings method (Fig. 11.13, lines 39–42) overrides class CommissionEmployee's Earnings method (Fig. 11.12, lines 88–91) to calculate the earnings of a BasePlusCommissionEmployee. The new version obtains the portion of the employee's earnings based on commission alone by calling CommissionEmployee's Earnings method with the expression base.Earnings() (Fig. 11.13, line 41), then adds the base salary to this value to calculate the total earnings of the employee. Note the syntax used to invoke an overridden base-class method from a derived class—place the keyword base and the member access (.) operator before the base-class method name. This method invocation is a good software engineering practice—by having BasePlusCommissionEmployee's Earnings method invoke CommissionEmployee's Earnings method to calculate part of a BasePlusCommissionEmployee object's earnings, we avoid duplicating the code and reduce code-maintenance problems.



#### **Common Programming Error 11.3**

*When a base-class method is overridden in a derived class, the derived-class version often calls the base-class version to do a portion of the work. Failure to prefix the base-class method name with the keyword base and the member access (.) operator when referencing the base class's method from the derived-class version causes the derived-class method to call itself, creating infinite recursion.*

***BasePlusCommissionEmployee Method ToString***

Similarly, `BasePlusCommissionEmployee`'s `ToString` method (Fig. 11.13, lines 45–49) overrides `CommissionEmployee`'s (Fig. 11.12, lines 94–101) to return a string representation that's appropriate for a base-salaried commission employee. The new version creates part of `BasePlusCommissionEmployee` string representation (i.e., the string "commission employee" and the values of `CommissionEmployee`'s private instance variables) by calling `CommissionEmployee`'s `ToString` method with the expression `base.ToString()` (Fig. 11.13, line 48). The derived class's `ToString` method then outputs the remainder of the object's string representation (i.e., the base salary).

***Class BasePlusCommissionEmployeeTest***

Figure 11.14 performs the same manipulations on a `BasePlusCommissionEmployee` object as did Figs. 11.7 and 11.11. Although each "base-salaried commission employee" class behaves identically, the `BasePlusCommissionEmployee` in this example is the best engineered. *By using inheritance and by using properties that hide the data and ensure consistency, we have efficiently and effectively constructed a well-engineered class.*

---

```

1 // Fig. 11.14: BasePlusCommissionEmployeeTest.cs
2 // Testing class BasePlusCommissionEmployee.
3 using System;
4
5 public class BasePlusCommissionEmployeeTest
6 {
7     public static void Main( string[] args )
8     {
9         // instantiate BasePlusCommissionEmployee object
10        BasePlusCommissionEmployee employee =
11            new BasePlusCommissionEmployee( "Bob", "Lewis",
12                "333-33-3333", 5000.00M, .04M, 300.00M );
13
14        // display BasePlusCommissionEmployee's data
15        Console.WriteLine(
16            "Employee information obtained by properties and methods: \n" );
17        Console.WriteLine( "First name is {0}", employee.FirstName );
18        Console.WriteLine( "Last name is {0}", employee.LastName );
19        Console.WriteLine( "Social security number is {0}",
20            employee.SocialSecurityNumber );
21        Console.WriteLine( "Gross sales are {0:C}", employee.GrossSales );
22        Console.WriteLine( "Commission rate is {0:F2}",
23            employee.CommissionRate );
24        Console.WriteLine( "Earnings are {0:C}", employee.Earnings() );
25        Console.WriteLine( "Base salary is {0:C}", employee.BaseSalary );
26
27        employee.BaseSalary = 1000.00M; // set base salary
28
29        Console.WriteLine( "\n{0}:\n{1}",
30            "Updated employee information obtained by ToString", employee );
31        Console.WriteLine( "earnings: {0:C}", employee.Earnings() );
32    } // end Main
33 } // end class BasePlusCommissionEmployeeTest

```

---

**Fig. 11.14** | Testing class `BasePlusCommissionEmployee`. (Part 1 of 2.)

Employee information obtained by properties and methods:

```
First name is Bob
Last name is Lewis
Social security number is 333-33-3333
Gross sales are $5,000.00
Commission rate is 0.04
Earnings are $500.00
Base salary is $300.00
```

Updated employee information obtained by `ToString`:

```
base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: $5,000.00
commission rate: 0.04
base salary: $1,000.00
earnings: $1,200.00
```

**Fig. 11.14** | Testing class `BasePlusCommissionEmployee`. (Part 2 of 2.)

In this section, you saw an evolutionary set of examples that was carefully designed to teach key capabilities for good software engineering with inheritance. You learned how to create a derived class using inheritance, how to use protected base-class members to enable a derived class to access inherited base-class instance variables and how to override base-class methods to provide versions that are more appropriate for derived-class objects. In addition, you applied effective software engineering techniques from Chapter 4, Chapter 10 and this chapter to create classes that are easy to maintain, modify and debug.

## 11.5 Constructors in Derived Classes

As we explained in the preceding section, instantiating a derived-class object begins a chain of constructor calls. The derived-class constructor, before performing its own tasks, invokes its direct base class's constructor either explicitly (via a constructor initializer with the `base` reference) or implicitly (calling the base class's default constructor or parameterless constructor). Similarly, if the base class is derived from another class (as every class except `object` is), the base-class constructor invokes the constructor of the next class up in the hierarchy, and so on. The *last* constructor called in the chain is always the constructor for `class object`. The original derived-class constructor's body finishes executing last. Each base class's constructor manipulates the base-class instance variables that the derived-class object inherits. For example, consider again the `CommissionEmployee`-`BasePlusCommissionEmployee` hierarchy from Figs. 11.12 and 11.13. When an app creates a `BasePlusCommissionEmployee` object, the `BasePlusCommissionEmployee` constructor is called. That constructor immediately calls `CommissionEmployee`'s constructor, which in turn immediately calls `object`'s constructor implicitly. `Class object`'s constructor has an empty body, so it immediately returns control to `CommissionEmployee`'s constructor, which then initializes the private instance variables of `CommissionEmployee` that are part of the `BasePlusCommissionEmployee` object. When `CommissionEmployee`'s constructor completes execution, it returns control to `BasePlusCommissionEmployee`'s constructor, which initializes the `BasePlusCommissionEmployee` object's `baseSalary`.

## 11.6 Software Engineering with Inheritance

This section discusses customizing existing software with inheritance. When a new class extends an existing class, the new class inherits the members of the existing class. We can customize the new class to meet our needs by including additional members and by overriding base-class members. Doing this does *not* require the derived-class programmer to change the base class's source code. C# simply requires access to the compiled base-class code, so it can compile and execute any app that uses or extends the base class. This powerful capability is attractive to independent software vendors (ISVs), who can develop proprietary classes for sale or license and make them available to users in class libraries. Users then can derive new classes from these library classes rapidly, without accessing the ISVs' proprietary source code.



### Software Engineering Observation 11.5

*Although inheriting from a class does not require access to the class's source code, developers often insist on seeing the source code to understand how the class is implemented. They may, for example, want to ensure that they're extending a class that performs well and is implemented securely.*

Students sometimes have difficulty appreciating the scope of the problems faced by designers who work on large-scale software projects in industry. People experienced with such projects say that effective software reuse improves the software-development process. Object-oriented programming facilitates software reuse, potentially shortening development time. The availability of substantial and useful class libraries helps deliver the maximum benefits of software reuse through inheritance.



### Software Engineering Observation 11.6

*At the design stage in an object-oriented system, the designer often finds that certain classes are closely related. The designer should "factor out" common members and place them in a base class. Then the designer should use inheritance to develop derived classes, specializing them with capabilities beyond those inherited from the base class.*



### Software Engineering Observation 11.7

*Declaring a derived class does not affect its base class's source code. Inheritance preserves the integrity of the base class.*

Reading derived-class declarations can be confusing, because inherited members are not declared explicitly in the derived classes, but are nevertheless present in them. A similar problem exists in documenting derived-class members.

## 11.7 Class object

As we discussed earlier in this chapter, all classes inherit directly or indirectly from the `object` class (`System.Object` in the Framework Class Library), so its seven methods are inherited by *all* classes. Figure 11.15 summarizes `object`'s methods. You can learn more about `object`'s methods at:

| Method                       | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>Equals</code>          | This method compares two objects for equality and returns <code>true</code> if they're equal and <code>false</code> otherwise. It takes any object as an argument. When objects of a particular class must be compared for equality, the class should override method <code>Equals</code> to compare the <i>contents</i> of the two objects. The following website explains the requirements for a properly overridden <code>Equals</code> method: <a href="http://bit.ly/OverridingEqualsCSharp">http://bit.ly/OverridingEqualsCSharp</a>                                                                                                                         |
| <code>Finalize</code>        | This method cannot be explicitly declared or called. When a class contains a destructor, the compiler implicitly renames it to override the <code>protected</code> method <code>Finalize</code> , which is called <i>only</i> by the garbage collector before it reclaims an object's memory. The garbage collector is not guaranteed to reclaim an object, thus it's <i>not</i> guaranteed that an object's <code>Finalize</code> method will execute. When a derived class's <code>Finalize</code> method executes, it performs its task, then invokes the base class's <code>Finalize</code> method. In general, you should avoid using <code>Finalize</code> . |
| <code>GetHashCode</code>     | A hashtable data structure relates objects, called <i>keys</i> , to corresponding objects, called <i>values</i> . We discuss <code>Hashtable</code> in Chapter 21, Collections. When a value is initially inserted in a hashtable, the key's <code>GetHashCode</code> method is called. The value returned is used by the hashtable to determine the location at which to insert the corresponding value. The key's hashcode is also used by the hashtable to locate the key's corresponding value.                                                                                                                                                                |
| <code>GetType</code>         | Every object knows its own type at execution time. Method <code>GetType</code> (used in Section 12.5) returns an object of class <code>Type</code> (namespace <code>System</code> ) that contains information about the object's type, such as its class name (obtained from <code>Type</code> property <code>FullName</code> ).                                                                                                                                                                                                                                                                                                                                   |
| <code>MemberwiseClone</code> | This <code>protected</code> method, which takes no arguments and returns an <code>object</code> reference, makes a copy of the object on which it's called. The implementation of this method performs a <b>shallow copy</b> —instance-variable values in one object are copied into another object of the same type. For reference types, only the references are copied.                                                                                                                                                                                                                                                                                         |
| <code>ReferenceEquals</code> | This <code>static</code> method receives two <code>object</code> references and returns <code>true</code> if they're the same instance or if they're <code>null</code> references. Otherwise, it returns <code>false</code> .                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <code>ToString</code>        | This method (introduced in Section 7.4) returns a <code>string</code> representation of an object. The default implementation of this method returns the namespace followed by a dot and the class name of the object's class.                                                                                                                                                                                                                                                                                                                                                                                                                                     |

**Fig. 11.15** | `object` methods that are inherited directly or indirectly by all classes.

## 11.8 Wrap-Up

This chapter introduced inheritance—the ability to create classes by absorbing an existing class's members and enhancing them with new capabilities. You learned the notions of base classes and derived classes and created a derived class that inherits members from a base class. The chapter introduced access modifier `protected`; derived-class members can access `protected` base-class members. You learned how to access base-class members with

base. You also saw how constructors are used in inheritance hierarchies. Finally, you learned about the methods of class `object`, the direct or indirect base class of *all* classes.

In Chapter 12, we build on our discussion of inheritance by introducing polymorphism—an object-oriented concept that enables us to write apps that handle, in a more general manner, objects of a wide variety of classes related by inheritance. After studying Chapter 12, you’ll be familiar with classes, objects, encapsulation, inheritance and polymorphism—the most essential aspects of object-oriented programming.

---

## Summary

### Section 11.1 Introduction

- Inheritance is a form of software reuse in which a new class is created by absorbing an existing class’s members and enhancing them with new or modified capabilities. With inheritance, you save time during app development by reusing proven and debugged high-quality software.
- A derived class is more specific than its base class and represents a more specialized group of objects.
- The *is-a* relationship represents inheritance. In an *is-a* relationship, an object of a derived class can also be treated as an object of its base class.

### Section 11.2 Base Classes and Derived Classes

- Inheritance relationships form treelike hierarchical structures. A base class exists in a hierarchical relationship with its derived classes.
- Objects of all classes that extend a common base class can be treated as objects of that base class. However, base-class objects cannot be treated as objects of their derived classes.
- When a base-class method is inherited by a derived class, that derived class often needs a customized version of the method. In such cases, the derived class can override the base-class method with an appropriate implementation.

### Section 11.3 **protected** Members

- Using **protected** access offers an intermediate level of access between **public** and **private**. A base class’s **protected** members can be accessed by members of that base class *and* by members of its derived classes.
- Base-class members retain their original access modifier when they become members of the derived class.
- Methods of a derived class cannot directly access **private** members of the base class.

### Section 11.4.1 Creating and Using a **CommissionEmployee** Class

- A colon (:) followed by a base-class name at the end of a class declaration header indicates that the declared class extends the base class.
- If a class does not specify that it inherits from another class, the class implicitly inherits from `object`.
- The first task of any derived class’s constructor is to call its direct base class’s constructor, either explicitly or implicitly (if no constructor call is specified).
- Constructors are not inherited. Even if a class does not have constructors, the default constructor that the compiler implicitly declares for the class will call the base class’s default or parameterless constructor.
- Method `ToString` is one of the methods that every class inherits directly or indirectly from class `object`, which is the root of the C# class hierarchy.

- To override a base-class method, a derived class must declare a method with keyword `override` and with the same signature (method name, number of parameters and parameter types) and return type as the base-class method.
- It's a compilation error to override a method with a different access modifier.

#### ***Section 11.4.2 Creating a BasePlusCommissionEmployee Class without Using Inheritance***

- Copying and pasting code from one class to another can spread errors across multiple source-code files. To avoid duplicating code (and possibly errors) in situations where you want one class to “absorb” the members of another class, use inheritance.

#### ***Section 11.4.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy***

- The `virtual` and `abstract` keywords indicate that a base-class property or method can be overridden in derived classes.
- The `override` modifier declares that a derived-class method overrides a `virtual` or `abstract` base-class method. This modifier also implicitly declares the derived-class method `virtual`.
- When a base class’s members are `private`, a derived class’s members are not allowed to access them.

#### ***Section 11.4.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Instance Variables***

- Inheriting `protected` instance variables enables you to directly access the variables in the derived class without invoking the `set` or `get` accessors of the corresponding property.
- Software is said to be fragile or brittle when a small change in the base class can “break” derived-class implementation. You should be able to change the base-class implementation while still providing the same services to the derived classes.
- Declaring base-class instance variables `private` enables the base-class implementation of these instance variables to change without affecting derived-class implementations.

#### ***Section 11.4.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Instance Variables***

- Place the keyword `base` and the member access `(.)` operator before the base-class method name to invoke an overridden base-class method from a derived class.
- Failure to prefix the base-class method name with the keyword `base` and the member access `(.)` operator when referencing the base class’s method causes the derived-class method to call itself, creating an error called infinite recursion.

#### ***Section 11.5 Constructors in Derived Classes***

- Instantiating a derived-class object begins a chain of constructor calls. The last constructor called in the chain is always the constructor for `object` class. The original derived class constructor’s body finishes executing last.

#### ***Section 11.6 Software Engineering with Inheritance***

- We can customize new classes to meet our needs by including additional members and by overriding base-class members.

#### ***Section 11.7 Class object***

- All classes in C# inherit directly or indirectly from the `object` class, so its seven methods are inherited by all other classes. These methods are `Equals`, `Finalize`, `GetHashCode`, `GetType`, `MemberwiseClone`, `ReferenceEquals` and `ToString`.

## Terminology

|                                      |                                         |
|--------------------------------------|-----------------------------------------|
| base class                           | inheritance hierarchy                   |
| base-class constructor               | inherited member                        |
| base-class constructor call syntax   | inherited method                        |
| base-class parameterless constructor | invoke a base-class constructor         |
| base keyword                         | invoke a base-class method              |
| brittle software                     | <i>is-a</i> relationship                |
| class hierarchy                      | MemberwiseClone method of class object  |
| class library                        | object class                            |
| composition                          | object of a derived class               |
| derived class                        | object of a base class                  |
| derived-class constructor            | override keyword                        |
| direct base class                    | override (redefine) a base-class method |
| Equals method of class object        | private base-class member               |
| extend a base class                  | protected base-class member             |
| Finalize method of class object      | protected access modifier               |
| fragile software                     | public base-class member                |
| GetHashCode method of class object   | ReferenceEquals method of class object  |
| GetType method of class object       | single inheritance                      |
| <i>has-a</i> relationship            | shallow copy                            |
| hierarchical relationship            | software reuse                          |
| hierarchy diagram                    | standardized reusable components        |
| indirect base class                  | ToString method of class object         |
| inheritance                          | virtual keyword                         |

## Self-Review Exercises

**11.1** Fill in the blanks in each of the following statements:

- \_\_\_\_\_ is a form of software reusability in which new classes acquire the members of existing classes and enhance those classes with new capabilities.
- A base class's \_\_\_\_\_ members can be accessed only in the base-class declaration and in derived-class declarations.
- In a(n) \_\_\_\_\_ relationship, an object of a derived class can also be treated as an object of its base class.
- In a(n) \_\_\_\_\_ relationship, a class object has references to objects of other classes as members.
- In single inheritance, a base class exists in a(n) \_\_\_\_\_ relationship with its derived classes.
- A base class's \_\_\_\_\_ members are accessible anywhere that the app has a reference to an object of that base class or to an object of any of its derived classes.
- When an object of a derived class is instantiated, a base class \_\_\_\_\_ is called implicitly or explicitly.
- Derived-class constructors can call base class constructors via the \_\_\_\_\_ keyword.

**11.2** State whether each of the following is *true* or *false*. If a statement is *false*, explain why.

- Base-class constructors are not inherited by derived classes.
- A *has-a* relationship is implemented via inheritance.
- A Car class has *is-a* relationships with the SteeringWheel and Brakes classes.
- Inheritance encourages the reuse of proven high-quality software.
- When a derived class redefines a base-class method by using the same signature and return type, the derived class is said to overload that base-class method.

## Answers to Self-Review Exercises

**11.1** a) Inheritance. b) protected. c) *is-a* or inheritance. d) *has-a* or composition. e) hierarchical. f) public. g) constructor. h) base.

**11.1** a) True. b) False. A *has-a* relationship is implemented via composition. An *is-a* relationship is implemented via inheritance. c) False. These are examples of *has-a* relationships. Class Car has an *is-a* relationship with class Vehicle. d) True. e) False. This is known as overriding, not overloading.

## Exercises

**11.2** (*Composition vs. Inheritance*) Many apps written with inheritance could be written with composition instead, and vice versa. Rewrite class BasePlusCommissionEmployee (Fig. 11.13) of the CommissionEmployee–BasePlusCommissionEmployee hierarchy to use composition rather than inheritance.

**11.3** (*Inheritance and Software Reuse*) Discuss the ways in which inheritance promotes software reuse, saves time during app development and helps prevent errors.

**11.4** (*Student Inheritance Hierarchy*) Draw a UML class diagram for an inheritance hierarchy for students at a university similar to the hierarchy shown in Fig. 11.2. Use Student as the base class of the hierarchy, then extend Student with classes UndergraduateStudent and GraduateStudent. Continue to extend the hierarchy as deeply (i.e., as many levels) as possible. For example, Freshman, Sophomore, Junior and Senior might extend UndergraduateStudent, and DoctoralStudent and MastersStudent might be derived classes of GraduateStudent. After drawing the hierarchy, discuss the relationships that exist between the classes. [Note: You do not need to write any code for this exercise.]

**11.5** (*Shape Inheritance Hierarchy*) The world of shapes is much richer than the shapes included in the inheritance hierarchy of Fig. 11.3. Write down all the shapes you can think of—both two-dimensional and three-dimensional—and form them into a more complete Shape hierarchy with as many levels as possible. Your hierarchy should have class Shape at the top. Class TwoDimensionalShape and class ThreeDimensionalShape should extend Shape. Add additional derived classes, such as Quadrilateral and Sphere, at their correct locations in the hierarchy as necessary.

**11.6** (*Protected vs. Private Access*) Some programmers prefer not to use protected access, because they believe it breaks the encapsulation of the base class. Discuss the relative merits of using protected access vs. using private access in base classes.

**11.7** (*Quadrilateral Inheritance Hierarchy*) Write an inheritance hierarchy for classes Quadrilateral, Trapezoid, Parallelogram, Rectangle and Square. Use Quadrilateral as the base class of the hierarchy. Make the hierarchy as deep (i.e., as many levels) as possible. Specify the instance variables, properties and methods for each class. The private instance variables of Quadrilateral should be the *x*–*y* coordinate pairs for the four endpoints of the Quadrilateral. Write an app that instantiates objects of your classes and outputs each object's area (except Quadrilateral).

**11.8** (*Account Inheritance Hierarchy*) Create an inheritance hierarchy that a bank might use to represent customers' bank accounts. All customers at this bank can deposit (i.e., credit) money into their accounts and withdraw (i.e., debit) money from their accounts. More specific types of accounts also exist. Savings accounts, for instance, earn interest on the money they hold. Checking accounts, on the other hand, charge a fee per transaction.

Create base class Account and derived classes SavingsAccount and CheckingAccount that inherit from class Account. Base class Account should include one private instance variable of type decimal to represent the account balance. The class should provide a constructor that receives an initial balance and uses it to initialize the instance variable with a public property. The property

should validate the initial balance to ensure that it's greater than or equal to 0.0; if not, throw an exception. The class should provide two public methods. Method `Credit` should add an amount to the current balance. Method `Debit` should withdraw money from the Account and ensure that the debit amount does not exceed the Account's balance. If it does, the balance should be left unchanged, and the method should display the message "Debit amount exceeded account balance." The class should also provide a get accessor in property `Balance` that returns the current balance.

Derived class `SavingsAccount` should inherit the functionality of an `Account`, but also include a `decimal` instance variable indicating the interest rate (percentage) assigned to the `Account`. `SavingsAccount`'s constructor should receive the initial balance, as well as an initial value for the interest rate. `SavingsAccount` should provide public method `CalculateInterest` that returns a `decimal` indicating the amount of interest earned by an account. Method `CalculateInterest` should determine this amount by multiplying the interest rate by the account balance. [Note: `SavingsAccount` should inherit methods `Credit` and `Debit` without redefining them.]

Derived class `CheckingAccount` should inherit from base class `Account` and include a `decimal` instance variable that represents the fee charged per transaction. `CheckingAccount`'s constructor should receive the initial balance, as well as a parameter indicating a fee amount. Class `CheckingAccount` should redefine methods `Credit` and `Debit` so that they subtract the fee from the account balance whenever either transaction is performed successfully. `CheckingAccount`'s versions of these methods should invoke the base-class `Account` version to perform the updates to an account balance. `CheckingAccount`'s `Debit` method should charge a fee only if money is actually withdrawn (i.e., the debit amount does not exceed the account balance). [Hint: Define `Account`'s `Debit` method so that it returns a `bool` indicating whether money was withdrawn. Then use the return value to determine whether a fee should be charged.]

After defining the classes in this hierarchy, write an app that creates objects of each class and tests their methods. Add interest to the `SavingsAccount` object by first invoking its `CalculateInterest` method, then passing the returned interest amount to the object's `Credit` method.

# OOP: Polymorphism, Interfaces and Operator Overloading

12



*General propositions do not decide concrete cases.*

—Oliver Wendell Holmes

*A philosopher of imposing stature doesn't think in a vacuum. Even his most abstract ideas are, to some extent, conditioned by what is or is not known in the time when he lives.*

—Alfred North Whitehead

## Objectives

In this chapter you'll learn:

- How polymorphism enables you to “program in the general” and make systems extensible.
- To use overridden methods to effect polymorphism.
- To create abstract classes and methods.
- To determine an object’s type at execution time.
- To create **sealed** methods and classes.
- To declare and implement interfaces.
- To overload operators to enable them to manipulate objects.

|             |                                                                                   |             |                                                                            |
|-------------|-----------------------------------------------------------------------------------|-------------|----------------------------------------------------------------------------|
| <b>12.1</b> | Introduction                                                                      | <b>12.6</b> | sealed Methods and Classes                                                 |
| <b>12.2</b> | Polymorphism Examples                                                             | <b>12.7</b> | Case Study: Creating and Using Interfaces                                  |
| <b>12.3</b> | Demonstrating Polymorphic Behavior                                                | 12.7.1      | Developing an IPayable Hierarchy                                           |
| <b>12.4</b> | Abstract Classes and Methods                                                      | 12.7.2      | Declaring Interface IPayable                                               |
| <b>12.5</b> | Case Study: Payroll System Using Polymorphism                                     | 12.7.3      | Creating Class Invoice                                                     |
| 12.5.1      | Creating Abstract Base Class Employee                                             | 12.7.4      | Modifying Class Employee to Implement Interface IPayable                   |
| 12.5.2      | Creating Concrete Derived Class SalariedEmployee                                  | 12.7.5      | Modifying Class Salaried-Employee for Use with IPayable                    |
| 12.5.3      | Creating Concrete Derived Class HourlyEmployee                                    | 12.7.6      | Using Interface IPayable to Process Invoices and Employees Polymorphically |
| 12.5.4      | Creating Concrete Derived Class CommissionEmployee                                | 12.7.7      | Common Interfaces of the .NET Framework Class Library                      |
| 12.5.5      | Creating Indirect Concrete Derived Class BasePlusCommission-Employee              | <b>12.8</b> | Operator Overloading                                                       |
| 12.5.6      | Polymorphic Processing, Operator is and Downcasting                               | <b>12.9</b> | Wrap-Up                                                                    |
| 12.5.7      | Summary of the Allowed Assignments Between Base-Class and Derived-Class Variables |             |                                                                            |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercise](#)

## 12.1 Introduction

We now continue our study of object-oriented programming by explaining and demonstrating **polymorphism** with inheritance hierarchies. Polymorphism enables us to *program in the general* rather than *program in the specific*. In particular, polymorphism enables us to write apps that process objects that share the *same* base class in a class hierarchy as if they were all objects of the base class.

Let's consider a polymorphism example. Suppose we create an app that simulates moving several types of animals for a biological study. Classes `Fish`, `Frog` and `Bird` represent the types of animals under investigation. Imagine that each class extends base class `Animal`, which contains a method `Move` and maintains an animal's current location as  $x$ - $y$ - $z$  coordinates. Each derived class implements method `Move`. Our app maintains an array of references to objects of the various `Animal`-derived classes. To simulate an animal's movements, the app sends each object the *same* message once per second—namely, `Move`. Each specific type of `Animal` responds to a `Move` message in a unique way—a `Fish` might swim three feet, a `Frog` might jump five feet and a `Bird` might fly 10 feet. The app issues the `Move` message to each animal object *generically*, but each object modifies its  $x$ - $y$ - $z$  coordinates appropriately for its *specific* type of movement. Relying on each object to “do the right thing” in response to the *same* method call is the key concept of polymorphism. The *same* message (in this case, `Move`) sent to a *variety* of objects has *many forms* of results—hence the term polymorphism.

### *Systems Are Easy to Extend*

With polymorphism, we can design and implement systems that are easily *extensible*—new classes can be added with little or no modification to the general portions of the app, as long as the new classes are part of the inheritance hierarchy that the app processes generically. The only parts of an app that must be altered to accommodate new classes are those that require direct knowledge of the new classes that you add to the hierarchy. For example, if we extend class `Animal` to create class `Tortoise` (which might respond to a `Move` message by crawling one inch), we need to write only the `Tortoise` class and the part of the simulation that instantiates a `Tortoise` object. The portions of the simulation that process each `Animal` generically can remain the *same*.

This chapter has several parts. First, we discuss common examples of polymorphism. We then provide a live-code example demonstrating polymorphic behavior. As you'll soon see, you'll use base-class references to manipulate both base-class objects *and* derived-class objects polymorphically.

### *Polymorphic Employee Inheritance Hierarchy*

We then present a case study that revisits the `Employee` hierarchy of Section 11.4.5. We develop a simple payroll app that polymorphically calculates the weekly pay of several different types of employees using each employee's `Earnings` method. Though the earnings of each type of employee are calculated in a specific way, polymorphism allows us to process the employees "in the general." In the case study, we enlarge the hierarchy to include two new classes—`SalariedEmployee` (for people paid a fixed weekly salary) and `HourlyEmployee` (for people paid an hourly salary and "time-and-a-half" for overtime). We declare a *common set of functionality* for all the classes in the updated hierarchy in an *abstract* class, `Employee` (Section 12.5.1), from which classes `SalariedEmployee`, `HourlyEmployee` and `CommissionEmployee` *inherit directly* and class `BasePlusCommissionEmployee` *inherits indirectly*. As you'll soon see, when we invoke each employee's `Earnings` method via a base-class `Employee` reference, the correct earnings calculation is performed due to C#'s polymorphic capabilities.

### *Determining the Type of an Object at Execution Time*

Occasionally, when performing polymorphic processing, we need to program "in the specific." Our `Employee` case study demonstrates that an app can determine the type of an object at *execution* time and act on that object accordingly. In the case study, we use these capabilities to determine whether a particular employee object *is-a* `BasePlusCommissionEmployee`. If so, we increase that employee's base salary by 10%.

### *Interfaces*

The chapter continues with an introduction to C# interfaces. An interface describes a set of methods and properties that can be called on an object, but does *not* provide *concrete* implementations for them. You can declare classes that **implement** (i.e., provide *concrete* implementations for the methods and properties of) one or more interfaces. Each interface member must be defined for *all* the classes that implement the interface. Once a class implements an interface, all objects of that class have an *is-a* relationship with the interface type, and all objects of the class are *guaranteed* to provide the functionality described by the interface. This is true of all *derived* classes of that class as well.

Interfaces are particularly useful for assigning common functionality to possibly *unrelated* classes. This allows objects of unrelated classes to be processed polymorphically—

objects of classes that implement the *same* interface can respond to the *same* method calls. To demonstrate creating and using interfaces, we modify our payroll app to create a general accounts-payable app that can calculate payments due for the earnings of company employees and for invoice amounts to be billed for purchased goods. As you'll see, interfaces enable polymorphic capabilities similar to those enabled by inheritance.

### ***Operator Overloading***

This chapter ends with an introduction to operator overloading. In previous chapters, we declared our own classes and used methods to perform tasks on objects of those classes. Operator overloading allows us to define the behavior of the built-in operators, such as +, - and <, when used on objects of our own classes. This provides a much more convenient notation than calling methods for performing certain tasks on objects.

## **12.2 Polymorphism Examples**

Let's consider several additional examples of polymorphism.

### ***Quadrilateral Inheritance Hierarchy***

If class `Rectangle` is derived from class `Quadrilateral` (a four-sided shape), then a `Rectangle` is a more specific version of a `Quadrilateral`. Any operation (e.g., calculating the perimeter or the area) that can be performed on a `Quadrilateral` object can also be performed on a `Rectangle` object. These operations also can be performed on other `Quadrilaterals`, such as `Squares`, `Parallelograms` and `Trapezoids`. The polymorphism occurs when an app invokes a method through a base-class variable—at execution time, the correct derived-class version of the method is called, based on the type of the referenced object. You'll see a simple code example that illustrates this process in Section 12.3.

### ***Video Game SpaceObject Inheritance Hierarchy***

As another example, suppose we design a video game that manipulates objects of many different types, including objects of classes `Martian`, `Venusian`, `Plutonian`, `SpaceShip` and `LaserBeam`. Imagine that each class inherits from the common base class `SpaceObject`, which contains method `Draw`. Each derived class implements this method. A screen-manager app maintains a collection (e.g., a `SpaceObject` array) of references to objects of the various classes. To refresh the screen, the screen manager periodically sends each object the *same message*—namely, `Draw`. However, each object responds in a unique way. For example, a `Martian` object might *draw itself* in red with the appropriate number of antennae. A `SpaceShip` object might *draw itself* as a bright silver flying saucer. A `LaserBeam` object might *draw itself* as a bright red beam across the screen. Again, the *same message* (in this case, `Draw`) sent to a variety of objects has *many forms* of results.

A polymorphic screen manager might use polymorphism to facilitate adding new classes to a system with minimal modifications to the system's code. Suppose we want to add `Mercurian` objects to our video game. To do so, we must build a `Mercurian` class that extends `SpaceObject` and provides its own `Draw` method implementation. When objects of class `Mercurian` appear in the `SpaceObject` collection, the screen-manager code invokes method `Draw`, exactly as it does for every other object in the collection, *regardless of its type*, so the new `Mercurian` objects simply “plug right in” without any modification of the screen-manager code by the programmer. Thus, without modifying the system (other than to build new

classes and modify the code that creates new objects), you can use polymorphism to include additional types that might not have been envisioned when the system was created.



### Software Engineering Observation 12.1

*Polymorphism promotes extensibility: Software that invokes polymorphic behavior is independent of the object types to which messages are sent. New object types that can respond to existing method calls can be incorporated into a system without requiring modification of the base system. Only client code that instantiates new objects must be modified to accommodate new types.*

## 12.3 Demonstrating Polymorphic Behavior

Section 11.4 created a commission-employee class hierarchy, in which class `BasePlusCommissionEmployee` inherited from class `CommissionEmployee`. The examples in that section manipulated `CommissionEmployee` and `BasePlusCommissionEmployee` objects by using references to them to invoke their methods. We aimed base-class references at base-class objects and derived-class references at derived-class objects. These assignments are natural and straightforward—base-class references are intended to refer to base-class objects, and derived-class references are intended to refer to derived-class objects. However, other assignments are possible.

In the next example, we aim a base-class reference at a derived-class object. We then show how invoking a method on a derived-class object via a base-class reference can invoke the derived-class functionality—the type of the actual referenced object, not the type of the reference, determines which method is called. This demonstrates the key concept that a derived-class object can be treated as an object of its base class, which enables various interesting manipulations. An app can create an array of base-class references that refer to objects of many derived-class types. This is allowed because each derived-class object is an object of its base class. For instance, we can assign the reference of a `BasePlusCommissionEmployee` object to a base-class `CommissionEmployee` variable because a `BasePlusCommissionEmployee` is a `CommissionEmployee`—so we can treat a `BasePlusCommissionEmployee` as a `CommissionEmployee`.

A base-class object is not an object of any of its derived classes. For example, we cannot directly assign the reference of a `CommissionEmployee` object to a derived-class `BasePlusCommissionEmployee` variable, because a `CommissionEmployee` is not a `BasePlusCommissionEmployee`—a `CommissionEmployee` does not, for example, have a `baseSalary` instance variable and does not have a `BaseSalary` property. The *is-a* relationship applies from a derived class to its direct and indirect base classes, but not vice versa.

The compiler allows the assignment of a base-class reference to a derived-class variable if we explicitly cast the base-class reference to the derived-class type—a technique we discuss in greater detail in Section 12.5.6. Why would we ever want to perform such an assignment? A base-class reference can be used to invoke only the methods declared in the base class—attempting to invoke a derived-class-only method through a base-class reference results in a compilation error. If an app needs to perform a derived-class-specific operation on a derived-class object referenced by a base-class variable, the app must first cast the base-class reference to a derived-class reference through a technique known as **downcasting**. This enables the app to invoke derived-class methods that are not in the base class. We present an example of downcasting in Section 12.5.6.

Figure 12.1 demonstrates three ways to use base-class and derived-class variables to store references to base-class and derived-class objects. The first two are straightforward—as in Section 11.4, we assign a base-class reference to a base-class variable, and we assign a derived class reference to a derived-class variable. Then we demonstrate the relationship between derived classes and base classes (i.e., the *is-a* relationship) by assigning a derived-class reference to a base-class variable. [Note: This app uses classes `CommissionEmployee` and `BasePlusCommissionEmployee` from Fig. 11.12 and Fig. 11.13, respectively.]

```

1 // Fig. 12.1: PolymorphismTest.cs
2 // Assigning base-class and derived-class references to base-class and
3 // derived-class variables.
4 using System;
5
6 public class PolymorphismTest
7 {
8     public static void Main( string[] args )
9     {
10         // assign base-class reference to base-class variable
11         CommissionEmployee commissionEmployee = new CommissionEmployee(
12             "Sue", "Jones", "222-22-2222", 10000.00M, .06M );
13
14         // assign derived-class reference to derived-class variable
15         BasePlusCommissionEmployee basePlusCommissionEmployee =
16             new BasePlusCommissionEmployee( "Bob", "Lewis",
17                 "333-33-3333", 5000.00M, .04M, 300.00M );
18
19         // invoke ToString and Earnings on base-class object
20         // using base-class variable
21         Console.WriteLine( "{0} {1}:\n\n{2}\n{3}: {4:C}\n",
22             "Call CommissionEmployee's ToString and Earnings methods ",
23             "with base-class reference to base class object",
24             commissionEmployee.ToString(),
25             "earnings", commissionEmployee.Earnings() );
26
27         // invoke ToString and Earnings on derived-class object
28         // using derived-class variable
29         Console.WriteLine( "{0} {1}:\n\n{2}\n{3}: {4:C}\n",
30             "Call BasePlusCommissionEmployee's ToString and Earnings ",
31             "methods with derived class reference to derived-class object",
32             basePlusCommissionEmployee.ToString(),
33             "earnings", basePlusCommissionEmployee.Earnings() );
34
35         // invoke ToString and Earnings on derived-class object
36         // using base-class variable
37         CommissionEmployee commissionEmployee2 =
38             basePlusCommissionEmployee;
39         Console.WriteLine( "{0} {1}:\n\n{2}\n{3}: {4:C}",
40             "Call BasePlusCommissionEmployee's ToString and Earnings ",
41             "with base class reference to derived-class object",

```

**Fig. 12.1** | Assigning base-class and derived-class references to base-class and derived-class variables. (Part 1 of 2.)

---

```

42         commissionEmployee2.ToString(), "earnings",
43         commissionEmployee2.Earnings() );
44     } // end Main
45 } // end class PolymorphismTest

```

Call CommissionEmployee's ToString and Earnings methods with base class reference to base class object:

```

commission employee: Sue Jones
social security number: 222-22-2222
gross sales: $10,000.00
commission rate: 0.06
earnings: $600.00

```

Call BasePlusCommissionEmployee's ToString and Earnings methods with derived class reference to derived class object:

```

base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: $5,000.00
commission rate: 0.04
base salary: $300.00
earnings: $500.00

```

Call BasePlusCommissionEmployee's ToString and Earnings methods with base class reference to derived class object:

```

base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: $5,000.00
commission rate: 0.04
base salary: $300.00
earnings: $500.00

```

**Fig. 12.1** | Assigning base-class and derived-class references to base-class and derived-class variables. (Part 2 of 2.)

In Fig. 12.1, lines 11–12 create a new `CommissionEmployee` object and assign its reference to a `CommissionEmployee` variable. Lines 15–17 create a new `BasePlusCommissionEmployee` object and assign its reference to a `BasePlusCommissionEmployee` variable. These assignments are *natural*—for example, a `CommissionEmployee` variable's primary purpose is to hold a reference to a `CommissionEmployee` object. Lines 21–25 use the reference `commissionEmployee` to invoke methods `ToString` and `Earnings`. Because `commissionEmployee` refers to a `CommissionEmployee` object, *base class* `CommissionEmployee`'s version of the methods are called. Similarly, lines 29–33 use the reference `basePlusCommissionEmployee` to invoke the methods `ToString` and `Earnings` on the `BasePlusCommissionEmployee` object. This invokes *derived class* `BasePlusCommissionEmployee`'s version of the methods.

Lines 37–38 then assign the reference to derived-class object `basePlusCommissionEmployee` to a base-class `CommissionEmployee` variable, which lines 39–43 use to invoke methods `ToString` and `Earnings`. *A base-class variable that contains a reference to a derived-class object and is used to call a virtual method actually calls the overriding derived-class ver-*

sion of the method. Hence, `commissionEmployee2.ToString()` in line 42 actually calls derived class `BasePlusCommissionEmployee`'s `ToString` method. The compiler allows this “crossover” because an object of a derived class is an object of its base class (but not vice versa). When the compiler encounters a `virtual` method call made through a variable, the compiler checks the *variable's* class type to determine if the method can be called. If that class contains the proper method declaration (or inherits one), the compiler allows the call to be compiled. At execution time, *the type of the object to which the variable refers* determines the actual method to use.

## 12.4 Abstract Classes and Methods

When we think of a class type, we assume that apps will create objects of that type. In some cases, however, it's useful to declare *classes for which you never intend to instantiate objects*. Such classes are called **abstract classes**. Because they're used only as base classes in inheritance hierarchies, we refer to them as **abstract base classes**. These classes *cannot* be used to instantiate objects, because, as you'll soon see, abstract classes are *incomplete*—derived classes must define the “missing pieces.” We demonstrate abstract classes in Section 12.5.1.

### *Purpose of an Abstract Class*

The purpose of an abstract class is primarily to provide an appropriate base class from which other classes can inherit, and thus *share a common design*. In the Shape hierarchy of Fig. 11.3, for example, derived classes inherit the notion of what it means to be a Shape—common attributes such as `location`, `color` and `borderThickness`, and behaviors such as `Draw`, `Move`, `Resize` and `ChangeColor`. Classes that can be used to instantiate objects are called **concrete classes**. Such classes provide implementations of *every* method they declare (some of the implementations can be inherited). For example, we could derive concrete classes `Circle`, `Square` and `Triangle` from abstract base class `TwoDimensionalShape`. Similarly, we could derive concrete classes `Sphere`, `Cube` and `Tetrahedron` from abstract base class `ThreeDimensionalShape`. Abstract base classes are *too general* to create real objects—they specify only what is common among derived classes. We need to be more *specific* before we can create objects. For example, if you send the `Draw` message to abstract class `TwoDimensionalShape`, the class knows that two-dimensional shapes should be drawable, but it does *not* know what *specific* shape to draw, so it cannot implement a real `Draw` method. *Concrete* classes provide the *specifications* that make it reasonable to instantiate objects.

### *Client Code That Uses Only Abstract Base-Class Types*

Not all inheritance hierarchies contain abstract classes. However, you'll often write client code that uses only abstract base-class types to reduce client code's dependencies on a range of specific derived-class types. For example, you can write a method with a parameter of an abstract base-class type. When called, such a method can be passed an object of any concrete class that directly or indirectly extends the base class specified as the parameter's type.

### *Multiple Levels of Abstract Base-Class Types in a Hierarchy*

Abstract classes sometimes constitute several levels of the hierarchy. For example, the Shape hierarchy of Fig. 11.3 begins with *abstract* class `Shape`. On the next level of the hierarchy are two more *abstract* classes, `TwoDimensionalShape` and `ThreeDimensionalShape`. The next

level of the hierarchy declares *concrete* classes for TwoDimensionalShapes (*Circle*, *Square* and *Triangle*) and for ThreeDimensionalShapes (*Sphere*, *Cube* and *Tetrahedron*).

### *Creating an Abstract Class*

You make a class abstract by declaring it with the keyword **abstract**. An abstract class normally contains one or more **abstract methods**. An abstract method is one with keyword **abstract** in its declaration, as in

```
public abstract void Draw(); // abstract method
```

*Abstract methods are implicitly virtual and do not provide implementations.* A class that contains abstract methods must be declared as an abstract class even if it contains some concrete (non-abstract) methods. Each *concrete* derived class of an abstract base class also must provide concrete implementations of the base class's abstract methods. We show an example of an abstract class with an abstract method in Fig. 12.4.

### *Abstract Properties*

Properties can also be declared **abstract** or **virtual**, then overridden in derived classes with the **override** keyword, just like methods. This allows an abstract base class to specify common properties of its derived classes. Abstract property declarations have the form:

```
public abstract PropertyType MyProperty
{
    get;
    set;
} // end abstract property
```

The semicolons after the **get** and **set** keywords indicate that we provide *no implementation* for these accessors. An abstract property omits implementations for the **get** accessor and/or the **set** accessor. Concrete derived classes *must* provide implementations for *every* accessor declared in the abstract property. When both **get** and **set** accessors are specified, every concrete derived class must implement both. If one accessor is omitted, the derived class is *not* allowed to implement that accessor. Doing so causes a compilation error.

### *Constructors and static Methods Cannot be Abstract*

Constructors and **static** methods *cannot* be declared abstract. Constructors are not inherited, so an abstract constructor could never be implemented. Similarly, derived classes cannot override **static** methods, so an abstract **static** method could never be implemented.



#### **Software Engineering Observation 12.2**

*An abstract class declares common attributes and behaviors of the various classes that inherit from it, either directly or indirectly, in a class hierarchy. An abstract class typically contains one or more abstract methods or properties that concrete derived classes must override. The instance variables, concrete methods and concrete properties of an abstract class are subject to the normal rules of inheritance.*



#### **Common Programming Error 12.1**

*Attempting to instantiate an object of an abstract class is a compilation error.*



### Common Programming Error 12.2

*Failure to implement a base class's abstract methods and properties in a derived class is a compilation error unless the derived class is also declared abstract.*

#### *Declaring Variables of Abstract Base-Class Types*

Although we cannot instantiate objects of abstract base classes, you'll soon see that we *can* use abstract base classes to declare variables that can hold references to objects of *any* concrete classes *derived* from those abstract classes. Apps typically use such variables to manipulate derived-class objects polymorphically. Also, you can use abstract base-class names to invoke **static** methods declared in those abstract base classes.

#### *Polymorphism and Device Drivers*

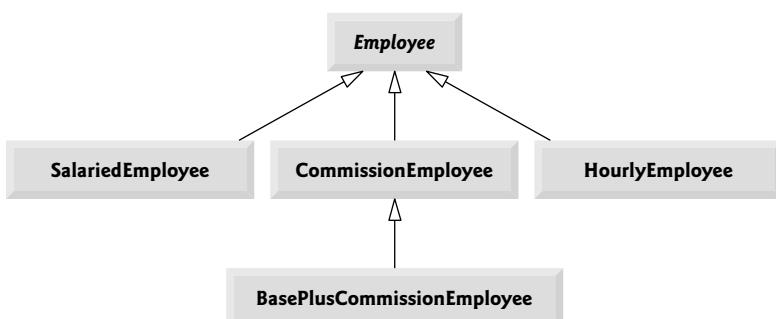
Polymorphism is particularly effective for implementing so-called *layered software systems*. In operating systems, for example, each type of physical device could operate quite differently from the others. Even so, common commands can read or write data from and to the devices. For each device, the operating system uses a piece of software called a *device driver* to control all communication between the system and the device. The write message sent to a device driver object needs to be interpreted *specifically* in the context of that driver and how it manipulates a specific device. However, the write call itself really is no different from the write to any other device in the system: Place some number of bytes from memory onto that device. An object-oriented operating system might use an abstract base class to provide an "interface" appropriate for all device drivers. Then, through inheritance from that abstract base class, derived classes are formed that all behave similarly. The device-driver methods are declared as abstract methods in the abstract base class. The implementations of these abstract methods are provided in the derived classes that correspond to the specific types of device drivers. New devices are always being developed, often long after the operating system has been released. When you buy a new device, it comes with a device driver provided by the device vendor. The device is immediately operational after you connect it to your computer and install the device driver. This is another elegant example of how polymorphism makes systems *extensible*.

## 12.5 Case Study: Payroll System Using Polymorphism

This section reexamines the `CommissionEmployee`-`BasePlusCommissionEmployee` hierarchy that we explored in Section 11.4. Now we use an abstract method and polymorphism to perform payroll calculations based on the type of employee. We create an enhanced employee hierarchy to solve the following problem:

*A company pays its employees on a weekly basis. The employees are of four types: Salaried employees are paid a fixed weekly salary regardless of the number of hours worked, hourly employees are paid by the hour and receive "time-and-a-half" overtime pay for all hours worked in excess of 40 hours, commission employees are paid a percentage of their sales, and salaried-commission employees receive a base salary plus a percentage of their sales. For the current pay period, the company has decided to reward salaried-commission employees by adding 10% to their base salaries. The company wants to implement an app that performs its payroll calculations polymorphically.*

We use abstract class `Employee` to represent the general concept of an employee. The classes that extend `Employee` are `SalariedEmployee`, `CommissionEmployee` and `HourlyEmployee`. Class `BasePlusCommissionEmployee`—which extends `CommissionEmployee`—represents the last employee type. The UML class diagram in Fig. 12.2 shows the inheritance hierarchy for our polymorphic employee payroll app. Abstract class `Employee` is *italicized*, as per the convention of the UML.



**Fig. 12.2** | `Employee` hierarchy UML class diagram.

Abstract base class `Employee` declares the “interface” to the hierarchy—that is, the set of members that an app can invoke on all `Employee` objects. We use the term “interface” here in a general sense to refer to the various ways apps can communicate with objects of any `Employee` derived class. Be careful not to confuse the general notion of an “interface” with the formal notion of a C# interface, the subject of Section 12.7. Each employee, regardless of the way his or her earnings are calculated, has a first name, a last name and a social security number, so those pieces of data appear in abstract base class `Employee`.

The following subsections implement the `Employee` class hierarchy. Section 12.5.1 implements abstract base class `Employee`. Sections 12.5.2–12.5.5 each implement one of the concrete classes. Section 12.5.6 implements a test app that builds objects of all these classes and processes those objects polymorphically.

### 12.5.1 Creating Abstract Base Class `Employee`

Class `Employee` (Fig. 12.4) provides methods `Earnings` and `ToString`, in addition to the auto-implemented properties that manipulate `Employee`'s data. An `Earnings` method certainly applies generically to all employees. But each earnings calculation depends on the employee's class. So we declare `Earnings` as abstract in base class `Employee`, because a default implementation does not make sense for that method—there's not enough information to determine what amount `Earnings` should return. Each derived class overrides `Earnings` with a specific implementation. To calculate an employee's earnings, the app assigns a reference to the employee's object to a base class `Employee` variable, then invokes the `Earnings` method on that variable. We maintain an array of `Employee` variables, each of which holds a reference to an `Employee` object (of course, there *cannot* be `Employee` objects because `Employee` is an *abstract* class—because of inheritance, however, all objects of all derived classes of `Employee` may nevertheless be thought of as `Employee` objects). The app iterates through the array and calls method `Earnings` for each `Employee` object. These

method calls are processed polymorphically. Including `Earnings` as an abstract method in `Employee` forces every directly derived *concrete* class of `Employee` to override `Earnings` with a method that performs an appropriate pay calculation.

Method `ToString` in class `Employee` returns a `string` containing the employee's first name, last name and social security number. Each derived class of `Employee` overrides method `ToString` to create a string representation of an object of that class containing the employee's type (e.g., "salaried employee:"), followed by the rest of the employee's information.

The diagram in Fig. 12.3 shows each of the five classes in the hierarchy down the left side and methods `Earnings` and `ToString` across the top. For each class, the diagram shows the desired results of each method. [Note: We do not list base class `Employee`'s properties because they're not overridden in any of the derived classes—each of these properties is inherited and used "as is" by each of the derived classes.]

|                                           | Earnings                                                                                                                                                                       | ToString                                                                                                                                                                                           |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>Employee</code>                     | <code>abstract</code>                                                                                                                                                          | <code>firstName lastName<br/>social security number: SSN</code>                                                                                                                                    |
| <code>Salaried-Employee</code>            | <code>weeklySalary</code>                                                                                                                                                      | <code>salaried employee: firstName lastName<br/>social security number: SSN<br/>weekly salary: weeklySalary</code>                                                                                 |
| <code>Hourly-Employee</code>              | $\begin{aligned} &\text{If } hours \leq 40 \\ &\quad wage * hours \\ &\text{If } hours > 40 \\ &\quad 40 * wage + \\ &\quad (hours - 40) * \\ &\quad wage * 1.5 \end{aligned}$ | <code>hourly employee: firstName lastName<br/>social security number: SSN<br/>hourly wage: wage<br/>hours worked: hours</code>                                                                     |
| <code>Commission-Employee</code>          | <code>commissionRate * grossSales</code>                                                                                                                                       | <code>commission employee: firstName lastName<br/>social security number: SSN<br/>gross sales: grossSales<br/>commission rate: commissionRate</code>                                               |
| <code>BasePlus-Commission-Employee</code> | <code>(commissionRate * grossSales) + baseSalary</code>                                                                                                                        | <code>base salaried commission employee:<br/>firstName lastName<br/>social security number: SSN<br/>gross sales: grossSales<br/>commission rate: commissionRate<br/>base salary: baseSalary</code> |

**Fig. 12.3** | Polymorphic interface for the `Employee` hierarchy classes.

### Class `Employee`

Let's consider class `Employee`'s declaration (Fig. 12.4). The class includes a constructor that takes the first name, last name and social security number as arguments (lines 15–20); properties with public `get` accessors for obtaining the first name, last name and social security number (lines 6, 9 and 12, respectively); method `ToString` (lines 23–27), which uses properties to return the string representation of the `Employee`; and abstract method

Earnings (line 30), which *must* be implemented by *concrete* derived classes. The Employee constructor does not validate the social security number in this example. Normally, such validation should be provided.

---

```

1 // Fig. 12.4: Employee.cs
2 // Employee abstract base class.
3 public abstract class Employee
4 {
5     // read-only property that gets employee's first name
6     public string FirstName { get; private set; }
7
8     // read-only property that gets employee's last name
9     public string LastName { get; private set; }
10
11    // read-only property that gets employee's social security number
12    public string SocialSecurityNumber { get; private set; }
13
14    // three-parameter constructor
15    public Employee( string first, string last, string ssn )
16    {
17        FirstName = first;
18        LastName = last;
19        SocialSecurityNumber = ssn;
20    } // end three-parameter Employee constructor
21
22    // return string representation of Employee object, using properties
23    public override string ToString()
24    {
25        return string.Format( "{0} {1}\nsocial security number: {2}",
26            FirstName, LastName, SocialSecurityNumber );
27    } // end method ToString
28
29    // abstract method overridden by derived classes
30    public abstract decimal Earnings(); // no implementation here
31 } // end abstract class Employee

```

---

**Fig. 12.4** | Employee abstract base class.

Why did we declare *Earnings* as an *abstract* method? As explained earlier, it simply does not make sense to provide an implementation of this method in class *Employee*. We cannot calculate the earnings for a *general Employee*—we first must know the *specific Employee* type to determine the appropriate earnings calculation. By declaring this method *abstract*, we indicate that each *concrete* derived class *must* provide an appropriate *Earnings* implementation and that an app will be able to use base-class *Employee* variables to invoke method *Earnings* polymorphically for *any* type of *Employee*.

### 12.5.2 Creating Concrete Derived Class SalariedEmployee

Class *SalariedEmployee* (Fig. 12.5) extends class *Employee* (line 5) and overrides *Earnings* (lines 34–37), which makes *SalariedEmployee* a concrete class. The class includes a constructor (lines 10–14) that takes a first name, a last name, a social security number and a weekly salary as arguments; property *WeeklySalary* (lines 17–31) to manipulate instance

variable `weeklySalary`, including a `set` accessor that ensures we assign only nonnegative values to `weeklySalary`; method `Earnings` (lines 34–37) to calculate a `SalariedEmployee`'s earnings; and method `ToString` (lines 40–44), which returns a `string` including the employee's type, namely, "salaried employee:", followed by employee-specific information produced by base class `Employee`'s `ToString` method and `SalariedEmployee`'s `WeeklySalary` property. Class `SalariedEmployee`'s constructor passes the first name, last name and social security number to the `Employee` constructor (line 11) via a constructor initializer to initialize the base class's data. Method `Earnings` overrides `Employee`'s abstract method `Earnings` to provide a concrete implementation that returns the `SalariedEmployee`'s weekly salary. If we do not implement `Earnings`, class `SalariedEmployee` must be declared `abstract`—otherwise, a compilation error occurs (and, of course, we want `SalariedEmployee` to be a concrete class).

---

```

1 // Fig. 12.5: SalariedEmployee.cs
2 // SalariedEmployee class that extends Employee.
3 using System;
4
5 public class SalariedEmployee : Employee
6 {
7     private decimal weeklySalary;
8
9     // four-parameter constructor
10    public SalariedEmployee( string first, string last, string ssn,
11        decimal salary ) : base( first, last, ssn )
12    {
13        WeeklySalary = salary; // validate salary via property
14    } // end four-parameter SalariedEmployee constructor
15
16    // property that gets and sets salaried employee's salary
17    public decimal WeeklySalary
18    {
19        get
20        {
21            return weeklySalary;
22        } // end get
23        set
24        {
25            if ( value >= 0 ) // validation
26                weeklySalary = value;
27            else
28                throw new ArgumentOutOfRangeException( "WeeklySalary",
29                    value, "WeeklySalary must be >= 0" );
30        } // end set
31    } // end property WeeklySalary
32
33    // calculate earnings; override abstract method Earnings in Employee
34    public override decimal Earnings()
35    {
36        return WeeklySalary;
37    } // end method Earnings

```

---

**Fig. 12.5** | `SalariedEmployee` class that extends `Employee`. (Part 1 of 2.)

---

```

38     // return string representation of SalariedEmployee object
39     public override string ToString()
40     {
41         return string.Format("salaried employee: {0}\n{1}: {2:C}",
42             base.ToString(), "weekly salary", WeeklySalary );
43     } // end method ToString
44 } // end class SalariedEmployee

```

**Fig. 12.5** | SalariedEmployee class that extends Employee. (Part 2 of 2.)

SalariedEmployee method `ToString` (lines 40–44) overrides `Employee`'s version. If class `SalariedEmployee` did *not* override `ToString`, `SalariedEmployee` would have inherited the `Employee` version. In that case, `SalariedEmployee`'s `ToString` method would simply return the employee's full name and social security number, which does not adequately represent a `SalariedEmployee`. To produce a complete string representation of a `SalariedEmployee`, the derived class's `ToString` method returns "salaried employee:", followed by the base-class `Employee`-specific information (i.e., first name, last name and social security number) obtained by invoking the base class's `ToString` (line 43)—this is a nice example of code reuse. The `string` representation of a `SalariedEmployee` also contains the employee's weekly salary, obtained by using the class's `WeeklySalary` property.

### 12.5.3 Creating Concrete Derived Class HourlyEmployee

Class `HourlyEmployee` (Fig. 12.6) also extends class `Employee` (line 5). The class includes a constructor (lines 11–17) that takes as arguments a first name, a last name, a social security number, an hourly wage and the number of hours worked. Lines 20–34 and 37–51 declare properties `Wage` and `Hours` for instance variables `wage` and `hours`, respectively. The `set` accessor in property `Wage` ensures that `wage` is nonnegative, and the `set` accessor in property `Hours` ensures that `hours` is in the range 0–168 (the total number of hours in a week) inclusive. The class overrides method `Earnings` (lines 54–60) to calculate an `HourlyEmployee`'s earnings and method `ToString` (lines 63–68) to return the employee's string representation. The `HourlyEmployee` constructor, similarly to the `SalariedEmployee` constructor, passes the first name, last name and social security number to the base-class `Employee` constructor (line 13) to initialize the base class's data. Also, method `ToString` calls base-class method `ToString` (line 67) to obtain the `Employee`-specific information (i.e., first name, last name and social security number).

---

```

1  // Fig. 12.6: HourlyEmployee.cs
2  // HourlyEmployee class that extends Employee.
3  using System;
4
5  public class HourlyEmployee : Employee
6  {
7      private decimal wage; // wage per hour
8      private decimal hours; // hours worked for the week
9

```

**Fig. 12.6** | HourlyEmployee class that extends Employee. (Part 1 of 3.)

```
10 // five-parameter constructor
11 public HourlyEmployee( string first, string last, string ssn,
12     decimal hourlyWage, decimal hoursWorked )
13     : base( first, last, ssn )
14 {
15     Wage = hourlyWage; // validate hourly wage via property
16     Hours = hoursWorked; // validate hours worked via property
17 } // end five-parameter HourlyEmployee constructor
18
19 // property that gets and sets hourly employee's wage
20 public decimal Wage
21 {
22     get
23     {
24         return wage;
25     } // end get
26     set
27     {
28         if ( value >= 0 ) // validation
29             wage = value;
30         else
31             throw new ArgumentException( "Wage",
32                 value, "Wage must be >= 0" );
33     } // end set
34 } // end property Wage
35
36 // property that gets and sets hourly employee's hours
37 public decimal Hours
38 {
39     get
40     {
41         return hours;
42     } // end get
43     set
44     {
45         if ( value >= 0 && value <= 168 ) // validation
46             hours = value;
47         else
48             throw new ArgumentException( "Hours",
49                 value, "Hours must be >= 0 and <= 168" );
50     } // end set
51 } // end property Hours
52
53 // calculate earnings; override Employee's abstract method Earnings()
54 public override decimal Earnings()
55 {
56     if ( Hours <= 40 ) // no overtime
57         return Wage * Hours;
58     else
59         return ( 40 * Wage ) + ( ( Hours - 40 ) * Wage * 1.5M );
60 } // end method Earnings
61
```

Fig. 12.6 | HourlyEmployee class that extends Employee. (Part 2 of 3.)

---

```

62     // return string representation of HourlyEmployee object
63     public override string ToString()
64     {
65         return string.Format(
66             "hourly employee: {0}\n{1}: {2:C}; {3}: {4:F2}",
67             base.ToString(), "hourly wage", Wage, "hours worked", Hours );
68     } // end method ToString
69 } // end class HourlyEmployee

```

---

**Fig. 12.6** | HourlyEmployee class that extends Employee. (Part 3 of 3.)

#### 12.5.4 Creating Concrete Derived Class CommissionEmployee

Class CommissionEmployee (Fig. 12.7) extends class Employee (line 5). The class includes a constructor (lines 11–16) that takes a first name, a last name, a social security number, a sales amount and a commission rate; properties (lines 19–33 and 36–50) for instance variables grossSales and commissionRate, respectively; method Earnings (lines 53–56) to calculate a CommissionEmployee's earnings; and method ToString (lines 59–64), which returns the employee's string representation. The CommissionEmployee's constructor also passes the first name, last name and social security number to the Employee constructor (line 12) to initialize Employee's data. Method ToString calls base-class method ToString (line 62) to obtain the Employee-specific information (i.e., first name, last name and social security number).

---

```

1 // Fig. 12.7: CommissionEmployee.cs
2 // CommissionEmployee class that extends Employee.
3 using System;
4
5 public class CommissionEmployee : Employee
6 {
7     private decimal grossSales; // gross weekly sales
8     private decimal commissionRate; // commission percentage
9
10    // five-parameter constructor
11    public CommissionEmployee( string first, string last, string ssn,
12        decimal sales, decimal rate ) : base( first, last, ssn )
13    {
14        GrossSales = sales; // validate gross sales via property
15        CommissionRate = rate; // validate commission rate via property
16    } // end five-parameter CommissionEmployee constructor
17
18    // property that gets and sets commission employee's gross sales
19    public decimal GrossSales
20    {
21        get
22        {
23            return grossSales;
24        } // end get
25        set
26        {

```

---

**Fig. 12.7** | CommissionEmployee class that extends Employee. (Part 1 of 2.)

```

27         if ( value >= 0 )
28             grossSales = value;
29         else
30             throw new ArgumentException(
31                 "GrossSales", value, "GrossSales must be >= 0" );
32     } // end set
33 } // end property GrossSales
34
35 // property that gets and sets commission employee's commission rate
36 public decimal CommissionRate
37 {
38     get
39     {
40         return commissionRate;
41     } // end get
42     set
43     {
44         if ( value > 0 && value < 1 )
45             commissionRate = value;
46         else
47             throw new ArgumentException( "CommissionRate",
48                 value, "CommissionRate must be > 0 and < 1" );
49     } // end set
50 } // end property CommissionRate
51
52 // calculate earnings; override abstract method Earnings in Employee
53 public override decimal Earnings()
54 {
55     return CommissionRate * GrossSales;
56 } // end method Earnings
57
58 // return string representation of CommissionEmployee object
59 public override string ToString()
60 {
61     return string.Format( "{0}: {1}\n{2}: {3:C}\n{4}: {5:F2}",
62         "commission employee", base.ToString(),
63         "gross sales", GrossSales, "commission rate", CommissionRate );
64 } // end method ToString
65 } // end class CommissionEmployee

```

**Fig. 12.7** | CommissionEmployee class that extends Employee. (Part 2 of 2.)

### 12.5.5 Creating Indirect Concrete Derived Class BasePlusCommissionEmployee

Class BasePlusCommissionEmployee (Fig. 12.8) extends class CommissionEmployee (line 5) and therefore is an *indirect* derived class of class Employee. Class BasePlusCommissionEmployee has a constructor (lines 10–15) that takes as arguments a first name, a last name, a social security number, a sales amount, a commission rate and a base salary. It then passes the first name, last name, social security number, sales amount and commission rate to the CommissionEmployee constructor (line 12) to initialize the base class's data. BasePlusCommissionEmployee also contains property BaseSalary (lines 19–33) to manipulate instance

variable `baseSalary`. Method `Earnings` (lines 36–39) calculates a `BasePlusCommissionEmployee`'s earnings. Line 38 in method `Earnings` calls base class `CommissionEmployee`'s `Earnings` method to calculate the commission-based portion of the employee's earnings. Again, this shows the benefits of code reuse. `BasePlusCommissionEmployee`'s `ToString` method (lines 42–46) creates a string representation of a `BasePlusCommissionEmployee` that contains "base-salaried", followed by the string obtained by invoking base class `CommissionEmployee`'s `ToString` method (another example of code reuse), then the base salary. The result is a string beginning with "base-salaried commission employee", followed by the rest of the `BasePlusCommissionEmployee`'s information. Recall that `CommissionEmployee`'s `ToString` method obtains the employee's first name, last name and social security number by invoking the `ToString` method of its base class (i.e., `Employee`)—a further demonstration of code reuse. `BasePlusCommissionEmployee`'s `ToString` initiates a *chain of method calls* that spans all three levels of the `Employee` hierarchy.

---

```

1 // Fig. 12.8: BasePlusCommissionEmployee.cs
2 // BasePlusCommissionEmployee class that extends CommissionEmployee.
3 using System;
4
5 public class BasePlusCommissionEmployee : CommissionEmployee
6 {
7     private decimal baseSalary; // base salary per week
8
9     // six-parameter constructor
10    public BasePlusCommissionEmployee( string first, string last,
11        string ssn, decimal sales, decimal rate, decimal salary )
12        : base( first, last, ssn, sales, rate )
13    {
14        BaseSalary = salary; // validate base salary via property
15    } // end six-parameter BasePlusCommissionEmployee constructor
16
17    // property that gets and sets
18    // base-salaried commission employee's base salary
19    public decimal BaseSalary
20    {
21        get
22        {
23            return baseSalary;
24        } // end get
25        set
26        {
27            if ( value >= 0 )
28                baseSalary = value;
29            else
30                throw new ArgumentException( "BaseSalary",
31                    value, "BaseSalary must be >= 0" );
32        } // end set
33    } // end property BaseSalary
34

```

---

**Fig. 12.8** | `BasePlusCommissionEmployee` class that extends `CommissionEmployee`. (Part 1 of 2.)

```

35  // calculate earnings; override method Earnings in CommissionEmployee
36  public override decimal Earnings()
37  {
38      return BaseSalary + base.Earnings();
39  } // end method Earnings
40
41  // return string representation of BasePlusCommissionEmployee object
42  public override string ToString()
43  {
44      return string.Format( "base-salaried {0}; base salary: {1:C}",
45          base.ToString(), BaseSalary );
46  } // end method ToString
47 } // end class BasePlusCommissionEmployee

```

**Fig. 12.8** | BasePlusCommissionEmployee class that extends CommissionEmployee. (Part 2 of 2.)

### 12.5.6 Polymorphic Processing, Operator *is* and Downcasting

To test our Employee hierarchy, the app in Fig. 12.9 creates an object of each of the four concrete classes SalariedEmployee, HourlyEmployee, CommissionEmployee and BasePlusCommissionEmployee. The app manipulates these objects, first via variables of each object's own type, then polymorphically, using an array of Employee variables. While processing the objects polymorphically, the app increases the base salary of each BasePlusCommissionEmployee by 10% (this, of course, requires determining the object's type at *execution* time). Finally, the app polymorphically determines and outputs the type of each object in the Employee array. Lines 10–20 create objects of each of the four concrete Employee derived classes. Lines 24–32 output the string representation and earnings of each of these objects. Each object's ToString method is called *implicitly* by WriteLine when the object is output as a string with format items.

#### Assigning Derived-Class Objects to Base-Class References

Line 35 declares employees and assigns it an array of four Employee variables. Lines 38–41 assign a SalariedEmployee object, an HourlyEmployee object, a CommissionEmployee object and a BasePlusCommissionEmployee object to employees[0], employees[1], employees[2] and employees[3], respectively. Each assignment is allowed, because a SalariedEmployee *is an* Employee, an HourlyEmployee *is an* Employee, a CommissionEmployee *is an* Employee and a BasePlusCommissionEmployee *is an* Employee. Therefore, we can assign the references of SalariedEmployee, HourlyEmployee, CommissionEmployee and BasePlusCommissionEmployee objects to base-class Employee variables, even though Employee is an *abstract* class.

```

1  // Fig. 12.9: PayrollSystemTest.cs
2  // Employee hierarchy test app.
3  using System;
4
5  public class PayrollSystemTest
6  {

```

**Fig. 12.9** | Employee hierarchy test app. (Part 1 of 4.)

```
7  public static void Main( string[] args )
8  {
9      // create derived-class objects
10     SalariedEmployee salariedEmployee =
11         new SalariedEmployee( "John", "Smith", "111-11-1111", 800.00M );
12     HourlyEmployee hourlyEmployee =
13         new HourlyEmployee( "Karen", "Price",
14             "222-22-2222", 16.75M, 40.0M );
15     CommissionEmployee commissionEmployee =
16         new CommissionEmployee( "Sue", "Jones",
17             "333-33-3333", 10000.00M, .06M );
18     BasePlusCommissionEmployee basePlusCommissionEmployee =
19         new BasePlusCommissionEmployee( "Bob", "Lewis",
20             "444-44-4444", 5000.00M, .04M, 300.00M );
21
22     Console.WriteLine( "Employees processed individually:\n" );
23
24     Console.WriteLine( "{0}\nearned: {1:C}\n",
25         salariedEmployee, salariedEmployee.Earnings() );
26     Console.WriteLine( "{0}\nearned: {1:C}\n",
27         hourlyEmployee, hourlyEmployee.Earnings() );
28     Console.WriteLine( "{0}\nearned: {1:C}\n",
29         commissionEmployee, commissionEmployee.Earnings() );
30     Console.WriteLine( "{0}\nearned: {1:C}\n",
31         basePlusCommissionEmployee,
32         basePlusCommissionEmployee.Earnings() );
33
34     // create four-element Employee array
35     Employee[] employees = new Employee[ 4 ];
36
37     // initialize array with Employees of derived types
38     employees[ 0 ] = salariedEmployee;
39     employees[ 1 ] = hourlyEmployee;
40     employees[ 2 ] = commissionEmployee;
41     employees[ 3 ] = basePlusCommissionEmployee;
42
43     Console.WriteLine( "Employees processed polymorphically:\n" );
44
45     // generically process each element in array employees
46     foreach ( Employee currentEmployee in employees )
47     {
48         Console.WriteLine( currentEmployee ); // invokes ToString
49
50         // determine whether element is a BasePlusCommissionEmployee
51         if ( currentEmployee is BasePlusCommissionEmployee )
52         {
53             // downcast Employee reference to
54             // BasePlusCommissionEmployee reference
55             BasePlusCommissionEmployee employee =
56                 ( BasePlusCommissionEmployee ) currentEmployee;
57
58             employee.BaseSalary *= 1.10M;
```

**Fig. 12.9** | Employee hierarchy test app. (Part 2 of 4.)

```
59         Console.WriteLine(
60             "new base salary with 10% increase is: {0:C}",
61             employee.BaseSalary );
62     } // end if
63
64     Console.WriteLine(
65         "earned {0:C}\n", currentEmployee.Earnings() );
66 } // end foreach
67
68 // get type name of each object in employees array
69 for ( int j = 0; j < employees.Length; j++ )
70     Console.WriteLine( "Employee {0} is a {1}", j,
71         employees[ j ].GetType() );
72 } // end Main
73 } // end class PayrollSystemTest
```

Employees processed individually:

```
salaried employee: John Smith
social security number: 111-11-1111
weekly salary: $800.00
earned: $800.00
```

```
hourly employee: Karen Price
social security number: 222-22-2222
hourly wage: $16.75; hours worked: 40.00
earned: $670.00
```

```
commission employee: Sue Jones
social security number: 333-33-3333
gross sales: $10,000.00
commission rate: 0.06
earned: $600.00
```

```
base-salaried commission employee: Bob Lewis
social security number: 444-44-4444
gross sales: $5,000.00
commission rate: 0.04; base salary: $300.00
earned: $500.00
```

Employees processed polymorphically:

```
salaried employee: John Smith
social security number: 111-11-1111
weekly salary: $800.00
earned $800.00
```

```
hourly employee: Karen Price
social security number: 222-22-2222
hourly wage: $16.75; hours worked: 40.00
earned $670.00
```

**Fig. 12.9** | Employee hierarchy test app. (Part 3 of 4.)

```

commission employee: Sue Jones
social security number: 333-33-3333
gross sales: $10,000.00
commission rate: 0.06
earned $600.00

base-salaried commission employee: Bob Lewis
social security number: 444-44-4444
gross sales: $5,000.00
commission rate: 0.04; base salary: $300.00
new base salary with 10% increase is: $330.00
earned $530.00

Employee 0 is a SalariedEmployee
Employee 1 is a HourlyEmployee
Employee 2 is a CommissionEmployee
Employee 3 is a BasePlusCommissionEmployee

```

**Fig. 12.9** | Employee hierarchy test app. (Part 4 of 4.)

### *Polymorphically Processing Employees*

Lines 46–66 iterate through array `employees` and invoke methods `ToString` and `Earnings` with `Employee` variable `currentEmployee`, which is assigned the reference to a different `Employee` during each iteration. The output illustrates that the appropriate methods for each class are indeed invoked. All calls to `virtual` methods `ToString` and `Earnings` are resolved at *execution* time, based on the type of the object to which `currentEmployee` refers. This process is known as **dynamic binding** or **late binding**. For example, line 48 *implicitly* invokes method `ToString` of the object to which `currentEmployee` refers. Only the methods of class `Employee` can be called via an `Employee` variable—and `Employee` includes class `object`'s methods, such as `ToString`. (Section 11.7 discussed the methods that all classes inherit from class `object`.) A base-class reference can be used to invoke only methods of the base class.

### *Giving BasePlusCommissionEmployees 10% Raises*

We perform special processing on `BasePlusCommissionEmployee` objects—as we encounter them, we increase their base salary by 10%. When processing objects polymorphically, we typically do not need to worry about the *specifics*, but to adjust the base salary, we do have to determine the specific type of each `Employee` object at execution time. Line 51 uses the `is` operator to determine whether a particular `Employee` object's type is `BasePlusCommissionEmployee`. The condition in line 51 is true if the object referenced by `currentEmployee` *is-a* `BasePlusCommissionEmployee`. This would also be true for any object of a `BasePlusCommissionEmployee` derived class (if there were any), because of the *is-a* relationship a derived class has with its base class. Lines 55–56 *downcast* `currentEmployee` from type `Employee` to type `BasePlusCommissionEmployee`—this cast is allowed only if the object has an *is-a* relationship with `BasePlusCommissionEmployee`. The condition at line 51 ensures that this is the case. This cast is *required* if we are to use derived class `BasePlusCommissionEmployee`'s `BaseSalary` property on the current `Employee` object—*attempting to invoke a derived-class-only method directly on a base class reference is a compilation error*.



### Common Programming Error 12.3

*Assigning a base-class variable to a derived-class variable (without an explicit downcast) is a compilation error.*



### Software Engineering Observation 12.3

*If at execution time the reference to a derived-class object has been assigned to a variable of one of its direct or indirect base classes, it's acceptable to cast the reference stored in that base-class variable back to a reference of the derived-class type. Before performing such a cast, use the `is` operator to ensure that the object is indeed an object of an appropriate derived-class type.*

When *downcasting* an object, an `InvalidCastException` (of namespace `System`) occurs if at execution time the object does not have an *is a* relationship with the type specified in the cast operator. An object can be cast only to its own type or to the type of one of its base classes. You can avoid a potential `InvalidCastException` by using the `as` operator to perform a downcast rather than a cast operator. For example, in the statement

```
BasePlusCommissionEmployee employee =  
    currentEmployee as BasePlusCommissionEmployee;
```

`employee` is assigned a reference to an object that *is a* `BasePlusCommissionEmployee`, or the value `null` if `currentEmployee` is not a `BasePlusCommissionEmployee`. You can then compare `employee` with `null` to determine whether the cast succeeded.

If the `is` expression in line 51 is true, the `if` statement (lines 51–62) performs the special processing required for the `BasePlusCommissionEmployee` object. Using `BasePlusCommissionEmployee` variable `employee`, line 58 accesses the derived-class-only property `BaseSalary` to retrieve and update the employee's base salary with the 10% raise.

Lines 64–65 invoke method `Earnings` on `currentEmployee`, which calls the appropriate derived-class object's `Earnings` method polymorphically. Obtaining the earnings of the `SalariedEmployee`, `HourlyEmployee` and `CommissionEmployee` polymorphically in lines 64–65 produces the same result as obtaining these employees' earnings individually in lines 24–29. However, the earnings amount obtained for the `BasePlusCommissionEmployee` in lines 64–65 is higher than that obtained in lines 30–32, due to the 10% increase in its base salary.

### *Every Object Knows Its Own Type*

Lines 69–71 display each employee's type as a string. Every object knows its own type and can access this information through method `GetType`, which all classes inherit from class `object`. Method `GetType` returns an object of class `Type` (of namespace `System`), which contains information about the object's type, including its class name, the names of its methods, and the name of its base class. Line 71 invokes method `GetType` on the object to get its runtime class (i.e., a `Type` object that represents the object's type). Then method `ToString` is *implicitly* invoked on the object returned by `GetType`. The `Type` class's `ToString` method returns the class name.

### *Avoiding Compilation Errors with Downcasting*

In the previous example, we avoid several compilation errors by *downcasting* an `Employee` variable to a `BasePlusCommissionEmployee` variable in lines 55–56. If we remove the cast operator (`BasePlusCommissionEmployee`) from line 56 and attempt to assign `Employee`

variable `currentEmployee` directly to `BasePlusCommissionEmployee` variable `employee`, we receive a “*Cannot implicitly convert type*” compilation error. This error indicates that the attempt to assign the reference of base-class object `currentEmployee` to derived-class variable `employee` is *not* allowed without an appropriate cast operator. The compiler prevents this assignment, because a `CommissionEmployee` is *not* a `BasePlusCommissionEmployee`—again, the *is-a* relationship applies only between the derived class and its base classes, not vice versa.

Similarly, if lines 58 and 61 use base-class variable `currentEmployee`, rather than derived-class variable `employee`, to use derived-class-only property `BaseSalary`, we receive an “*'Employee' does not contain a definition for 'BaseSalary'*” compilation error on each of these lines. *Attempting to invoke derived-class-only methods on a base-class reference is not allowed.* While lines 58 and 61 execute only if `is` in line 51 returns `true` to indicate that `currentEmployee` has been assigned a reference to a `BasePlusCommissionEmployee` object, we *cannot* attempt to use derived-class `BasePlusCommissionEmployee` property `BaseSalary` with base-class `Employee` reference `currentEmployee`. The compiler would generate errors in lines 58 and 61, because `BaseSalary` is not a base-class member and cannot be used with a base-class variable. Although the actual method that’s called depends on the object’s type at execution time, *a variable can be used to invoke only those methods that are members of that variable's type*, which the compiler verifies. Using a base-class `Employee` variable, we can invoke only methods and properties found in class `Employee`—methods `Earnings` and `ToString`, and properties `FirstName`, `LastName` and `SocialSecurityNumber`—and method methods inherited from class `object`.

### 12.5.7 Summary of the Allowed Assignments Between Base-Class and Derived-Class Variables

Now that you’ve seen a complete app that processes diverse derived-class objects polymorphically, we summarize what you can and cannot do with base-class and derived-class objects and variables. Although a derived-class object also *is a* base-class object, the two are nevertheless different. As discussed previously, derived-class objects can be treated as if they were base-class objects. However, the derived class can have additional derived-class-only members. For this reason, assigning a base-class reference to a derived-class variable is *not* allowed without an *explicit* cast—such an assignment would leave the derived-class members *undefined* for a base-class object.

We’ve discussed four ways to assign base-class and derived-class references to variables of base-class and derived-class types:

1. *Assigning a base-class reference to a base-class variable* is straightforward.
2. *Assigning a derived-class reference to a derived-class variable* is straightforward.
3. *Assigning a derived-class reference to a base-class variable* is safe, because the derived-class object is *an* object of its base class. However, this reference can be used to refer *only* to base-class members. If this code refers to derived-class-only members through the base-class variable, the compiler reports errors.
4. *Attempting to assign a base-class reference to a derived-class variable* is a compilation error. To avoid this error, the base-class reference must be cast to a derived-class type explicitly or must be converted using the `as` operator. At execution time, if the object to which the reference refers is *not* a derived-class object, an exception will

occur (unless you use the `as` operator). The `is` operator can be used to ensure that such a cast is performed *only* if the object is a derived-class object.

## 12.6 sealed Methods and Classes

Only methods declared `virtual`, `override` or `abstract` can be *overridden* in derived classes. A method declared `sealed` in a base class *cannot* be overridden in a derived class. Methods that are declared `private` are implicitly `sealed`, because it's impossible to override them in a derived class (though the derived class can declare a new method with the same signature as the `private` method in the base class). Methods that are declared `static` also are implicitly `sealed`, because `static` methods cannot be overridden either. A derived-class method declared both `override` and `sealed` can override a base-class method, but cannot be overridden in derived classes further down the inheritance hierarchy.

A `sealed` method's declaration can never change, so all derived classes use the same method implementation, and calls to `sealed` methods (and non-`virtual` methods) are resolved at *compile time*—this is known as **static binding**. Since the compiler knows that `sealed` methods cannot be overridden, it can often *optimize* code by removing calls to `sealed` methods and replacing them with the expanded code of their declarations at each method-call location—a technique known as **inlining the code**.



### Performance Tip 12.1

*The compiler can decide to inline a sealed method call and will do so for small, simple sealed methods. Inlining does not violate encapsulation or information hiding, but does improve performance, because it eliminates the overhead of making a method call.*

A class that's declared `sealed` *cannot* be a base class (i.e., a class cannot extend a `sealed` class). All methods in a `sealed` class are implicitly `sealed`. Class `string` is a `sealed` class. This class cannot be extended, so apps that use `strings` can rely on the functionality of `string` objects as specified in the Framework Class Library.



### Common Programming Error 12.4

*Attempting to declare a derived class of a sealed class is a compilation error.*

## 12.7 Case Study: Creating and Using Interfaces

Our next example (Figs. 12.11–12.15) reexamines the payroll system of Section 12.5. Suppose that the company involved wishes to perform several accounting operations in a single accounts-payable app—in addition to calculating the payroll earnings that must be paid to each employee, the company must also calculate the payment due on each of several invoices (i.e., bills for goods purchased). Though applied to unrelated things (i.e., employees and invoices), both operations have to do with calculating some kind of payment amount. For an employee, the payment refers to the employee's earnings. For an invoice, the payment refers to the total cost of the goods listed on the invoice. Can we calculate such different things as the payments due for employees and invoices polymorphically in a single app? Is there a capability that requires that *unrelated* classes implement a set of common methods (e.g., a method that calculates a payment amount)? *Interfaces* offer exactly this capability.

### **Standardized Interactions**

Interfaces define and standardize the ways in which people and systems can interact with one another. For example, the controls on a radio serve as an interface between a radio's users and its internal components. The controls allow users to perform a limited set of operations (e.g., changing the station, adjusting the volume, choosing between AM and FM), and different radios may implement the controls in different ways (e.g., using push buttons, dials, voice commands). The interface specifies *what* operations a radio must permit users to perform but does not specify *how* they're performed. Similarly, the interface between a driver and a car with a manual transmission includes the steering wheel, the gear shift, the clutch pedal, the gas pedal and the brake pedal. This same interface is found in nearly all manual-transmission cars, enabling someone who knows how to drive one particular manual-transmission car to drive just about any other. The components of each car may look a bit different, but the *general* purpose is the same—to allow people to drive the car.

### **Interfaces in Software**

Software objects also communicate via interfaces. A C# interface describes a set of methods and properties that can be called on an object—to tell it, for example, to perform some task or return some piece of information. The next example introduces an interface named `IPayable` that describes the functionality of any object that must be capable of being paid and thus must offer a method to determine the proper payment amount due. An **interface declaration** begins with the keyword **interface** and can contain only abstract methods, abstract properties, abstract indexers (not covered in this book) and abstract events (events are discussed in Chapter 14, Graphical User Interfaces with Windows Forms: Part 1.) All interface members are *implicitly* declared both `public` and `abstract`. In addition, each interface can extend one or more other interfaces to create a more elaborate interface that other classes can implement.



#### **Common Programming Error 12.5**

*It's a compilation error to declare an interface member `public` or `abstract` explicitly, because they're redundant in interface-member declarations. It's also a compilation error to specify any implementation details, such as concrete method declarations, in an interface.*

### **Implementing an Interface**

To use an interface, a class must specify that it **implements** the interface by listing the interface after the colon (:) in the class declaration. This is the *same* syntax used to indicate inheritance from a base class. A concrete class implementing the interface must declare each member of the interface with the signature specified in the interface declaration. A class that implements an interface but does *not* implement all its members is an abstract class—it must be declared `abstract` and must contain an `abstract` declaration for each unimplemented member of the interface. Implementing an interface is like signing a contract with the compiler that states, “I will provide an implementation for all the members specified by the interface, or I will declare them `abstract`.”



#### **Common Programming Error 12.6**

*Failing to define or declare any member of an interface in a class that implements the interface results in a compilation error.*

### **Common Methods for Unrelated Classes**

An interface is typically used when *unrelated* classes need to *share* common methods. This allows objects of unrelated classes to be processed polymorphically—objects of classes that implement the same interface can respond to the *same* method calls. You can create an interface that describes the desired functionality, then implement this interface in any classes requiring that functionality. For example, in the accounts-payable app developed in this section, we implement interface `IPayable` in any class that must be able to calculate a payment amount (e.g., `Employee`, `Invoice`).

### **Interfaces vs. Abstract Classes**

An interface often is used in place of an *abstract* class when there's no default implementation to inherit—that is, no fields and no default method implementations. Like abstract classes, interfaces are typically `public` types, so they're normally declared in files by themselves with the same name as the interface and the `.cs` file-name extension.

### **12.7.1 Developing an IPayable Hierarchy**

To build an app that can determine payments for employees and invoices alike, we first create an interface named `IPayable`. Interface `IPayable` contains method `GetPaymentAmount` that returns a decimal amount to be paid for an object of any class that implements the interface. Method `GetPaymentAmount` is a general-purpose version of method `Earnings` of the `Employee` hierarchy—method `Earnings` calculates a payment amount specifically for an `Employee`, while `GetPaymentAmount` can be applied to a broad range of *unrelated* objects. After declaring interface `IPayable`, we introduce class `Invoice`, which implements interface `IPayable`. We then modify class `Employee` such that it also implements interface `IPayable`. Finally, we update `Employee` derived class `SalariedEmployee` to “fit” into the `IPayable` hierarchy (i.e., we rename `SalariedEmployee` method `Earnings` as `GetPaymentAmount`).



#### **Good Programming Practice 12.1**

*By convention, the name of an interface begins with I. This helps distinguish interfaces from classes, improving code readability.*



#### **Good Programming Practice 12.2**

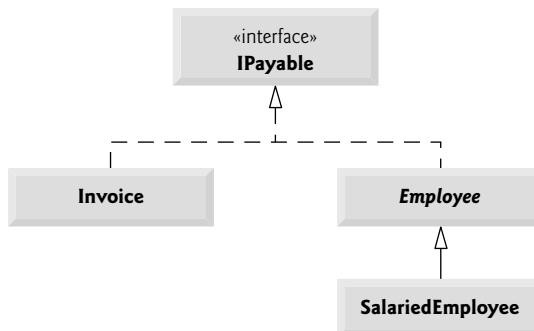
*When declaring a method in an interface, choose a name that describes the method's purpose in a general manner, because the method may be implemented by a broad range of unrelated classes.*

Classes `Invoice` and `Employee` both represent things for which the company must be able to calculate a payment amount. Both classes implement `IPayable`, so an app can invoke method `GetPaymentAmount` on `Invoice` objects and `Employee` objects alike. This enables the polymorphic processing of `Invoices` and `Employees` required for our company's accounts-payable app.

### **UML Diagram Containing an Interface**

The UML class diagram in Fig. 12.10 shows the interface and class hierarchy used in our accounts-payable app. The hierarchy begins with interface `IPayable`. The UML distinguishes an interface from a class by placing the word “interface” in guillemets (« and »)

above the interface name. The UML expresses the relationship between a class and an interface through a **realization**. A class is said to “realize,” or implement, an interface. A class diagram models a realization as a dashed arrow with a *hollow arrowhead* pointing from the implementing class to the interface. The diagram in Fig. 12.10 indicates that classes `Invoice` and `Employee` each realize (i.e., implement) interface `IPayable`. As in the class diagram of Fig. 12.2, class `Employee` appears in italics, indicating that it’s an abstract class. Concrete class `SalariedEmployee` extends `Employee` and inherits its base class’s realization relationship with interface `IPayable`.



**Fig. 12.10** | `IPayable` interface and class hierarchy UML class diagram.

### 12.7.2 Declaring Interface `IPayable`

The declaration of interface `IPayable` begins in Fig. 12.11 at line 3. Interface `IPayable` contains `public abstract` method `GetPaymentAmount` (line 5). The method cannot be *explicitly* declared `public` or `abstract`. Interfaces can have *any* number of members and interface methods can have parameters.

---

```

1 // Fig. 12.11: IPayable.cs
2 // IPayable interface declaration.
3 public interface IPayable
4 {
5     decimal GetPaymentAmount(); // calculate payment; no implementation
6 } // end interface IPayable
  
```

---

**Fig. 12.11** | `IPayable` interface declaration.

### 12.7.3 Creating Class `Invoice`

We now create class `Invoice` (Fig. 12.12) to represent a simple invoice that contains billing information for one kind of part. The class contains properties `PartNumber` (line 11), `PartDescription` (line 14), `Quantity` (lines 27–41) and `PricePerItem` (lines 44–58) that indicate the part number, the description of the part, the quantity of the part ordered and the price per item. Class `Invoice` also contains a constructor (lines 17–24) and a `ToString` method (lines 61–67) that returns a string representation of an `Invoice` object. The set accessors of properties `Quantity` and `PricePerItem` ensure that `quantity` and `pricePerItem` are assigned only nonnegative values.

```
1 // Fig. 12.12: Invoice.cs
2 // Invoice class implements IPayable.
3 using System;
4
5 public class Invoice : IPayable
6 {
7     private int quantity;
8     private decimal pricePerItem;
9
10    // property that gets and sets the part number on the invoice
11    public string PartNumber { get; set; }
12
13    // property that gets and sets the part description on the invoice
14    public string PartDescription { get; set; }
15
16    // four-parameter constructor
17    public Invoice( string part, string description, int count,
18                    decimal price )
19    {
20        PartNumber = part;
21        PartDescription = description;
22        Quantity = count; // validate quantity via property
23        PricePerItem = price; // validate price per item via property
24    } // end four-parameter Invoice constructor
25
26    // property that gets and sets the quantity on the invoice
27    public int Quantity
28    {
29        get
30        {
31            return quantity;
32        } // end get
33        set
34        {
35            if ( value >= 0 ) // validate quantity
36                quantity = value;
37            else
38                throw new ArgumentOutOfRangeException( "Quantity",
39                                         value, "Quantity must be >= 0" );
40        } // end set
41    } // end property Quantity
42
43    // property that gets and sets the price per item
44    public decimal PricePerItem
45    {
46        get
47        {
48            return pricePerItem;
49        } // end get
50        set
51        {
52            if ( value >= 0 ) // validate price
53                quantity = value;
```

Fig. 12.12 | Invoice class implements IPayable. (Part I of 2.)

---

```

54         else
55             throw new ArgumentOutOfRangeException( "PricePerItem",
56                                         value, "PricePerItem must be >= 0" );
57     } // end set
58 } // end property PricePerItem
59
60 // return string representation of Invoice object
61 public override string ToString()
62 {
63     return string.Format(
64         "{0}: \n{1}: {2} ({3}) \n{4}: {5} \n{6}: {7:C}",
65         "invoice", "part number", PartNumber, PartDescription,
66         "quantity", Quantity, "price per item", PricePerItem );
67 } // end method ToString
68
69 // method required to carry out contract with interface IPayable
70 public decimal GetPaymentAmount()
71 {
72     return Quantity * PricePerItem; // calculate total cost
73 } // end method GetPaymentAmount
74 } // end class Invoice

```

---

**Fig. 12.12** | Invoice class implements IPayable. (Part 2 of 2.)

Line 5 indicates that class `Invoice` implements interface `IPayable`. Like all classes, class `Invoice` also implicitly inherits from class `object`. *C# does not allow derived classes to inherit from more than one base class, but it does allow a class to inherit from a base class and implement any number of interfaces.* All objects of a class that implement multiple interfaces have the *is-a* relationship with each implemented interface type. To implement more than one interface, use a comma-separated list of interface names after the colon (:) in the class declaration, as in:

```
public class ClassName : BaseClassName, FirstInterface, SecondInterface, ...
```

When a class inherits from a base class and implements one or more interfaces, the class declaration *must* list the base-class name *before* any interface names.

Class `Invoice` implements the one method in interface `IPayable`—method `GetPaymentAmount` is declared in lines 70–73. The method calculates the amount required to pay the invoice. The method multiplies the values of `quantity` and `pricePerItem` (obtained through the appropriate properties) and returns the result (line 72). This method satisfies the implementation requirement for the method in interface `IPayable`—we've fulfilled the *interface contract* with the compiler.

#### 12.7.4 Modifying Class Employee to Implement Interface IPayable

We now modify class `Employee` to implement interface `IPayable`. Figure 12.13 contains the modified `Employee` class. This class declaration is identical to that of Fig. 12.4 with two exceptions. First, line 3 of Fig. 12.13 indicates that class `Employee` now implements interface `IPayable`. Because of this, we renamed `Earnings` to `GetPaymentAmount` throughout the `Employee` hierarchy. As with method `Earnings` in Fig. 12.4, however, it does not make sense to implement method `GetPaymentAmount` in class `Employee`, because we cannot calculate the

earnings payment owed to a *general* Employee—first, we must know the *specific* type of Employee. In Fig. 12.4, we declared method `Earnings` as abstract for this reason, and as a result, class `Employee` had to be declared abstract. This forced each Employee derived class to override `Earnings` with a concrete implementation. [Note: Though we renamed `Earnings` to `GetPaymentAmount`, in class `Employee` we could have defined `GetPaymentAmount` and had it call `Earnings`. Then the other Employee hierarchy classes would not need to change.]

---

```

1 // Fig. 12.13: Employee.cs
2 // Employee abstract base class.
3 public abstract class Employee : IPayable
4 {
5     // read-only property that gets employee's first name
6     public string FirstName { get; private set; }
7
8     // read-only property that gets employee's last name
9     public string LastName { get; private set; }
10
11    // read-only property that gets employee's social security number
12    public string SocialSecurityNumber { get; private set; }
13
14    // three-parameter constructor
15    public Employee( string first, string last, string ssn )
16    {
17        FirstName = first;
18        LastName = last;
19        SocialSecurityNumber = ssn;
20    } // end three-parameter Employee constructor
21
22    // return string representation of Employee object
23    public override string ToString()
24    {
25        return string.Format( "{0} {1}\nsocial security number: {2}",
26            FirstName, LastName, SocialSecurityNumber );
27    } // end method ToString
28
29    // Note: We do not implement IPayable method GetPaymentAmount here, so
30    // this class must be declared abstract to avoid a compilation error.
31    public abstract decimal GetPaymentAmount();
32 } // end abstract class Employee

```

---

**Fig. 12.13** | Employee abstract base class.

In Fig. 12.13, we handle this situation the same way. Recall that when a class implements an interface, the class makes a contract with the compiler stating that the class either will implement *each* of the methods in the interface *or* will declare them abstract. If the latter option is chosen, we must also declare the class abstract. As we discussed in Section 12.4, any concrete derived class of the abstract class must implement the abstract methods of the base class. If the derived class does not do so, it too must be declared abstract. As indicated by the comments in lines 29–30 of Fig. 12.13, class `Employee` does not implement method `GetPaymentAmount`, so the class is declared abstract.

### 12.7.5 Modifying Class SalariedEmployee for Use with IPayable

Figure 12.14 contains a modified version of class SalariedEmployee that extends Employee and implements method GetPaymentAmount. This version of SalariedEmployee is identical to that of Fig. 12.5 with the exception that the version here implements method GetPaymentAmount (lines 35–38) instead of method Earnings. The two methods contain the *same* functionality but have different names. Recall that the IPayable version of the method has a more general name to be applicable to possibly disparate classes. The remaining Employee derived classes (e.g., HourlyEmployee, CommissionEmployee and BasePlusCommissionEmployee) also must be modified to contain method GetPaymentAmount in place of Earnings to reflect the fact that Employee now implements IPayable. We leave these modifications as an exercise and use only SalariedEmployee in our test app in this section.

---

```

1 // Fig. 12.14: SalariedEmployee.cs
2 // SalariedEmployee class that extends Employee.
3 using System;
4
5 public class SalariedEmployee : Employee
6 {
7     private decimal weeklySalary;
8
9     // four-parameter constructor
10    public SalariedEmployee( string first, string last, string ssn,
11        decimal salary ) : base( first, last, ssn )
12    {
13        WeeklySalary = salary; // validate salary via property
14    } // end four-parameter SalariedEmployee constructor
15
16    // property that gets and sets salaried employee's salary
17    public decimal WeeklySalary
18    {
19        get
20        {
21            return weeklySalary;
22        } // end get
23        set
24        {
25            if ( value >= 0 ) // validation
26                weeklySalary = value;
27            else
28                throw new ArgumentOutOfRangeException( "WeeklySalary",
29                    value, "WeeklySalary must be >= 0" );
30        } // end set
31    } // end property WeeklySalary
32
33    // calculate earnings; implement interface IPayable method
34    // that was abstract in base class Employee
35    public override decimal GetPaymentAmount()
36    {
37        return WeeklySalary;
38    } // end method GetPaymentAmount

```

**Fig. 12.14** | SalariedEmployee class that extends Employee. (Part I of 2.)

```

39     // return string representation of SalariedEmployee object
40     public override string ToString()
41     {
42         return string.Format("salaried employee: {0}\n{1}: {2:C}",
43             base.ToString(), "weekly salary", WeeklySalary );
44     } // end method ToString
45 } // end class SalariedEmployee

```

**Fig. 12.14** | SalariedEmployee class that extends Employee. (Part 2 of 2.)

When a class implements an interface, the same *is-a* relationship provided by inheritance applies. Class Employee implements IPayable, so we can say that an Employee *is an* IPayable, as are any classes that extend Employee. As such, SalariedEmployee objects are IPayable objects. An object of a class that implements an interface may be thought of as an object of the interface type. Objects of any classes derived from the class that implements the interface can also be thought of as objects of the interface type. Thus, just as we can assign the reference of a SalariedEmployee object to a base-class Employee variable, we can assign the reference of a SalariedEmployee object to an interface IPayable variable. Invoice implements IPayable, so an Invoice object also *is an* IPayable object, and we can assign the reference of an Invoice object to an IPayable variable.



#### Software Engineering Observation 12.4

*Inheritance and interfaces are similar in their implementation of the is-a relationship. An object of a class that implements an interface may be thought of as an object of that interface type. An object of any derived classes of a class that implements an interface also can be thought of as an object of the interface type.*



#### Software Engineering Observation 12.5

*The is-a relationship that exists between base classes and derived classes, and between interfaces and the classes that implement them, holds when passing an object to a method. When a method parameter receives an argument of a base class or interface type, the method polymorphically processes the object received as an argument.*

### 12.7.6 Using Interface IPayable to Process Invoices and Employees Polymorphically

PayableInterfaceTest (Fig. 12.15) illustrates that interface IPayable can be used to process a set of Invoices and Employees polymorphically in a single app. Line 10 declares payableObjects and assigns it an array of four IPayable variables. Lines 13–14 assign the references of Invoice objects to the first two elements of payableObjects. Lines 15–18 assign the references of SalariedEmployee objects to the remaining two elements of payableObjects. These assignments are allowed because an Invoice *is an* IPayable, a SalariedEmployee *is an* Employee and an Employee *is an* IPayable. Lines 24–29 use a foreach statement to process each IPayable object in payableObjects polymorphically, displaying the object as a string, along with the payment due. Lines 27–28 implicitly invokes method ToString off an IPayable interface reference, even though ToString is not declared in interface IPayable—all references (including those of interface types) refer to

objects that extend `object` and therefore have a `ToString` method. Line 28 invokes `IPayable` method `GetPaymentAmount` to obtain the payment amount for each object in `payableObjects`, regardless of the actual type of the object. The output reveals that the method calls in lines 27–28 invoke the appropriate class's implementation of methods `ToString` and `GetPaymentAmount`. For instance, when `currentPayable` refers to an `Invoice` during the first iteration of the `foreach` loop, class `Invoice`'s `ToString` and `GetPaymentAmount` methods execute.



### Software Engineering Observation 12.6

*All methods of class `object` can be called by using a reference of an interface type—the reference refers to an object, and all objects inherit the methods of class `object`.*

```

1 // Fig. 12.15: PayableInterfaceTest.cs
2 // Tests interface IPayable with disparate classes.
3 using System;
4
5 public class PayableInterfaceTest
6 {
7     public static void Main( string[] args )
8     {
9         // create four-element IPayable array
10        IPayable[] payableObjects = new IPayable[ 4 ];
11
12        // populate array with objects that implement IPayable
13        payableObjects[ 0 ] = new Invoice( "01234", "seat", 2, 375.00M );
14        payableObjects[ 1 ] = new Invoice( "56789", "tire", 4, 79.95M );
15        payableObjects[ 2 ] = new SalariedEmployee( "John", "Smith",
16            "111-11-1111", 800.00M );
17        payableObjects[ 3 ] = new SalariedEmployee( "Lisa", "Barnes",
18            "888-88-8888", 1200.00M );
19
20        Console.WriteLine(
21            "Invoices and Employees processed polymorphically:\n" );
22
23        // generically process each element in array payableObjects
24        foreach ( var currentPayable in payableObjects )
25        {
26            // output currentPayable and its appropriate payment amount
27            Console.WriteLine( "{0}\npayment due: {1:C}\n",
28                currentPayable, currentPayable.GetPaymentAmount() );
29        } // end foreach
30    } // end Main
31 } // end class PayableInterfaceTest

```

Invoices and Employees processed polymorphically:

```

invoice:
part number: 01234 (seat)
quantity: 2
price per item: $375.00
payment due: $750.00

```

**Fig. 12.15** | Tests interface `IPayable` with disparate classes. (Part I of 2.)

```

invoice:
part number: 56789 (tire)
quantity: 4
price per item: $79.95
payment due: $319.80

salaried employee: John Smith
social security number: 111-11-1111
weekly salary: $800.00
payment due: $800.00

salaried employee: Lisa Barnes
social security number: 888-88-8888
weekly salary: $1,200.00
payment due: $1,200.00

```

**Fig. 12.15** | Tests interface IPayable with disparate classes. (Part 2 of 2.)

### 12.7.7 Common Interfaces of the .NET Framework Class Library

In this section, we overview several common interfaces defined in the .NET Framework Class Library. These interfaces are implemented and used in the same manner as those you create (e.g., interface `IPayable` in Section 12.7.2). The Framework Class Library's interfaces enable you to extend many important aspects of C# with your own classes. Figure 12.16 overviews several commonly used Framework Class Library interfaces.

| Interface                | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>IComparable</code> | As you learned in Chapter 3, C# contains several comparison operators (e.g., <code>&lt;</code> , <code>&lt;=</code> , <code>&gt;</code> , <code>&gt;=</code> , <code>==</code> , <code>!=</code> ) that allow you to compare simple-type values. In Section 12.8 you'll see that these operators can be defined to compare two objects. Interface <code>IComparable</code> can also be used to allow objects of a class that implements the interface to be compared to one another. The interface contains one method, <code>CompareTo</code> , that compares the object that calls the method to the object passed as an argument to the method. Classes must implement <code>CompareTo</code> to return a value indicating whether the object on which it's invoked is less than (negative integer return value), equal to (0 return value) or greater than (positive integer return value) the object passed as an argument, using any criteria you specify. For example, if class <code>Employee</code> implements <code>IComparable</code> , its <code>CompareTo</code> method could compare <code>Employee</code> objects by their earnings amounts. Interface <code>IComparable</code> is commonly used for ordering objects in a collection such as an array. We use <code>IComparable</code> in Chapter 20, Generics, and Chapter 21, Collections. |
| <code>IComponent</code>  | Implemented by any class that represents a component, including Graphical User Interface (GUI) controls (such as buttons or labels). Interface <code>IComponent</code> defines the behaviors that components must implement. We discuss <code>IComponent</code> and many GUI controls that implement this interface in Chapter 14, Graphical User Interfaces with Windows Forms: Part 1, and Chapter 15, Graphical User Interfaces with Windows Forms: Part 2.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

**Fig. 12.16** | Common interfaces of the .NET Framework Class Library. (Part 1 of 2.)

| Interface   | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IDisposable | Implemented by classes that must provide an explicit mechanism for <i>releasing</i> resources. Some resources can be used by only one program at a time. In addition, some resources, such as files on disk, are unmanaged resources that, unlike memory, cannot be released by the garbage collector. Classes that implement interface IDisposable provide a Dispose method that can be called to explicitly release resources. We discuss IDisposable briefly in Chapter 13, Exception Handling: A Deeper Look. You can learn more about this interface at <a href="http://msdn.microsoft.com/en-us/library/system.idisposable.aspx">msdn.microsoft.com/en-us/library/system.idisposable.aspx</a> . The MSDN article <i>Implementing a Dispose Method</i> at <a href="http://msdn.microsoft.com/en-us/library/fs2xkftw.aspx">msdn.microsoft.com/en-us/library/fs2xkftw.aspx</a> discusses the proper implementation of this interface in your classes. |
| IEnumerator | Used for iterating through the elements of a <i>collection</i> (such as an array) one element at a time. Interface IEnumerator contains method MoveNext to move to the next element in a collection, method Reset to move to the position before the first element and property Current to return the object at the current location. We use IEnumerator in Chapter 21.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

**Fig. 12.16** | Common interfaces of the .NET Framework Class Library. (Part 2 of 2.)

## 12.8 Operator Overloading

Object manipulations are accomplished by sending *messages* (in the form of method calls) to the objects. This method-call notation is cumbersome for certain kinds of classes, especially mathematical classes. For these classes, it would be convenient to use C#'s rich set of built-in operators to specify object manipulations. In this section, we show how to enable these operators to work with class objects—via a process called **operator overloading**.

You can overload most operators to make them sensitive to the context in which they're used. Some operators are overloaded more frequently than others, especially the various arithmetic operators, such as + and -, where operator notation often is more natural. Figures 12.17 and 12.18 provide an example of using operator overloading with a ComplexNumber class. For a list of overloadable operators, see [msdn.microsoft.com/en-us/library/8edha89s.aspx](http://msdn.microsoft.com/en-us/library/8edha89s.aspx).

### Class ComplexNumber

Class ComplexNumber (Fig. 12.17) overloads the plus (+), minus (-) and multiplication (\*) operators to enable programs to add, subtract and multiply instances of class ComplexNumber using common mathematical notation. Lines 9 and 12 define properties for the Real and Imaginary components of the complex number.

---

```

1 // Fig. 12.17: ComplexNumber.cs
2 // Class that overloads operators for adding, subtracting
3 // and multiplying complex numbers.
4 using System;

```

---

**Fig. 12.17** | Class that overloads operators for adding, subtracting and multiplying complex numbers. (Part 1 of 2.)

```

5  public class ComplexNumber
6  {
7      // read-only property that gets the real component
8      public double Real { get; private set; }
9
10     // read-only property that gets the imaginary component
11     public double Imaginary { get; private set; }
12
13     // constructor
14     public ComplexNumber( double a, double b )
15     {
16         Real = a;
17         Imaginary = b;
18     } // end constructor
19
20     // return string representation of ComplexNumber
21     public override string ToString()
22     {
23         return string.Format( "{0} {1} {2}i",
24             Real, ( Imaginary < 0 ? "-" : "+" ), Math.Abs( Imaginary ) );
25     } // end method ToString
26
27     // overload the addition operator
28     public static ComplexNumber operator+
29     {
30         ComplexNumber x, ComplexNumber y
31     }
32         return new ComplexNumber( x.Real + y.Real,
33             x.Imaginary + y.Imaginary );
34     } // end operator +
35
36     // overload the subtraction operator
37     public static ComplexNumber operator-
38     {
39         ComplexNumber x, ComplexNumber y
40     }
41         return new ComplexNumber( x.Real - y.Real,
42             x.Imaginary - y.Imaginary );
43     } // end operator -
44
45     // overload the multiplication operator
46     public static ComplexNumber operator*
47     {
48         ComplexNumber x, ComplexNumber y
49     }
50         return new ComplexNumber(
51             x.Real * y.Real - x.Imaginary * y.Imaginary,
52             x.Real * y.Imaginary + y.Real * x.Imaginary );
53     } // end operator *
54 } // end class ComplexNumber

```

**Fig. 12.17** | Class that overloads operators for adding, subtracting and multiplying complex numbers. (Part 2 of 2.)

Lines 29–34 overload the plus operator (+) to perform addition of ComplexNumbers. Keyword **operator**, followed by an operator symbol, indicates that a method overloads the

specified operator. Methods that overload binary operators must take two arguments. The *first* argument is the *left* operand, and the *second* argument is the *right* operand. Class `ComplexNumber`'s overloaded plus operator takes two `ComplexNumber` references as arguments and returns a `ComplexNumber` that represents the sum of the arguments. This method is marked `public` and `static`, which is required for overloaded operators. The body of the method (lines 32–33) performs the addition and returns the result as a new `ComplexNumber`. Notice that we do *not* modify the contents of either of the original operands passed as arguments `x` and `y`. This matches our intuitive sense of how this operator should behave—adding two numbers does not modify either of the original numbers. Lines 37–51 provide similar overloaded operators for subtracting and multiplying `ComplexNumbers`.



### Software Engineering Observation 12.7

*Overload operators to perform the same function or similar functions on class objects as the operators perform on objects of simple types. Avoid nonintuitive use of operators.*



### Software Engineering Observation 12.8

*At least one parameter of an overloaded operator method must be a reference to an object of the class in which the operator is overloaded. This prevents you from changing how operators work on simple types.*

#### *Class ComplexNumber*

Class `ComplexTest` (Fig. 12.18) demonstrates the overloaded `ComplexNumber` operators `+`, `-` and `*`. Lines 14–27 prompt the user to enter two complex numbers, then use this input to create two `ComplexNumbers` and assign them to variables `x` and `y`.

---

```

1 // Fig. 12.18: ComplexTest.cs
2 // Overloading operators for complex numbers.
3 using System;
4
5 public class ComplexTest
6 {
7     public static void Main( string[] args )
8     {
9         // declare two variables to store complex numbers
10        // to be entered by user
11        ComplexNumber x, y;
12
13        // prompt the user to enter the first complex number
14        Console.Write( "Enter the real part of complex number x: " );
15        double realPart = Convert.ToDouble( Console.ReadLine() );
16        Console.Write(
17            "Enter the imaginary part of complex number x: " );
18        double imaginaryPart = Convert.ToDouble( Console.ReadLine() );
19        x = new ComplexNumber( realPart, imaginaryPart );
20
21        // prompt the user to enter the second complex number
22        Console.Write( "\nEnter the real part of complex number y: " );
23        realPart = Convert.ToDouble( Console.ReadLine() );

```

---

**Fig. 12.18** | Overloading operators for complex numbers. (Part I of 2.)

```

24     Console.WriteLine(
25         "Enter the imaginary part of complex number y: ");
26     imaginaryPart = Convert.ToDouble( Console.ReadLine() );
27     y = new ComplexNumber( realPart, imaginaryPart );
28
29     // display the results of calculations with x and y
30     Console.WriteLine();
31     Console.WriteLine( "{0} + {1} = {2}", x, y, x + y );
32     Console.WriteLine( "{0} - {1} = {2}", x, y, x - y );
33     Console.WriteLine( "{0} * {1} = {2}", x, y, x * y );
34 } // end method Main
35 } // end class ComplexTest

```

Enter the real part of complex number x: 2  
 Enter the imaginary part of complex number x: 4

Enter the real part of complex number y: 4  
 Enter the imaginary part of complex number y: -2

$(2 + 4i) + (4 - 2i) = (6 + 2i)$   
 $(2 + 4i) - (4 - 2i) = (-2 + 6i)$   
 $(2 + 4i) * (4 - 2i) = (16 + 12i)$

**Fig. 12.18** | Overloading operators for complex numbers. (Part 2 of 2.)

Lines 31–33 add, subtract and multiply x and y with the overloaded operators, then output the results. In line 31, we perform the addition by using the plus operator with `ComplexNumber` operands x and y. Without operator overloading, the expression `x + y` wouldn't make sense—the compiler wouldn't know how two objects of class `ComplexNumber` should be added. This expression makes sense here because we've defined the plus operator for two `ComplexNumbers` in lines 29–34 of Fig. 12.17. When the two `ComplexNumbers` are “added” in line 31 of Fig. 12.18, this invokes the `operator+` declaration, passing the left operand as the first argument and the right operand as the second argument. When we use the subtraction and multiplication operators in lines 32–33, their respective overloaded operator declarations are invoked similarly.

Each calculation's result is a reference to a new `ComplexNumber` object. When this new object is passed to the `Console` class's `WriteLine` method, its `ToString` method (Fig. 12.17, lines 22–26) is implicitly invoked. Line 31 of Fig. 12.18 could be rewritten to explicitly invoke the `ToString` method of the object created by the overloaded plus operator, as in:

```
Console.WriteLine( "{0} + {1} = {2}", x, y, ( x + y ).ToString() );
```

## 12.9 Wrap-Up

This chapter introduced polymorphism—the ability to process objects that share the same base class in a class hierarchy as if they were all objects of the base class. The chapter discussed how polymorphism makes systems extensible and maintainable, then demonstrated how to use overridden methods to effect polymorphic behavior. We introduced the notion of an abstract class, which allows you to provide an appropriate base class from which other

classes can inherit. You learned that an abstract class can declare abstract methods that each derived class must implement to become a concrete class, and that an app can use variables of an abstract class to invoke derived class implementations of abstract methods polymorphically. You also learned how to determine an object's type at execution time. We showed how to create sealed methods and classes. The chapter discussed declaring and implementing an interface as another way to achieve polymorphic behavior, often among objects of different classes. Finally, you learned how to define the behavior of the built-in operators on objects of your own classes with operator overloading.

You should now be familiar with classes, objects, encapsulation, inheritance, interfaces and polymorphism—the most essential aspects of object-oriented programming. Next, we take a deeper look at using exception handling to deal with runtime errors.

---

## Summary

### *Section 12.1 Introduction*

- With polymorphism, we can design and implement systems that are easily extensible—new classes can be added with little or no modification to the general portions of the app.

### *Section 12.2 Polymorphism Examples*

- With polymorphism, the same method name and signature can be used to cause different actions to occur, depending on the type of object on which the method is invoked.
- Polymorphism promotes extensibility: Software that invokes polymorphic behavior is independent of the object types to which messages are sent. New object types that can respond to existing method calls can be incorporated in a system without requiring modification of the base system.

### *Section 12.3 Demonstrating Polymorphic Behavior*

- Invoking a method on a derived-class object via a base-class reference invokes the derived-class functionality—the type of the referenced object determines which method is called.
- A base-class reference can be used to invoke only the methods declared in the base class. If an app needs to perform a derived-class-specific operation on a derived-class object referenced by a base-class variable, the app must first downcast the base-class reference to a derived-class reference.

### *Section 12.4 Abstract Classes and Methods*

- Abstract base classes are incomplete classes for which you never intend to instantiate objects.
- The purpose of an abstract class is primarily to provide an appropriate base class from which other classes can inherit, and thus share a common design.
- Classes that can be used to instantiate objects are called concrete classes.
- You make a class abstract by declaring it with keyword `abstract`.
- Each concrete derived class of an abstract base class must provide concrete implementations of the base class's `abstract` methods and properties.
- Failure to implement a base class's `abstract` methods and properties in a derived class is a compilation error unless the derived class is also declared `abstract`.
- Although we cannot instantiate objects of `abstract` base classes, we can use them to declare variables that can hold references to objects of any concrete class derived from those `abstract` classes.

### **Section 12.5 Case Study: Payroll System Using Polymorphism**

- By declaring a method `abstract`, we indicate that each concrete derived class must provide an appropriate implementation.
- All `virtual` method calls are resolved at execution time, based on the type of the object to which the reference-type variable refers. This process is known as dynamic binding or late binding.
- The `is` operator determines whether the type of the object in the left operand matches the type specified by the right operand and returns true if the two have an *is-a* relationship.
- The `as` operator performs a downcast that returns a reference to the appropriate object if the downcast is successful and returns `null` if the downcast fails.
- Every object knows its own type and can access this information through method `GetType`, which all classes inherit from class `object`.
- Assigning a base-class reference to a derived-class variable is not allowed without an explicit cast or without using the `as` operator. The `is` operator can be used to ensure that such a cast is performed only if the object is a derived-class object.

### **Section 12.6 sealed Methods and Classes**

- A method that's declared `sealed` in a base class cannot be overridden in a derived class.
- A class that's declared `sealed` cannot be a base class (i.e., a class cannot extend a `sealed` class). All methods in a `sealed` class are implicitly `sealed`.

### **Section 12.7 Case Study: Creating and Using Interfaces**

- Interfaces define and standardize the ways in which things such as people and systems can interact with one another.
- An interface declaration begins with keyword `interface` and can contain only `abstract` methods, properties, indexers and events.
- All interface members are implicitly declared both `public` and `abstract`. They do not specify any implementation details, such as concrete method declarations.
- Each interface can extend one or more other interfaces to create a more elaborate interface that other classes can implement.
- To use an interface, a class must specify that it implements the interface by listing it after the colon (`:`) in the class declaration.
- A class that implements an interface but doesn't implement all the interface's members must be declared `abstract` and contain an abstract declaration of each unimplemented interface member.
- The UML expresses the relationship between a class and an interface through a realization. A class is said to "realize," or implement, an interface.
- To implement more than one interface, use a comma-separated list of interface names after the colon (`:`) in the class declaration.
- Inheritance and interfaces are similar in their implementation of the *is-a* relationship. An object of a class that implements an interface may be thought of as an object of that interface type.
- All methods of class `object` can be called by using a reference of an interface type—the reference refers to an object, and all objects inherit the methods of class `object`.

### **Section 12.8 Operator Overloading**

- Method-call notation is cumbersome for certain kinds of classes, especially mathematical classes. Sometimes, it's convenient to use C#'s built-in operators to specify object manipulations.

- Keyword operator, followed by an operator, indicates that a method overloads the specified operator. Methods that overload binary operators must be declared `static` and must take two arguments. The first argument is the left operand, and the second is the right operand.
- Overload operators to perform the same function or similar functions on class objects as the operators perform on objects of simple types. Avoid nonintuitive use of operators.

## Terminology

|                                                          |                               |
|----------------------------------------------------------|-------------------------------|
| <code>abstract</code> base class                         | interface declaration         |
| <code>abstract</code> class                              | interface inheritance         |
| <code>abstract</code> keyword                            | interface keyword             |
| <code>abstract</code> method                             | <i>is-a</i> relationship      |
| <code>abstract</code> operation                          | <code>is</code> operator      |
| <code>as</code> operator                                 | late binding                  |
| base-class reference                                     | <code>operator</code> keyword |
| concrete class                                           | operator overloading          |
| derived-class reference                                  | polymorphism                  |
| downcasting                                              | realization                   |
| dynamic binding                                          | <code>sealed</code> class     |
| generalization in the UML                                | <code>sealed</code> method    |
| <code>GetType</code> method of class <code>object</code> | static binding                |
| implement an interface                                   | Type class                    |
| inlining code                                            |                               |

## Self-Review Exercises

**12.1** Fill in the blanks in each of the following statements:

- If a class contains at least one abstract method, it must be declared as a(n) \_\_\_\_\_ class.
- Classes from which objects can be instantiated are called \_\_\_\_\_ classes.
- \_\_\_\_\_ involves using a base-class variable to invoke methods on base-class and derived-class objects, enabling you to “program in the general.”
- Methods in a class that do not provide implementations must be declared using keyword \_\_\_\_\_.
- Casting a reference stored in a base-class variable to a derived-class type is called \_\_\_\_\_.

**12.2** State whether each of the statements that follows is *true* or *false*. If *false*, explain why.

- It’s possible to treat base-class objects and derived-class objects similarly.
- All methods in an `abstract` class must be declared as `abstract` methods.
- Attempting to invoke a derived-class-only method through a base-class variable is an error.
- If a base class declares an `abstract` method, a derived class must implement that method.
- An object of a class that implements an interface may be thought of as an object of that interface type.

## Answers to Self-Review Exercises

**12.1** a) `abstract`. b) `concrete`. c) Polymorphism. d) `abstract`. e) downcasting.

**12.2** a) True. b) False. An abstract class can include methods with implementations and `abstract` methods. c) True. d) False. Only a concrete derived class must implement the method. e) True.

## Exercises

**12.3 (Programming in the General)** How does polymorphism enable you to program “in the general” rather than “in the specific”? Discuss the key advantages of programming “in the general.”

**12.4 (Inheriting Interface vs. Inheriting Implementation)** A derived class can inherit “interface” or “implementation” from a base class. How do inheritance hierarchies designed for inheriting interface differ from those designed for inheriting implementation?

**12.5 (Abstract Methods)** What are abstract methods? Describe the circumstances in which an abstract method would be appropriate.

**12.6 (Polymorphism and Extensibility)** How does polymorphism promote extensibility?

**12.7 (Assigning Base Class and Derived Class References)** Discuss four ways in which you can assign base-class and derived-class references to variables of base-class and derived-class types.

**12.8 (Abstract Classes vs. Interfaces)** Compare and contrast abstract classes and interfaces. Why would you use an abstract class? Why would you use an interface?

**12.9 (Payroll System Modification)** Modify the payroll system of Figs. 12.4–12.9 to include private instance variable `birthDate` in class `Employee`. Use class `Date` of Fig. 10.7 to represent an employee’s birthday. Assume that payroll is processed once per month. Create an array of `Employee` variables to store references to the various employee objects. In a loop, calculate the payroll for each `Employee` (polymorphically), and add a \$100.00 bonus to the person’s payroll amount if the current month is the month in which the `Employee`’s birthday occurs.

**12.10 (Shape Hierarchy)** Implement the `Shape` hierarchy of Fig. 11.3. Omit the `Triangle` and `Tetrahedron` classes. Each `TwoDimensionalShape` should contain read-only abstract property `Area` to calculate the area of the two-dimensional shape. Each `ThreeDimensionalShape` should have read-only abstract properties `Area` and `Volume` to calculate the surface area and volume, respectively, of the three-dimensional shape. Create an app that uses an array of `Shape` references to objects of each concrete class in the hierarchy. Display a text description of the object to which each array element refers. Also, in the loop that processes all the shapes in the array, determine whether each shape is a `TwoDimensionalShape` or a `ThreeDimensionalShape`. If a shape is a `TwoDimensionalShape`, display its area. If a shape is a `ThreeDimensionalShape`, display its area and volume.

**12.11 (Payroll System Modification)** Modify the payroll system of Figs. 12.4–12.9 to include an additional `Employee` derived class, `PieceWorker`, that represents an employee whose pay is based on the number of pieces of merchandise produced. Class `PieceWorker` should contain private instance variables `wage` (to store the employee’s wage per piece) and `pieces` (to store the number of pieces produced). Provide a concrete implementation of method `Earnings` in class `PieceWorker` that calculates the employee’s earnings by multiplying the number of pieces produced by the wage per piece. Create an array of `Employee` variables to store references to objects of each concrete class in the new `Employee` hierarchy. Display each `Employee`’s string representation and earnings.

**12.12 (Accounts Payable System Modification)** Modify the accounts payable app of Figs. 12.11–12.15 to include the complete functionality of the payroll app of Figs. 12.4–12.9. The app should still process two `Invoice` objects, but now should process one object of each of the four `Employee` derived classes. If the object currently being processed is a `BasePlusCommissionEmployee`, the app should increase the `BasePlusCommissionEmployee`’s base salary by 10%. Finally, the app should output the payment amount for each object. Complete the following steps to create the new app:

- Modify classes `HourlyEmployee` (Fig. 12.6) and `CommissionEmployee` (Fig. 12.7) to place them in the `IPayable` hierarchy as derived classes of the version of `Employee` (Fig. 12.13) that implements `IPayable`. [Hint: Change the name of method `Earnings` to `GetPaymentAmount` in each derived class.]

- b) Modify class `BasePlusCommissionEmployee` (Fig. 12.8) such that it extends the version of class `CommissionEmployee` created in *Part a.*
- c) Modify `PayableInterfaceTest` (Fig. 12.15) to polymorphically process two `Invoices`, one `SalariedEmployee`, one `HourlyEmployee`, one `CommissionEmployee` and one `BasePlusCommissionEmployee`. First, output a string representation of each `IPayable` object. Next, if an object is a `BasePlusCommissionEmployee`, increase its base salary by 10%. Finally, output the payment amount for each `IPayable` object.

**12.13 (Polymorphic Banking Program Using Account Hierarchy)** Develop a polymorphic banking app using the `Account` hierarchy created in Exercise 11.8. Create an array of `Account` references to `SavingsAccount` and `CheckingAccount` objects. For each `Account` in the array, allow the user to specify an amount of money to withdraw from the `Account` using method `Debit` and an amount of money to deposit into the `Account` using method `Credit`. As you process each `Account`, determine its type. If an `Account` is a `SavingsAccount`, calculate the amount of interest owed to the `Account` using method `CalculateInterest`, then add the interest to the account balance using method `Credit`. After processing an `Account`, display the updated account balance obtained by using base-class property `Balance`.

## Making a Difference Exercise

**12.14 (CarbonFootprint Interface: Polymorphism)** Using interfaces, as you learned in this chapter, you can specify similar behaviors for possibly disparate classes. Governments and companies worldwide are becoming increasingly concerned with carbon footprints (annual releases of carbon dioxide into the atmosphere) from buildings burning various types of fuels for heat, vehicles burning fuels for power, and the like. Many scientists blame these greenhouse gases for the phenomenon called global warming. Create three small classes unrelated by inheritance—classes `Building`, `Car` and `Bicycle`. Write an interface `ICarbonFootprint` with a `GetCarbonFootprint` method. Have each of your classes implement that interface, so that its `GetCarbonFootprint` method calculates an appropriate carbon footprint for that class (check out a few websites that explain how to calculate carbon footprints). Write an app that creates objects of each of the three classes, places references to those objects in `List<CarbonFootprint>`, then iterates through the `List`, polymorphically invoking each object's `GetCarbonFootprint` method.

# 13

## Exception Handling: A Deeper Look

*It is common sense to take a method and try it. If it fails, admit it frankly and try another. But above all, try something.*

—Franklin Delano Roosevelt

*O! throw away the  
worse part of it,  
And live the purer  
with the other half.*

—William Shakespeare

*If they're running and they don't  
look where they're going I have  
to come out from somewhere  
and catch them.*

—J. D. Salinger

### Objectives

In this chapter you'll learn:

- What exceptions are and how they're handled.
- When to use exception handling.
- To use `try` blocks to delimit code in which exceptions might occur.
- To `throw` exceptions to indicate a problem.
- To use `catch` blocks to specify exception handlers.
- To use the `finally` block to release resources.
- The .NET exception class hierarchy.
- `Exception` properties.
- To create user-defined exceptions.



# Outline

|                                                                           |                                                     |
|---------------------------------------------------------------------------|-----------------------------------------------------|
| <b>13.1</b> Introduction                                                  | <b>13.4</b> .NET Exception Hierarchy                |
| <b>13.2</b> Example: Divide by Zero without Exception Handling            | 13.4.1 Class SystemException                        |
| <b>13.3</b> Example: Handling DivideByZeroExceptions and FormatExceptions | 13.4.2 Determining Which Exceptions a Method Throws |
| 13.3.1 Enclosing Code in a try Block                                      | <b>13.5</b> finally Block                           |
| 13.3.2 Catching Exceptions                                                | <b>13.6</b> The using Statement                     |
| 13.3.3 Uncaught Exceptions                                                | <b>13.7</b> Exception Properties                    |
| 13.3.4 Termination Model of Exception Handling                            | <b>13.8</b> User-Defined Exception Classes          |
| 13.3.5 Flow of Control When Exceptions Occur                              | <b>13.9</b> Wrap-Up                                 |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 13.1 Introduction

In this chapter, we take a deeper look at **exception handling**. As you know from Section 8.4, an **exception** indicates that a problem occurred during a program’s execution. The name “exception” comes from the fact that, although the problem can occur, it occurs infrequently. As we showed in Section 8.4 and in Chapter 10, exception handling enables you to create apps that can handle exceptions—in many cases allowing a program to continue executing as if no problems were encountered. More severe problems may prevent a program from continuing normal execution, instead requiring the program to notify the user of the problem, then terminate in a controlled manner. The features presented in this chapter enable you to write clear, **robust** and more **fault-tolerant programs** (i.e., programs that are able to deal with problems that may arise and continue executing). The style and details of C# exception handling are based in part on the work of Andrew Koenig and Bjarne Stroustrup. “Best practices” for exception handling in Visual C# are specified in the Visual Studio documentation.<sup>1</sup>

After reviewing exception-handling concepts and basic exception-handling techniques, we overview .NET’s exception-handling class hierarchy. Programs typically *request* and *release* resources (such as files on disk) during program execution. Often, the supply of these resources is limited, or the resources can be used by only one program at a time. We demonstrate a part of the exception-handling mechanism that enables a program to use a resource, then *guarantee* that it will be released for use by other programs, even if an exception occurs. We show several properties of class `System.Exception` (the base class of all exception classes) and discuss how you can create and use your own exception classes.

### *A Note About the Version of Visual Studio Used in This Chapter*

In earlier versions of Visual Studio, all versions included a useful tool known as the *Exception Assistant* that we’ll discuss in Section 13.3.3. Unfortunately, this tool is *not* part of the various Visual Studio Express 2012 editions (at the time of this writing). For this reason, we used Visual Studio Professional 2012 in this chapter. If you have only Visual Studio Express 2012 for Windows Desktop, the programs in this chapter will still execute. Start-

1. “Best Practices for Handling Exceptions [C#],” *.NET Framework Developer’s Guide*, Visual Studio .NET Online Help. Available at [msdn.microsoft.com/en-us/library/seyhsts.aspx](http://msdn.microsoft.com/en-us/library/seyhsts.aspx).

ing in the next section, we'll discuss the differences between the IDE versions when you run a program with **DEBUG > Start Debugging** and exceptions occur.

## 13.2 Example: Divide by Zero without Exception Handling

Let's revisit what happens when errors arise in a console app that does not use exception handling. Figure 13.1 inputs two integers from the user, then divides the first integer by the second using integer division to obtain an `int` result. In this example, an exception is thrown (i.e., an exception occurs) when a method detects a problem and is unable to handle it.

```

1 // Fig. 13.1: DivideByZeroNoExceptionHandling.cs
2 // Integer division without exception handling.
3 using System;
4
5 class DivideByZeroNoExceptionHandling
6 {
7     static void Main()
8     {
9         // get numerator
10        Console.Write("Please enter an integer numerator: ");
11        int numerator = Convert.ToInt32(Console.ReadLine());
12
13        // get denominator
14        Console.Write("Please enter an integer denominator: ");
15        int denominator = Convert.ToInt32(Console.ReadLine());
16
17        // divide the two integers, then display the result
18        int result = numerator / denominator;
19        Console.WriteLine("\nResult: {0:D} / {1:D} = {2:D}",
20                      numerator, denominator, result);
21    } // end Main
22 } // end class DivideByZeroNoExceptionHandling

```

```

Please enter an integer numerator: 100
Please enter an integer denominator: 7

Result: 100 / 7 = 14

```

```

Please enter an integer numerator: 100
Please enter an integer denominator: 0

Unhandled Exception: System.DivideByZeroException:
Attempted to divide by zero.
at DivideByZeroNoExceptionHandling.Main()
in C:\examples\ch13\Fig13_01\DivideByZeroNoExceptionHandling\
DivideByZeroNoExceptionHandling\
DivideByZeroNoExceptionHandling.cs:line 18

```

**Fig. 13.1** | Integer division without exception handling. (Part I of 2.)

```

Please enter an integer numerator: 100
Please enter an integer denominator: hello

Unhandled Exception: System.FormatException:
  Input string was not in a correct format.
  at System.Number.StringToNumber(String str, NumberStyles options,
    NumberBuffer& number, NumberFormatInfo info, Boolean parseDecimal)
  at System.Number.ParseInt32(String s, NumberStyles style,
    NumberFormatInfo info)
  at DivideByZeroNoExceptionHandling.Main()
    in C:\examples\ch13\Fig13_01\DivideByZeroNoExceptionHandling\
      DivideByZeroNoExceptionHandling\
        DivideByZeroNoExceptionHandling.cs:line 15

```

**Fig. 13.1** | Integer division without exception handling. (Part 2 of 2.)

### *Running the App*

In most of our examples, an app appears to run the same with or without debugging. As we discuss shortly, the example in Fig. 13.1 might cause exceptions, depending on the user's input. If you run this app in Visual Studio Express 2012 for Windows Desktop using the **DEBUG > Start Debugging** menu option and an exception occurs, the IDE displays a dialog like the one below:



You can click the **Break** button to pause the program at the line where the exception occurred, allowing you to analyze the program's state and debug the program. For this example, we do not wish to debug the app; we simply want to see what happens when errors arise. For this reason, we executed this app with **DEBUG > Start Without Debugging**. If an exception occurs during execution, a dialog appears indicating that the app "has stopped working." You can simply click **Close the Program** to terminate the app. An error message describing the exception that occurred is displayed in the output window. We formatted the error messages in Fig. 13.1 for readability.

### *Successful Execution*

The first sample execution shows a successful division.

### *Attempting to Divide By Zero*

In the second, the user enters 0 as the denominator. Several lines of information are displayed in response to the invalid input. This information—known as a **stack trace**—includes the exception class's name (`System.DivideByZeroException`) in a message indicating the problem that occurred and the path of execution that led to the exception, method by method. Stack traces help you debug a program. The first line of the error message specifies that a `DivideByZeroException` occurred. When a program divides an integer by 0, the CLR throws a `DivideByZeroException` (namespace `System`). The text after the exception name, “Attempted to divide by zero,” indicates why this exception occurred. Division by zero is not allowed in integer arithmetic.<sup>2</sup>

Each “at” line in a stack trace indicates a line of code in the particular method that was executing when the exception occurred. The “at” line contains the namespace, class and method in which the exception occurred (`DivideByZeroNoExceptionHandling.Main`), the location and name of the file containing the code (`C:\examples\ch13\Fig13_01\DivideByZeroNoExceptionHandling\DivideByZeroNoExceptionHandling\DivideByZeroNoExceptionHandling.cs`) and the line number (:line 18) where the exception occurred. In this case, the stack trace indicates that the `DivideByZeroException` occurred when the program was executing line 18 of method `Main`. The first “at” line in the stack trace indicates the exception’s **throw point**—the initial point at which the exception occurred (i.e., line 18 in `Main`). This information makes it easy for you to see which method call caused the exception, and what method calls were made to get to that point in the program.

### *Attempting to Enter a Non-Integer Value for the Denominator*

In the third sample execution, the user enters the string “he11o” as the denominator. This causes a `FormatException`, and another stack trace is displayed. Our earlier examples that read numeric values from the user assumed that the user would input an integer value, but a noninteger value could be entered. A `FormatException` (namespace `System`) occurs, for example, when `Convert` method `ToInt32` receives a string that does not represent a valid integer. Starting from the last “at” line in the stack trace, we see that the exception was detected in line 15 of method `Main`. The stack trace also shows the other methods that led to the exception being thrown. To perform its task, `Convert.ToInt32` calls method `Number.ParseInt32`, which in turn calls `Number.StringToNumber`. The throw point occurs in `Number.StringToNumber`, as indicated by the first “at” line in the stack trace. Method `Convert.ToInt32` is *not in the stack trace* because the compiler *optimized* this call out of the code—all it does forward its arguments to `Number.ParseInt32`.

### *Program Termination Due to an Unhandled Exception*

In the sample executions in Fig. 13.1, the program terminates when an *unhandled* exception occurs and a stack trace is displayed. This does not always happen—sometimes a program may continue executing even though an exception has occurred and a stack trace has been displayed. In such cases, the app may produce incorrect results. The next section demonstrates how to handle exceptions to enable the program to run to normal completion.

- 
2. Division by zero with floating-point values *is* allowed and results in the value infinity—represented by either constant `Double.PositiveInfinity` or constant `Double.NegativeInfinity`, depending on whether the numerator is positive or negative. These values are displayed as `Infinity` or `-Infinity`. If *both* the numerator and denominator are *zero*, the result of the calculation is the constant `Double.NaN` (“not a number”), which is returned when a calculation’s result is *undefined*.

### 13.3 Example: Handling DivideByZeroExceptions and FormatExceptions

Now, let's consider a simple example of exception handling. The app in Fig. 13.2 uses exception handling to process any `DivideByZeroExceptions` and `FormatExceptions` that might arise. The app reads two integers from the user (lines 18–21). Assuming that the user provides integers as input and does not specify 0 as the denominator for the division, line 25 performs the division and lines 28–29 display the result. However, if the user inputs a noninteger value or supplies 0 as the denominator, an exception occurs. This program demonstrates how to **catch** and **handle** such exceptions—in this case, displaying an error message and allowing the user to enter another set of values.

```

1 // Fig. 13.2: DivideByZeroExceptionHandling.cs
2 // FormatException and DivideByZeroException handlers.
3 using System;
4
5 class DivideByZeroExceptionHandling
6 {
7     static void Main( string[] args )
8     {
9         bool continueLoop = true; // determines whether to keep looping
10
11         do
12     {
13         // retrieve user input and calculate quotient
14         try
15     {
16             // Convert.ToInt32 generates FormatException
17             // if argument cannot be converted to an integer
18             Console.Write( "Enter an integer numerator: " );
19             int numerator = Convert.ToInt32( Console.ReadLine() );
20             Console.Write( "Enter an integer denominator: " );
21             int denominator = Convert.ToInt32( Console.ReadLine() );
22
23             // division generates DivideByZeroException
24             // if denominator is 0
25             int result = numerator / denominator;
26
27             // display result
28             Console.WriteLine( "\nResult: {0} / {1} = {2}",
29                             numerator, denominator, result );
30             continueLoop = false;
31         } // end try
32         catch ( FormatException formatException )
33     {
34             Console.WriteLine( "\n" + formatException.Message );
35             Console.WriteLine(
36                 "You must enter two integers. Please try again.\n" );
37         } // end catch
38         catch ( DivideByZeroException divideByZeroException )
39     {

```

**Fig. 13.2** | `FormatException` and `DivideByZeroException` handlers. (Part 1 of 2.)

```

40         Console.WriteLine( "\n" + divideByZeroException.Message );
41         Console.WriteLine(
42             "Zero is an invalid denominator. Please try again.\n" );
43     } // end catch
44 } while ( continueLoop ); // end do...while
45 } // end Main
46 } // end class DivideByZeroExceptionHandling

```

Please enter an integer numerator: **100**  
 Please enter an integer denominator: **7**

Result:  $100 / 7 = 14$

Enter an integer numerator: **100**  
 Enter an integer denominator: **0**

Attempted to divide by zero.  
 Zero is an invalid denominator. Please try again.

Enter an integer numerator: **100**  
 Enter an integer denominator: **7**

Result:  $100 / 7 = 14$

Enter an integer numerator: **100**  
 Enter an integer denominator: **hello**

Input string was not in a correct format.  
 You must enter two integers. Please try again.

Enter an integer numerator: **100**  
 Enter an integer denominator: **7**

Result:  $100 / 7 = 14$

**Fig. 13.2 |** FormatException and DivideByZeroException handlers. (Part 2 of 2.)

### Sample Outputs

Before we discuss the details of the program, let's consider the sample outputs in Fig. 13.2. The first sample output shows a successful calculation in which the user enters the numerator 100 and the denominator 7. The result (14) is an `int`, because integer division always yields an `int` result. The second sample output demonstrates the result of an attempt to divide by zero. In integer arithmetic, the CLR tests for division by zero and generates a `DivideByZeroException` if the denominator is zero. The program detects the exception and displays an error message indicating the attempt to divide by zero. The last sample output depicts the result of inputting a non-`int` value—in this case, the user enters "hello" as the denominator. The program attempts to convert the input strings to `ints` using method `Convert.ToInt32` (lines 19 and 21). If an argument cannot be converted to an `int`, the method throws a `FormatException`. The program catches the exception and displays an error message indicating that the user must enter two `ints`.

### *Another Way to Convert Strings to Integers*

Another way to validate the input is to use the `Int32.TryParse` method, which converts a `string` to an `int` value if possible. All of the numeric types have `TryParse` methods. The method requires two arguments—one is the `string` to parse and the other is the variable in which the converted value is to be stored. The method returns a `bool` value that's `true` only if the `string` was parsed successfully. If the `string` could not be converted, the value `0` is assigned to the second argument, which is passed by reference so its value can be modified in the calling method. Method `TryParse` can be used to validate input in code rather than allowing the code to throw an exception—this technique is generally preferred.

#### **13.3.1 Enclosing Code in a `try` Block**

Now we consider the user interactions and flow of control that yield the results shown in the sample output windows. Lines 14–31 define a `try` block enclosing the code that might throw exceptions, as well as the code that's skipped when an exception occurs. For example, the program should not display a new result (lines 28–29) unless the calculation in line 25 completes successfully.

The user inputs values that represent the numerator and denominator. The two statements that read the `ints` (lines 19 and 21) call method `Convert.ToInt32` to convert `strings` to `int` values. This method throws a `FormatException` if it cannot convert its `string` argument to an `int`. If lines 19 and 21 convert the values properly (i.e., no exceptions occur), then line 25 divides the numerator by the denominator and assigns the result to variable `result`. If `denominator` is 0, line 25 causes the CLR to throw a `DivideByZeroException`. If line 25 does not cause an exception to be thrown, then lines 28–29 display the result of the division.

#### **13.3.2 Catching Exceptions**

Exception-handling code appears in a `catch` block. In general, when an exception occurs in a `try` block, a corresponding `catch` block *catches* the exception and *handles* it. The `try` block in this example is followed by two `catch` blocks—one that handles a `FormatException` (lines 32–37) and one that handles a `DivideByZeroException` (lines 38–43). A `catch` block specifies an exception parameter representing the exception that the `catch` block can handle. The `catch` block can use the parameter's identifier (which you choose) to interact with a caught exception object. If there's no need to use the exception object in the `catch` block, the exception parameter's identifier can be omitted. The type of the `catch`'s parameter is the type of the exception that the `catch` block handles. Optionally, you can include a `catch` block that does *not* specify an exception type—such a `catch` block (known as a **general catch clause**) catches all exception types. At least one `catch` block and/or a `finally` block (discussed in Section 13.5) must immediately follow a `try` block.

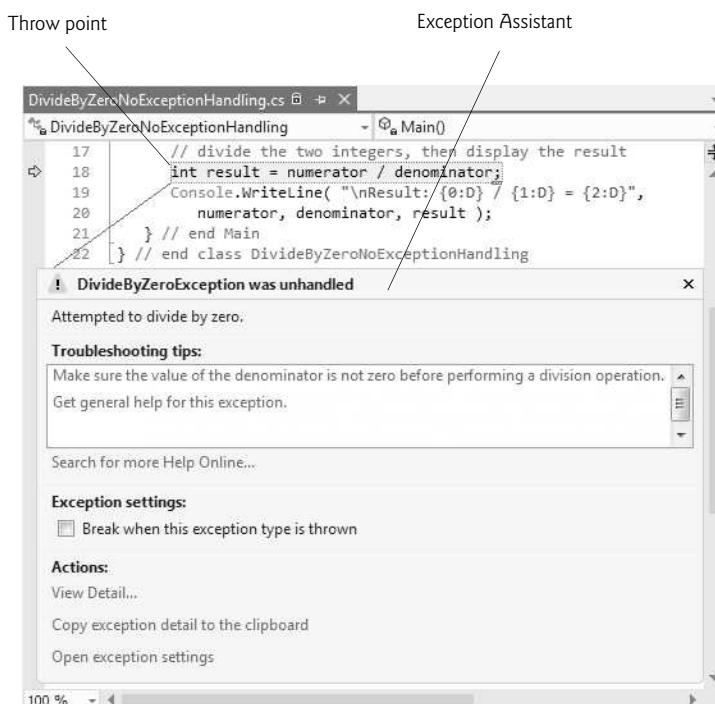
In Fig. 13.2, the first `catch` block catches `FormatExceptions` (thrown by method `Convert.ToInt32`), and the second `catch` block catches `DivideByZeroExceptions` (thrown by the CLR). If an exception occurs, the program executes only the first matching `catch` block. Both exception handlers in this example display an error-message dialog. After either `catch` block terminates, program control continues with the first statement after the last `catch` block (the end of the method, in this example). We'll soon take a deeper look at how this flow of control works in exception handling.

### 13.3.3 Uncaught Exceptions

An **uncaught exception** (or **unhandled exception**) is an exception for which there's no matching catch block. You saw the results of uncaught exceptions in the second and third outputs of Fig. 13.1. Recall that when exceptions occur in that example, the app terminates early (after displaying the exception's stack trace). The result of an uncaught exception depends on how you execute the program—Fig. 13.1 demonstrated the results of an uncaught exception when an app is executed using **DEBUG > Start Without Debugging**. If you run the app from a non-Express version of Visual Studio by using **DEBUG > Start Debugging** and the runtime environment detects an uncaught exception, the app pauses, and the **Exception Assistant** window appears containing:

- a line pointing from the Exception Assistant to the line of code that caused the exception
- the type of the exception
- **Troubleshooting tips** with links to helpful information on what might have caused the exception and how to handle it
- links to view or copy the complete exception details

Figure 13.3 shows the Exception Assistant that's displayed if the user attempts to divide by zero in the app of Fig. 13.1.



**Fig. 13.3** | Exception Assistant.

### 13.3.4 Termination Model of Exception Handling

Recall that the point in the program at which an exception occurs is called the *throw point*—this is an important location for debugging purposes (as we demonstrate in Section 13.7). If an exception occurs in a try block (such as a `FormatException` being thrown as a result of the code in lines 19 and 21 in Fig. 13.2), the try block terminates immediately, and program control transfers to the first of the following catch blocks in which the exception parameter's type matches that of the thrown exception. In Fig. 13.2, the first catch block catches `FormatExceptions` (which occur if input of an invalid type is entered); the second catch block catches `DivideByZeroExceptions` (which occur if an attempt is made to divide by zero). After the exception is handled, program control does *not* return to the throw point because the try block has *exited* (which also causes any of its local variables to go out of scope). Rather, control resumes after the last catch block. This is known as the **termination model of exception handling**. [Note: Some languages use the **resumption model of exception handling**, in which, after an exception is handled, control resumes just after the throw point.]

If no exceptions occur in the try block, the program of Fig. 13.2 successfully completes the try block by ignoring the catch blocks in lines 32–37 and 38–43, and passing line 43. Then the program executes the first statement following the try and catch blocks. In this example, the program reaches the end of the `do...while` loop (line 44), so the method terminates, and the program awaits the next user interaction.

The try block and its corresponding catch and finally blocks together form a **try statement**. It's important not to confuse the terms "try block" and "try statement"—the term "try block" refers to the block of code following the keyword `try` (but before any catch or finally blocks), while the term "try statement" includes all the code from the opening `try` keyword to the end of the last catch or finally block. This includes the try block, as well as any associated catch blocks and finally block.

When a try block terminates, local variables defined in the block go out of scope. If a try block terminates due to an exception, the CLR searches for the first catch block that can process the type of exception that occurred. The CLR locates the matching catch by comparing the type of the thrown exception to each catch's parameter type. A match occurs if the types are identical or if the thrown exception's type is a derived class of the catch's parameter type. Once an exception is matched to a catch block, the code in that block executes and the other catch blocks in the try statement are ignored.

### 13.3.5 Flow of Control When Exceptions Occur

In the third sample output of Fig. 13.2, the user inputs `hello` as the denominator. When line 21 executes, `Convert.ToInt32` cannot convert this string to an `int`, so the method throws a `FormatException` object to indicate that the method was unable to convert the string to an `int`. When the exception occurs, the try block exits (terminates). Next, the CLR attempts to locate a matching catch block. A match occurs with the catch block in line 32, so the exception handler displays the exception's `Message` property (to retrieve the error message associated with the exception) and the program ignores all other exception handlers following the try block. Program control then continues with line 44.



#### Common Programming Error 13.1

Specifying a comma-separated list of parameters in a catch block is a syntax error. A catch block can have at most one parameter.

In the second sample output of Fig. 13.2, the user inputs 0 as the denominator. When the division in line 25 executes, a `DivideByZeroException` occurs. Once again, the try block terminates, and the program attempts to locate a matching catch block. In this case, the first catch block does not match—the exception type in the catch-handler declaration is not the same as the type of the thrown exception, and `FormatException` is not a base class of `DivideByZeroException`. Therefore the program continues to search for a matching catch block, which it finds in line 38. Line 40 displays the exception's `Message` property. Again, program control then continues with line 44.

## 13.4 .NET Exception Hierarchy

In C#, the exception-handling mechanism allows only objects of class `Exception` (namespace `System`) and its derived classes to be thrown and caught. Note, however, that C# programs may interact with software components written in other .NET languages (such as C++) that do not restrict exception types. The general catch clause can be used to catch such exceptions.

This section overviews several of the .NET Framework's exception classes and focuses exclusively on exceptions that derive from class `Exception`. In addition, we discuss how to determine whether a particular method throws exceptions.

### 13.4.1 Class SystemException

Class `Exception` (namespace `System`) is the base class of .NET's exception class hierarchy. An important derived class is `SystemException`. The CLR generates `SystemExceptions`. Many of these can be avoided if apps are coded properly. For example, if a program attempts to access an `out-of-range array index`, the CLR throws an exception of type `IndexOutOfRangeException` (a derived class of `SystemException`). Similarly, an exception occurs when a program uses a reference-type variable to call a method when the reference has a value of `null`. This causes a `NullReferenceException` (another derived class of `SystemException`). You saw earlier in this chapter that a `DivideByZeroException` occurs in integer division when a program attempts to divide by zero.

Other exceptions thrown by the CLR include `OutOfMemoryException`, `StackOverflowException` and `ExecutionEngineException`, which are thrown when something goes wrong that causes the CLR to become unstable. Sometimes such exceptions cannot even be caught. It's best to simply log such exceptions (using a tool such as Apache's `log4net`—[logging.apache.org/log4net/](http://logging.apache.org/log4net/)), then terminate your app.

A benefit of the exception class hierarchy is that a catch block can catch exceptions of a particular type or—because of the *is-a* relationship of inheritance—can use a base-class type to catch exceptions in a hierarchy of related exception types. For example, Section 13.3.2 discussed the catch block with no parameter, which catches exceptions of all types (including those that are not derived from `Exception`). A catch block that specifies a parameter of type `Exception` can catch all exceptions that derive from `Exception`, because `Exception` is the base class of all exception classes. The advantage of this approach is that the exception handler can access the caught exception's information via the parameter in the catch. We'll say more about accessing exception information in Section 13.7.

Using inheritance with exceptions enables a catch block to catch related exceptions using a concise notation. A set of exception handlers could catch each derived-class excep-

tion type individually, but catching the base-class exception type is more concise. However, this technique makes sense *only* if the handling behavior is the same for a base class and all derived classes. Otherwise, catch each derived-class exception individually.



### Common Programming Error 13.2

*The compiler issues an error if a catch block that catches a base-class exception is placed before a catch block for any of that class's derived-class types. In this case, the base-class catch block would catch all base-class and derived-class exceptions, so the derived-class exception handler would never execute.*

#### 13.4.2 Determining Which Exceptions a Method Throws

How do we determine that an exception might occur in a program? For methods contained in the .NET Framework classes, read the detailed descriptions of the methods in the online documentation. If a method throws an exception, its description contains a section called **Exceptions** that specifies the types of exceptions the method throws and briefly describes what causes them. For an example, search for “Convert.ToInt32 method” in the Visual Studio online documentation. The **Exceptions** section of this method’s web page indicates that method Convert.ToInt32 throws two exception types—FormatException and OverflowException—and describes the reason why each might occur. [Note: You can also find this information in the **Object Browser** described in Section 10.12.]



### Software Engineering Observation 13.1

*If a method throws exceptions, statements that invoke the method directly or indirectly should be placed in try blocks, and those exceptions should be caught and handled.*

It's more difficult to determine when the CLR throws exceptions. Such information appears in the *C# Language Specification* (available from [bit.ly/CSharp4Spec](http://bit.ly/CSharp4Spec)). This document defines C#'s syntax and specifies cases in which exceptions are thrown.

## 13.5 finally Block

Programs frequently request and release resources dynamically (i.e., at execution time). For example, a program that reads a file from disk first makes a file-open request (as we'll see in Chapter 17, Files and Streams). If that request succeeds, the program reads the contents of the file. Operating systems typically prevent more than one program from manipulating a file at once. Therefore, when a program finishes processing a file, the program should close the file (i.e., release the resource) so other programs can use it. If the file is not closed, a **resource leak** occurs. In such a case, the file resource is not available to other programs.

In programming languages such as C and C++, in which the programmer is responsible for dynamic memory management, the most common type of resource leak is a **memory leak**. A memory leak occurs when a program allocates memory (as C# programmers do via keyword `new`), but does not deallocate the memory when it's no longer needed. Normally, this is *not* an issue in C#, because the CLR performs *garbage collection* of memory that's no longer needed by an executing program (Section 10.8). However, other kinds of resource leaks (such as unclosed files) can occur.



### Error-Prevention Tip 13.1

*The CLR does not completely eliminate memory leaks. The CLR will not garbage collect an object until the program contains no more references to that object, and even then there may be a delay until the memory is required. Thus, memory leaks can occur if you inadvertently keep references to unwanted objects.*

### Moving Resource-Release Code to a `finally` Block

Exceptions often occur when an app processes resources that require explicit release. For example, a program that processes a file might receive `IOExceptions` during the processing. For this reason, file-processing code normally appears in a `try` block. Regardless of whether a program experiences exceptions while processing a file, the program should close the file when it's no longer needed. Suppose a program places all resource-request and resource-release code in a `try` block. If no exceptions occur, the `try` block executes normally and releases the resources after using them. However, if an exception occurs, the `try` block may exit *before* the resource-release code can execute. We could duplicate all the resource-release code in each of the `catch` blocks, but this would make the code more difficult to modify and maintain. We could also place the resource-release code after the `try` statement; however, if the `try` block terminated due to a `return` statement or an exception occurred, code following the `try` statement would never execute.

To address these problems, C#'s exception-handling mechanism provides the `finally` block, which is guaranteed to execute regardless of whether the `try` block executes successfully or an exception occurs. This makes the `finally` block an ideal location in which to place resource-release code for resources that are acquired and manipulated in the corresponding `try` block. If the `try` block executes successfully, the `finally` block executes immediately after the `try` block terminates. If an exception occurs in the `try` block, the `finally` block executes immediately after a `catch` block completes. If the exception is not caught by a `catch` block associated with the `try` block, or if a `catch` block associated with the `try` block throws an exception itself, the `finally` block executes before the exception is processed by the next enclosing `try` block, which could be in the calling method. By placing the resource-release code in a `finally` block, we ensure that even if the program terminates due to an uncaught exception, the resource will be deallocated. Local variables in a `try` block cannot be accessed in the corresponding `finally` block. For this reason, variables that must be accessed in both a `try` block, and its corresponding `finally` block should be declared before the `try` block.



### Error-Prevention Tip 13.2

*A `finally` block typically contains code to release resources acquired in the corresponding `try` block, which makes the `finally` block an effective mechanism for eliminating resource leaks.*



### Performance Tip 13.1

*As a rule, resources should be released as soon as they're no longer needed in a program. This makes them available for reuse promptly.*

If one or more `catch` blocks follow a `try` block, the `finally` block is optional. However, if no `catch` blocks follow a `try` block, a `finally` block must appear immediately after the `try` block. If any `catch` blocks follow a `try` block, the `finally` block (if there is one)

appears *after* the last catch block. Only whitespace and comments can separate the blocks in a try statement.

### Demonstrating the **finally** Block

The app in Fig. 13.4 demonstrates that the finally block *always* executes, regardless of whether an exception occurs in the corresponding try block. The app consists of method Main (lines 8–47) and four other methods that Main invokes to demonstrate finally. These methods are DoesNotThrowException (lines 50–67), ThrowExceptionWithCatch (lines 70–89), ThrowExceptionWithoutCatch (lines 92–108) and ThrowException-CatchRethrow (lines 111–136).

---

```

1 // Fig. 13.4: UsingExceptions.cs
2 // Using finally blocks.
3 // finally blocks always execute, even when no exception occurs.
4 using System;
5
6 class UsingExceptions
7 {
8     static void Main()
9     {
10         // Case 1: No exceptions occur in called method
11         Console.WriteLine( "Calling DoesNotThrowException" );
12         DoesNotThrowException();
13
14         // Case 2: Exception occurs and is caught in called method
15         Console.WriteLine( "\nCalling ThrowExceptionWithCatch" );
16         ThrowExceptionWithCatch();
17
18         // Case 3: Exception occurs, but is not caught in called method
19         // because there is no catch block.
20         Console.WriteLine( "\nCalling ThrowExceptionWithoutCatch" );
21
22         // call ThrowExceptionWithoutCatch
23         try
24         {
25             ThrowExceptionWithoutCatch();
26         } // end try
27         catch
28         {
29             Console.WriteLine( "Caught exception from " +
30                               "ThrowExceptionWithoutCatch in Main" );
31         } // end catch
32
33         // Case 4: Exception occurs and is caught in called method,
34         // then rethrown to caller.
35         Console.WriteLine( "\nCalling ThrowExceptionCatchRethrow" );
36
37         // call ThrowExceptionCatchRethrow
38         try
39         {

```

**Fig. 13.4** | finally blocks always execute, even when no exception occurs. (Part I of 4.)

```
40         ThrowExceptionCatchRethrow();
41     } // end try
42     catch
43     {
44         Console.WriteLine( "Caught exception from " +
45             "ThrowExceptionCatchRethrow in Main" );
46     } // end catch
47 } // end method Main
48
49 // no exceptions thrown
50 static void DoesNotThrowException()
51 {
52     // try block does not throw any exceptions
53     try
54     {
55         Console.WriteLine( "In DoesNotThrowException" );
56     } // end try
57     catch
58     {
59         Console.WriteLine( "This catch never executes" );
60     } // end catch
61     finally
62     {
63         Console.WriteLine( "finally executed in DoesNotThrowException" );
64     } // end finally
65
66     Console.WriteLine( "End of DoesNotThrowException" );
67 } // end method DoesNotThrowException
68
69 // throws exception and catches it locally
70 static void ThrowExceptionWithCatch()
71 {
72     // try block throws exception
73     try
74     {
75         Console.WriteLine( "In ThrowExceptionWithCatch" );
76         throw new Exception( "Exception in ThrowExceptionWithCatch" );
77     } // end try
78     catch ( Exception exceptionParameter )
79     {
80         Console.WriteLine( "Message: " + exceptionParameter.Message );
81     } // end catch
82     finally
83     {
84         Console.WriteLine(
85             "finally executed in ThrowExceptionWithCatch" );
86     } // end finally
87
88     Console.WriteLine( "End of ThrowExceptionWithCatch" );
89 } // end method ThrowExceptionWithCatch
90
```

---

**Fig. 13.4 |** finally blocks always execute, even when no exception occurs. (Part 2 of 4.)

```

91 // throws exception and does not catch it locally
92 static void ThrowExceptionWithoutCatch()
93 {
94     // throw exception, but do not catch it
95     try
96     {
97         Console.WriteLine( "In ThrowExceptionWithoutCatch" );
98         throw new Exception( "Exception in ThrowExceptionWithoutCatch" );
99     } // end try
100 finally
101 {
102     Console.WriteLine( "finally executed in " +
103         "ThrowExceptionWithoutCatch" );
104 } // end finally
105
106 // unreachable code; logic error
107 Console.WriteLine( "End of ThrowExceptionWithoutCatch" );
108 } // end method ThrowExceptionWithoutCatch
109
110 // throws exception, catches it and rethrows it
111 static void ThrowExceptionCatchRethrow()
112 {
113     // try block throws exception
114     try
115     {
116         Console.WriteLine( "In ThrowExceptionCatchRethrow" );
117         throw new Exception( "Exception in ThrowExceptionCatchRethrow" );
118     } // end try
119     catch ( Exception exceptionParameter )
120     {
121         Console.WriteLine( "Message: " + exceptionParameter.Message );
122
123         // rethrow exception for further processing
124         throw;
125
126         // unreachable code; logic error
127     } // end catch
128     finally
129     {
130         Console.WriteLine( "finally executed in " +
131             "ThrowExceptionCatchRethrow" );
132     } // end finally
133
134     // any code placed here is never reached
135     Console.WriteLine( "End of ThrowExceptionCatchRethrow" );
136 } // end method ThrowExceptionCatchRethrow
137 } // end class UsingExceptions

```

Calling DoesNotThrowException  
 In DoesNotThrowException  
 finally executed in DoesNotThrowException  
 End of DoesNotThrowException

**Fig. 13.4** | finally blocks always execute, even when no exception occurs. (Part 3 of 4.)

```

Calling ThrowExceptionWithCatch
In ThrowExceptionWithCatch
Message: Exception in ThrowExceptionWithCatch
finally executed in ThrowExceptionWithCatch
End of ThrowExceptionWithCatch

Calling ThrowExceptionWithoutCatch
In ThrowExceptionWithoutCatch
finally executed in ThrowExceptionWithoutCatch
Caught exception from ThrowExceptionWithoutCatch in Main

Calling ThrowExceptionCatchRethrow
In ThrowExceptionCatchRethrow
Message: Exception in ThrowExceptionCatchRethrow
finally executed in ThrowExceptionCatchRethrow
Caught exception from ThrowExceptionCatchRethrow in Main

```

**Fig. 13.4 |** finally blocks always execute, even when no exception occurs. (Part 4 of 4.)

Line 12 of `Main` invokes method `DoesNotThrowException`. This method's try block outputs a message (line 55). Because the try block does *not* throw any exceptions, program control ignores the catch block (lines 57–60) and executes the finally block (lines 61–64), which outputs a message. At this point, program control continues with the first statement after the close of the finally block (line 66), which outputs a message indicating that the end of the method has been reached. Then, program control returns to `Main`.

#### *Throwing Exceptions Using the throw Statement*

Line 16 of `Main` invokes method `ThrowExceptionWithCatch` (lines 70–89), which begins in its try block (lines 73–77) by outputting a message. Next, the try block creates an `Exception` object and uses a **throw statement** to throw it (line 76). Executing the throw statement indicates that a problem has occurred in the code. As you've seen in earlier chapters, you can throw exceptions by using the throw statement. Just as with exceptions thrown by the Framework Class Library's methods and the CLR, this indicates to client apps that an error has occurred. A throw statement specifies an object to be thrown. The operand of a throw statement can be of type `Exception` or of any type derived from class `Exception`.

The string passed to the constructor becomes the exception object's error message. When a throw statement in a try block executes, the try block *exits immediately*, and program control continues with the first matching catch block (lines 78–81) following the try block. In this example, the type thrown (`Exception`) matches the type specified in the catch, so line 80 outputs a message indicating the exception that occurred. Then, the finally block (lines 82–86) executes and outputs a message. At this point, program control continues with the first statement after the close of the finally block (line 88), which outputs a message indicating that the end of the method has been reached. Program control then returns to `Main`. In line 80, we use the exception object's `Message` property to retrieve the error message associated with the exception (i.e., the message passed to the `Exception` constructor). Section 13.7 discusses several properties of class `Exception`.

Lines 23–31 of `Main` define a try statement in which `Main` invokes method `ThrowExceptionWithoutCatch` (lines 92–108). The try block enables `Main` to catch any exceptions thrown by `ThrowExceptionWithoutCatch`. The try block in lines 95–99 of

`ThrowExceptionWithoutCatch` begins by outputting a message. Next, the `try` block throws an `Exception` (line 98) and exits immediately.

Normally, program control would continue at the first `catch` following this `try` block. However, this `try` block does not have any `catch` blocks. Therefore, the exception is not caught in method `ThrowExceptionWithoutCatch`. Program control proceeds to the `finally` block (lines 100–104), which outputs a message. At this point, program control returns to `Main`—any statements appearing after the `finally` block (e.g., line 107) do not execute. In this example, such statements could cause logic errors, because the exception thrown in line 98 is not caught. In `Main`, the `catch` block in lines 27–31 catches the exception and displays a message indicating that the exception was caught in `Main`.

### *Rethrowing Exceptions*

Lines 38–46 of `Main` define a `try` statement in which `Main` invokes method `ThrowExceptionCatchRethrow` (lines 111–136). The `try` statement enables `Main` to catch any exceptions thrown by `ThrowExceptionCatchRethrow`. The `try` statement in lines 114–132 of `ThrowExceptionCatchRethrow` begins by outputting a message. Next, the `try` block throws an `Exception` (line 117). The `try` block *exits immediately*, and program control continues at the first `catch` (lines 119–127) following the `try` block. In this example, the type thrown (`Exception`) matches the type specified in the `catch`, so line 121 outputs a message indicating where the exception occurred. Line 124 uses the `throw` statement to `rethrow` the exception. This indicates that the `catch` block performed partial processing of the exception and now is throwing the exception again (in this case, back to the method `Main`) for further processing. In general, it's considered better practice to throw a new exception and pass the original one to the new exception's constructor. This maintains all of the stack-trace information from the original exception. Rethrowing an exception loses the original exception's stack-trace information.

You can also rethrow an exception with a version of the `throw` statement which takes an operand that's the reference to the exception that was caught. It's important to note, however, that this form of `throw` statement *resets the throw point*, so the original throw point's stack-trace information is *lost*. Section 13.7 demonstrates using a `throw` statement with an operand from a `catch` block. In that section, you'll see that after an exception is caught, you can create and throw a different type of exception object from the `catch` block and you can include the original exception as part of the new exception object. Class library designers often do this to *customize* the exception types thrown from methods in their class libraries or to provide additional debugging information.

The exception handling in method `ThrowExceptionCatchRethrow` does not complete, because the `throw` statement in line 124 immediately terminates the `catch` block—if there were any code between line 124 and the end of the block, it would not execute. When line 124 executes, method `ThrowExceptionCatchRethrow` terminates and returns control to `Main`. Once again, the `finally` block (lines 128–132) executes and outputs a message before control returns to `Main`. When control returns to `Main`, the `catch` block in lines 42–46 catches the exception and displays a message indicating that the exception was caught. Then the program terminates.

### *Returning After a finally Block*

The next statement to execute after a `finally` block terminates depends on the exception-handling state. If the `try` block successfully completes, or if a `catch` block catches and han-

dles an exception, the program continues its execution with the next statement after the `finally` block. However, if an exception is not caught, or if a `catch` block rethrows an exception, program control continues in the next enclosing `try` block. The enclosing `try` could be in the calling method or in one of its callers. It also is possible to nest a `try` statement in a `try` block; in such a case, the outer `try` statement's `catch` blocks would process any exceptions that were not caught in the inner `try` statement. If a `try` block executes and has a corresponding `finally` block, the `finally` block executes even if the `try` block terminates due to a `return` statement. The `return` occurs after the execution of the `finally` block.



### Common Programming Error 13.3

*If an uncaught exception is awaiting processing when the `finally` block executes, and the `finally` block throws a new exception that's not caught in the `finally` block, the first exception is lost, and the new exception is passed to the next enclosing `try` block.*



### Error-Prevention Tip 13.3

*When placing code that can throw an exception in a `finally` block, always enclose the code in a `try` statement that catches the appropriate exception types. This prevents the loss of any uncaught and rethrown exceptions that occur before the `finally` block executes.*



### Software Engineering Observation 13.2

*Do not place `try` blocks around every statement that might throw an exception—this can make programs difficult to read. Instead, place one `try` block around a significant portion of code, and follow this `try` block with `catch` blocks that handle each possible exception. Then follow the `catch` blocks with a single `finally` block. Use separate `try` blocks to distinguish between multiple statements that can throw the same exception type.*

## 13.6 The `using` Statement

Typically resource-release code should be placed in a `finally` block to ensure that a resource is released, *regardless* of whether there were exceptions when the resource was used in the corresponding `try` block. An alternative notation—the `using` statement (not to be confused with the `using` directive for using namespaces)—simplifies writing code in which you obtain a resource, use the resource in a `try` block and release the resource in a corresponding `finally` block. For example, a file-processing app (Chapter 17) could process a file with a `using` statement to ensure that the file is closed properly when it's no longer needed. The resource must be an object that implements the `IDisposable` interface and therefore has a `Dispose` method. The general form of a `using` statement is

```
using ( ExampleClass exampleObject = new ExampleClass() )
{
    exampleObject.SomeMethod();
}
```

where `ExampleClass` is a class that implements the `IDisposable` interface. This code creates an object of type `ExampleClass` and uses it in a statement, then calls its `Dispose` method to release any resources used by the object. The `using` statement implicitly places the code in its body in a `try` block with a corresponding `finally` block that calls the object's `Dispose` method. For instance, the preceding brief code segment is equivalent to

```

{
    ExampleClass exampleObject = new ExampleClass();

    try
    {
        exampleObject.SomeMethod();
    }
    finally
    {
        if (exampleObject != null)
            ((IDisposable)exampleObject).Dispose();
    }
}

```

The `if` statement ensures that `exampleObject` still references an object; otherwise, a `NullReferenceException` might occur.

## 13.7 Exception Properties

As we discussed in Section 13.4, exception types derive from class `Exception`, which has several properties. These frequently are used to formulate error messages indicating a caught exception. Two important properties are `Message` and `StackTrace`. Property `Message` stores the error message associated with an `Exception` object. This message can be a default message associated with the exception type or a customized message passed to an `Exception` object's constructor when the `Exception` object is thrown. Property `StackTrace` contains a `string` that represents the `method-call stack`. Recall that the runtime environment at all times keeps a list of open method calls that have been made but have not yet returned. The `StackTrace` represents the series of methods that have not finished processing at the time the exception occurs. If the debugging information that's generated by the compiler for the method is accessible to the IDE, the stack trace also includes line numbers; the first line number indicates the *throw point*, and subsequent line numbers indicate the locations from which the methods in the stack trace were called. The IDE creates PDB files to maintain the debugging information for your projects.

### ***Property InnerException***

Another property used frequently is `InnerException`. Typically, class library programmers “wrap” exception objects caught in their code so that they then can throw new exception types that are specific to their libraries. For example, a programmer implementing an accounting system might have some account-number processing code in which account numbers are input as `strings` but represented as `ints` in the code. Recall that a program can convert `strings` to `int` values with `Convert.ToInt32`, which throws a `FormatException` when it encounters an invalid number format. When an invalid account-number format occurs, the accounting-system programmer might wish to employ a different error message than the default message supplied by `FormatException` or might wish to indicate a new exception type, such as `InvalidAccountNumberFormatException`. In such cases, you'd provide code to catch the `FormatException`, then create an appropriate type of `Exception` object in the `catch` block and pass the original exception as one of the constructor arguments. The original exception object becomes the `InnerException` of the new exception object. When an `InvalidAccountNumberFormatException` occurs in code that uses the accounting system library, the `catch` block that catches the exception can obtain a reference to the original ex-

ception via property `InnerException`. So the exception indicates *both* that the user specified an invalid account number and that the number format was invalid. If the `InnerException` property is `null`, this indicates that the exception was not caused by another exception.

### *Other Exception Properties*

Class `Exception` provides other properties, including `HelpLink`, `Source` and `TargetSite`. Property `HelpLink` specifies the location of the help file that describes the problem that occurred. This property is `null` if no such file exists. Property `Source` specifies the name of the app or object that caused the exception. Property `TargetSite` specifies the method where the exception originated.

### *Demonstrating Exception Properties and Stack Unwinding*

Our next example (Fig. 13.5) demonstrates properties `Message`, `StackTrace` and `InnerException` of class `Exception`. In addition, the example introduces **stack unwinding**—when an exception is thrown but not caught in a particular scope, the method-call stack is “unwound,” and an attempt is made to catch the exception in the next outer `try` block. We keep track of the methods on the call stack as we discuss property `StackTrace` and the stack-unwinding mechanism. To see the proper stack trace, you should execute this program using steps similar to those presented in Section 13.2.

---

```

1 // Fig. 13.5: Properties.cs
2 // Stack unwinding and Exception class properties.
3 // Demonstrates using properties Message, StackTrace and InnerException.
4 using System;
5
6 class Properties
7 {
8     static void Main()
9     {
10         // call Method1; any Exception generated is caught
11         // in the catch block that follows
12         try
13         {
14             Method1();
15         } // end try
16         catch ( Exception exceptionParameter )
17         {
18             // output the string representation of the Exception, then output
19             // properties Message, StackTrace and InnerException
20             Console.WriteLine( "exceptionParameter.ToString(): \n{0}\n",
21                 exceptionParameter );
22             Console.WriteLine( "exceptionParameter.Message: \n{0}\n",
23                 exceptionParameter.Message );
24             Console.WriteLine( "exceptionParameter.StackTrace: \n{0}\n",
25                 exceptionParameter.StackTrace );
26             Console.WriteLine( "exceptionParameter.InnerException: \n{0}\n",
27                 exceptionParameter.InnerException );
28         } // end catch
29     } // end method Main

```

---

**Fig. 13.5** | Stack unwinding and `Exception` class properties. (Part 1 of 3.)

```

30
31     // calls Method2
32     static void Method1()
33     {
34         Method2();
35     } // end method Method1
36
37     // calls Method3
38     static void Method2()
39     {
40         Method3();
41     } // end method Method2
42
43     // throws an Exception containing an InnerException
44     static void Method3()
45     {
46         // attempt to convert string to int
47         try
48         {
49             Convert.ToInt32( "Not an integer" );
50         } // end try
51         catch ( FormatException formatExceptionParameter )
52         {
53             // wrap FormatException in new Exception
54             throw new Exception( "Exception occurred in Method3",
55                                 formatExceptionParameter );
56         } // end catch
57     } // end method Method3
58 } // end class Properties

```

```

exceptionParameter.ToString:
System.Exception: Exception occurred in Method3 --->
System.FormatException: Input string was not in a correct format.
at System.Number.StringToNumber(String str, NumberStyles options,
    NumberBuffer& number, NumberFormatInfo info, Boolean parseDecimal)
at System.Number.ParseInt32(String s, NumberStyles style,
    NumberFormatInfo info)
at Properties.Method3() in C:\examples\ch13\Fig13_05\Properties\
    Properties\Properties.cs:line 49
--- End of inner exception stack trace ---
at Properties.Method3() in C:\examples\ch13\Fig13_05\Properties\
    Properties\Properties.cs:line 54
at Properties.Method2() in C:\examples\ch13\Fig13_05\Properties\
    Properties\Properties.cs:line 40
at Properties.Method1() in C:\examples\ch13\Fig13_05\Properties\
    Properties\Properties.cs:line 34
at Properties.Main() in C:\examples\ch13\Fig13_05\Properties\
    Properties\Properties.cs:line 14

exceptionParameter.Message:
Exception occurred in Method3

exceptionParameter.StackTrace:
at Properties.Method3() in C:\examples\ch13\Fig13_05\Properties\
    Properties\Properties.cs:line 54

```

**Fig. 13.5** | Stack unwinding and Exception class properties. (Part 2 of 3.)

```

at Properties.Method2() in C:\examples\ch13\Fig13_05\Properties\
Properties\Properties.cs:line 40
at Properties.Method1() in C:\examples\ch13\Fig13_05\Properties\
Properties\Properties.cs:line 34
at Properties.Main() in C:\examples\ch13\Fig13_05\Properties\
Properties\Properties.cs:line 14

exceptionParameter.InnerException:
System.FormatException: Input string was not in a correct format.
at System.Number.StringToNumber(String str, NumberStyles options,
NumberBuffer& number, NumberFormatInfo info, Boolean parseDecimal)
at System.Number.ParseInt32(String s, NumberStyles style,
NumberFormatInfo info)
at Properties.Method3() in C:\examples\ch13\Fig13_05\Properties\
Properties\Properties.cs:line 49

```

**Fig. 13.5 |** Stack unwinding and Exception class properties. (Part 3 of 3.)

Program execution begins with `Main`, which becomes the first method on the method-call stack. Line 14 of the `try` block in `Main` invokes `Method1` (declared in lines 32–35), which becomes the second method on the stack. If `Method1` throws an exception, the `catch` block in lines 16–28 handles the exception and outputs information about the exception that occurred. Line 34 of `Method1` invokes `Method2` (lines 38–41), which becomes the third method on the stack. Then line 40 of `Method2` invokes `Method3` (lines 44–57), which becomes the fourth method on the stack.

At this point, the method-call stack (from top to bottom) for the program is:

```

Method3
Method2
Method1
Main

```

The method called *most recently* (`Method3`) appears at the *top* of the stack; the *first* method called (`Main`) appears at the *bottom*. The `try` statement (lines 47–56) in `Method3` invokes method `Convert.ToInt32` (line 49), which attempts to convert a `string` to an `int`. At this point, `Convert.ToInt32` becomes the fifth and final method on the call stack.

### ***Throwing an Exception with an InnerException***

Because the argument to `Convert.ToInt32` is not in `int` format, line 49 throws a `FormatException` that's caught in line 51 of `Method3`. The exception terminates the call to `Convert.ToInt32`, so the method is *unwound* (i.e., removed) from the method-call stack. The `catch` block in `Method3` then creates and throws an `Exception` object. The first argument to the `Exception` constructor is the custom error message for our example, “`Exception occurred in Method3.`” The second argument is the `InnerException`—the `FormatException` that was caught. The `StackTrace` for this new exception object reflects the point at which the exception was thrown (lines 54–55). Now `Method3` terminates, because the exception thrown in the `catch` block is not caught in the method body. Thus, control returns to the statement that invoked `Method3` in the prior method in the call stack (`Method2`). This *unwinds* `Method3` from the method-call stack.

When control returns to line 40 in `Method2`, the CLR determines that line 40 is not in a `try` block. Therefore the exception cannot be caught in `Method2`, and `Method2` terminates. This *unwinds* `Method2` from the call stack and returns control to line 34 in `Method1`.

Here again, line 34 is not in a `try` block, so `Method1` cannot catch the exception. The method terminates and is *unwound* from the call stack, returning control to line 14 in `Main`, which *is* located in a `try` block. The `try` block in `Main` exits and the `catch` block (lines 16–28) catches the exception. The `catch` block uses properties `Message`, `StackTrace` and `InnerException` to create the output. Stack unwinding continues until a `catch` block catches the exception or the program terminates.

### *Displaying Information About the Exception*

The first block of output (which we reformatted for readability) in Fig. 13.5 contains the exception's string representation, which is returned from an *implicit* call to method `ToString`. The string begins with the name of the exception class followed by the `Message` property value. The next four items present the stack trace of the `InnerException` object. The remainder of the block of output shows the `StackTrace` for the exception thrown in `Method3`. The `StackTrace` represents the state of the method-call stack at the throw point of the exception, rather than at the point where the exception eventually is caught. Each `StackTrace` line that begins with "at" represents a method on the call stack. These lines indicate the method in which the exception occurred, the file in which the method resides and the line number of the throw point in the file. The inner-exception information includes the *inner-exception stack trace*.



#### Error-Prevention Tip 13.4

*When catching and rethrowing an exception, provide additional debugging information in the rethrown exception. To do so, create an `Exception` object containing more specific debugging information, then pass the original caught exception to the new exception object's constructor to initialize the `InnerException` property.*

The next block of output (two lines) simply displays the `Message` property's value (`Exception occurred in Method3`) of the exception thrown in `Method3`.

The third block of output displays the `StackTrace` property of the exception thrown in `Method3`. This `StackTrace` property contains the stack trace starting from line 54 in `Method3`, because that's the point at which the `Exception` object was created and thrown. The stack trace *always* begins from the exception's throw point.

Finally, the last block of output displays the string representation of the `InnerException` property, which includes the namespace and class name of the exception object, as well as its `Message` and `StackTrace` properties.

## 13.8 User-Defined Exception Classes

In many cases, you can use existing exception classes from the .NET Framework Class Library to indicate exceptions that occur in your programs. In some cases, however, you might wish to create new exception classes specific to the problems that occur in your programs. **User-defined exception classes** should derive directly or indirectly from class `Exception` of namespace `System`. When you create code that throws exceptions, they should be well documented, so that other developers who use your code will know how to handle them.



### Good Programming Practice 13.1

*Associating each type of malfunction with an appropriately named exception class improves program clarity.*



### Software Engineering Observation 13.3

*Before creating a user-defined exception class, investigate the existing exceptions in the .NET Framework Class Library to determine whether an appropriate exception type already exists.*

#### *Class NegativeNumberException*

Figures 13.6–13.7 demonstrate a user-defined exception class. `NegativeNumberException` (Fig. 13.6) represents exceptions that occur when a program performs an illegal operation on a negative number, such as attempting to calculate its square root.

```

1 // Fig. 13.6: NegativeNumberException.cs
2 // NegativeNumberException represents exceptions caused by
3 // illegal operations performed on negative numbers.
4 using System;
5
6 class NegativeNumberException : Exception
7 {
8     // default constructor
9     public NegativeNumberException()
10        : base( "Illegal operation for a negative number" )
11    {
12        // empty body
13    } // end default constructor
14
15    // constructor for customizing error message
16    public NegativeNumberException( string messageValue )
17        : base( messageValue )
18    {
19        // empty body
20    } // end one-argument constructor
21
22    // constructor for customizing the exception's error
23    // message and specifying the InnerException object
24    public NegativeNumberException( string messageValue,
25        Exception inner )
26        : base( messageValue, inner )
27    {
28        // empty body
29    } // end two-argument constructor
30 } // end class NegativeNumberException

```

**Fig. 13.6 |** `NegativeNumberException` represents exceptions caused by illegal operations performed on negative numbers.

According to Microsoft’s document on “Best Practices for Handling Exceptions” ([bit.ly/ExceptionsBestPractices](http://bit.ly/ExceptionsBestPractices)), user-defined exceptions should typically extend class `Exception`, have a class name that ends with “Exception” and define three construc-

tors: a *parameterless constructor*, a *constructor that receives a string argument* (the error message); and a *constructor that receives a string argument and an Exception argument* (the error message and the inner-exception object). Defining these three constructors makes your exception class more flexible, allowing other programmers to easily use and extend it.

`NegativeNumberExceptions` most frequently occur during arithmetic operations, so it seems logical to derive class `NegativeNumberException` from class `ArithmeticException`. However, class `ArithmeticException` derives from class `SystemException`—the category of exceptions thrown by the CLR. Per Microsoft's best practices for exception handling, *user-defined exception classes should inherit from `Exception` rather than `SystemException`.* In this case, we could have used the built-in `ArgumentException` class, which is recommended in the best practices for invalid argument values. We create our own exception type here simply for demonstration purposes.

### **Class `NegativeNumberException`**

Class `SquareRootTest` (Fig. 13.7) demonstrates our user-defined exception class. The app enables the user to input a numeric value, then invokes method `SquareRoot` (lines 40–48) to calculate the square root of that value. To perform this calculation, `SquareRoot` invokes class `Math`'s `Sqrt` method, which receives a `double` value as its argument. Normally, if the argument is *negative*, method `Sqrt` returns `NaN`. In this program, we'd like to *prevent* the user from calculating the square root of a negative number. If the numeric value that the user enters is negative, method `SquareRoot` throws a `NegativeNumberException` (lines 44–45). Otherwise, `SquareRoot` invokes class `Math`'s method `Sqrt` to compute the square root (line 47).

When the user inputs a value, the `try` statement (lines 14–34) attempts to invoke `SquareRoot` using the value input by the user. If the user input is not a number, a `FormatException` occurs, and the catch block in lines 25–29 processes the exception. If the user inputs a negative number, method `SquareRoot` throws a `NegativeNumberException` (lines 44–45); the catch block in lines 30–34 catches and handles this type of exception.

---

```

1 // Fig. 13.7: SquareRootTest.cs
2 // Demonstrating a user-defined exception class.
3 using System;
4
5 class SquareRootTest
6 {
7     static void Main( string[] args )
8     {
9         bool continueLoop = true;
10
11         do
12         {
13             // catch any NegativeNumberException thrown
14             try
15             {
16                 Console.Write(
17                     "Enter a value to calculate the square root of: " );
18                 double inputValue = Convert.ToDouble( Console.ReadLine() );

```

---

**Fig. 13.7** | Demonstrating a user-defined exception class. (Part I of 2.)

```

19         double result = SquareRoot( inputValue );
20
21         Console.WriteLine( "The square root of {0} is {1:F6}\n",
22             inputValue, result );
23         continueLoop = false;
24     } // end try
25     catch ( FormatException formatException )
26     {
27         Console.WriteLine( "\n" + formatException.Message );
28         Console.WriteLine( "Please enter a double value.\n" );
29     } // end catch
30     catch ( NegativeNumberException negativeNumberException )
31     {
32         Console.WriteLine( "\n" + negativeNumberException.Message );
33         Console.WriteLine( "Please enter a non-negative value.\n" );
34     } // end catch
35 } while ( continueLoop );
36 } // end Main
37
38 // computes square root of parameter; throws
39 // NegativeNumberException if parameter is negative
40 public static double SquareRoot( double value )
41 {
42     // if negative operand, throw NegativeNumberException
43     if ( value < 0 )
44         throw new NegativeNumberException(
45             "Square root of negative number not permitted" );
46     else
47         return Math.Sqrt( value ); // compute square root
48 } // end method SquareRoot
49 } // end class SquareRootTest

```

Enter a value to calculate the square root of: 30  
 The square root of 30 is 5.477226

Enter a value to calculate the square root of: hello

Input string was not in a correct format.  
 Please enter a double value.

Enter a value to calculate the square root of: 25  
 The square root of 25 is 5.000000

Enter a value to calculate the square root of: -2

Square root of negative number not permitted  
 Please enter a non-negative value.

Enter a value to calculate the square root of: 2  
 The square root of 2 is 1.414214

**Fig. 13.7** | Demonstrating a user-defined exception class. (Part 2 of 2.)

## 13.9 Wrap-Up

In this chapter, you learned how to use exception handling to deal with errors in an app. We demonstrated that exception handling enables you to remove error-handling code from the “main line” of the program’s execution. You saw exception handling in the context of a divide-by-zero example. You learned how to use `try` blocks to enclose code that may throw an exception, and how to use `catch` blocks to deal with exceptions that may arise. We explained the termination model of exception handling, in which, after an exception is handled, program control does not return to the throw point. We discussed several important classes of the .NET Exception hierarchy, including `Exception` (from which user-defined exception classes are derived) and `SystemException`. Next you learned how to use the `finally` block to release resources whether or not an exception occurs, and how to throw and rethrow exceptions with the `throw` statement. We showed how the `using` statement can be used to automate the process of releasing a resource. You then learned how to obtain information about an exception using `Exception` properties `Message`, `StackTrace` and `InnerException`, and method `ToString`. You learned how to create your own exception classes. In the next two chapters, we present an in-depth treatment of graphical user interfaces. In these chapters and throughout the rest of the book, we use exception handling to make our examples more robust, while demonstrating new features of the language.

---

## Summary

### *Section 13.1 Introduction*

- An exception is an indication of a problem that occurs during a program’s execution.
- Exception handling enables you to create apps that can resolve (or handle) exceptions.

### *Section 13.2 Example: Divide by Zero without Exception Handling*

- An exception is thrown when a method or the CLR detects a problem and is unable to handle it.
- A stack trace includes the name of the exception in a descriptive message that indicates the problem that occurred and the complete method-call stack at the time the exception occurred.
- Division by zero is not allowed in integer arithmetic.
- Division by zero is allowed with floating-point values. Such a calculation results in the value infinity, which is represented by `Double.PositiveInfinity` or `Double.NegativeInfinity`, depending on whether the numerator is positive or negative. If both the numerator and denominator are zero, the result of the calculation is `Double.NaN`.
- When division by zero occurs in integer arithmetic, a `DivideByZeroException` is thrown.
- A `FormatException` occurs when `Convert` method `ToInt32` receives a string that does not represent a valid integer.

### *Section 13.3 Example: Handling `DivideByZeroException` and `FormatException`*

- A `try` block encloses the code that might throw exceptions, as well as the code that should not execute if an exception occurs.
- A `catch` block can specify an identifier representing the exception that the `catch` block can handle. A general `catch` clause catches all exception types, but cannot access exception information.
- At least one `catch` block and/or a `finally` block must immediately follow the `try` block.

- An uncaught exception is an exception that occurs for which there's no matching catch block.
- When a method called in a program detects an exception, or when the CLR detects a problem, the method or the CLR throws an exception.
- The point in the program at which an exception occurs is called the throw point.
- If an exception occurs in a try block, the try block terminates immediately, and program control transfers to the first of the following catch blocks in which the exception parameter's type matches the type of the thrown exception.
- After an exception is handled, program control does not return to the throw point, because the try block has exited. Instead, control resumes after the try statement's last catch block. This is known as the termination model of exception handling.
- The try block and its corresponding catch and finally blocks together form a try statement.
- The CLR locates the matching catch by comparing the thrown exception's type to each catch's exception-parameter type. A match occurs if the types are identical or if the thrown exception's type is a derived class of the exception-parameter type.
- Once an exception is matched to a catch block, the other catch blocks are ignored.

### ***Section 13.4 .NET Exception Hierarchy***

- The C# exception-handling mechanism allows objects only of class `Exception` and its derived classes to be thrown and caught.
- Class `Exception` of namespace `System` is the base class of the .NET Framework Class Library exception class hierarchy.
- The CLR generates `SystemExceptions`, which can occur at any point during the execution of the program. Many of these exceptions can be avoided if apps are coded properly.
- A benefit of using the exception class hierarchy is that a catch block can catch exceptions of a particular type or—because of the *is-a* relationship of inheritance—can use a base-class type to catch exceptions in a hierarchy of related exception types.
- A catch block that specifies an exception parameter of type `Exception` can catch all exceptions that derive from `Exception`, because `Exception` is the base class of all exception classes.

### ***Section 13.5 finally Block***

- The most common type of resource leak is a memory leak.
- A memory leak occurs when a program allocates memory but does not deallocate it when it's no longer needed. Normally, this is not an issue in C#, because the CLR performs garbage collection of memory that's no longer needed by an executing program.
- C#'s exception-handling mechanism provides the `finally` block, which is guaranteed to execute if program control enters the corresponding `try` block.
- The `finally` block executes regardless of whether the corresponding `try` block executes successfully or an exception occurs. This makes the `finally` block an ideal location in which to place resource-release code for resources acquired and manipulated in the corresponding `try` block.
- If a `try` block executes successfully, the `finally` block executes immediately after the `try` block terminates. If an exception occurs in the `try` block, the `finally` block executes immediately after a catch block completes.
- If the exception is not caught by a catch block associated with the `try` block, or if a catch block associated with the `try` block throws an exception, the `finally` block executes before the exception is processed by the next enclosing `try` block (if there is one).

- A `throw` statement can rethrow an exception, indicating that a `catch` block performed partial processing of the exception and now is throwing the exception again for further processing.
- If a `try` block executes and has a corresponding `finally` block, the `finally` block always executes.

### **Section 13.6 The `using` Statement**

- The `using` statement simplifies writing code in which you obtain an `IDisposable` resource, use the resource in a `try` block and release the resource in a corresponding `finally` block.

### **Section 13.7 Exception Properties**

- Property `Message` of class `Exception` stores the error message associated with an `Exception` object.
- Property `StackTrace` of class `Exception` contains a `string` that represents the method-call stack.
- Another `Exception` property used frequently by class library programmers is `InnerException`. Typically, you use this property to “wrap” exception objects caught in your code, so that you then can throw new exception types specific to your libraries.
- When an exception is thrown but not caught in a particular scope, stack unwinding occurs and an attempt is made to catch the exception in the next outer `try` block.

### **Section 13.8 User-Defined Exception Classes**

- User-defined exception classes should derive directly or indirectly from class `Exception` of namespace `System`.
- User-defined exceptions should typically extend `Exception`, have a class name that ends with “`Exception`” and define a parameterless constructor, a constructor that receives a `string` argument (the error message), and a constructor that receives a `string` argument and an `Exception` argument (the error message and the inner-exception object).

## **Terminology**

|                                                                      |                                                                  |
|----------------------------------------------------------------------|------------------------------------------------------------------|
| catch an exception                                                   | resource leak                                                    |
| catch block                                                          | resumption model of exception handling                           |
| divide by zero                                                       | rethrow an exception                                             |
| <code>DivideByZeroException</code> class                             | robust program                                                   |
| error-processing code                                                | <code>Source</code> property of class <code>Exception</code>     |
| exception                                                            | stack trace                                                      |
| <code>Exception</code> Assistant                                     | stack unwinding                                                  |
| <code>Exception</code> class                                         | <code>StackTrace</code> property of class <code>Exception</code> |
| exception handling                                                   | <code>SystemException</code> class                               |
| fault-tolerant program                                               | <code>TargetSite</code> property of class <code>Exception</code> |
| <code>finally</code> block                                           | termination model of exception handling                          |
| <code>FormatException</code> class                                   | throw an exception                                               |
| general catch clause                                                 | throw point                                                      |
| handle an exception                                                  | throw statement                                                  |
| <code>HelpLink</code> property of class <code>Exception</code>       | <code>try</code> block                                           |
| <code>IndexOutOfRangeException</code> class                          | <code>try</code> statement                                       |
| <code>InnerException</code> property of class <code>Exception</code> | <code>TryParse</code> method of structure <code>Int32</code>     |
| memory leak                                                          | uncaught exception                                               |
| method-call stack                                                    | unhandled exception                                              |
| <code>NullReferenceException</code> class                            | user-defined exception class                                     |
| out-of-range array index                                             | <code>using</code> statement                                     |

## Self-Review Exercises

- 13.1** Fill in the blanks in each of the following statements:
- A method is said to \_\_\_\_\_ an exception when it detects that a problem has occurred.
  - When present, the \_\_\_\_\_ block associated with a `try` block always executes.
  - Exception classes are derived from class \_\_\_\_\_.
  - The statement that throws an exception is called the \_\_\_\_\_ of the exception.
  - C# uses the \_\_\_\_\_ model of exception handling as opposed to the \_\_\_\_\_ model of exception handling.
  - An uncaught exception in a method causes the method to \_\_\_\_\_ from the method-call stack.
  - Method `Convert.ToInt32` can throw a(n) \_\_\_\_\_ exception if its argument is not a valid integer value.
- 13.2** State whether each of the following is *true* or *false*. If *false*, explain why.
- Exceptions always are handled in the method that initially detects the exception.
  - User-defined exception classes should extend class `SystemException`.
  - Accessing an out-of-bounds array index causes the CLR to throw an exception.
  - A `finally` block is optional after a `try` block that does not have any corresponding `catch` blocks.
  - A `finally` block is guaranteed to execute.
  - It's possible to return to the throw point of an exception using keyword `return`.
  - Exceptions can be rethrown.
  - Property `Message` of class `Exception` returns a `string` indicating the method from which the exception was thrown.

## Answers to Self-Review Exercises

- 13.1** a) throw. b) `finally`. c) `Exception`. d) throw point. e) termination, resumption. f) unwind.  
g) `FormatException`.
- 13.2** a) False. Exceptions can be handled by other methods on the method-call stack. b) False. User-defined exception classes should typically extend class `Exception`. c) True. d) False. A `try` block that does not have any `catch` blocks requires a `finally` block. e) False. The `finally` block executes only if program control enters the corresponding `try` block. f) False. `return` causes control to return to the caller. g) True. h) False. Property `Message` of class `Exception` returns a `string` representing the error message.

## Exercises

- 13.3** (*Exception Base Classes and Derived Classes*) Use inheritance to create an exception base class and various exception-derived classes. Write a program to demonstrate that the `catch` specifying the base class catches derived-class exceptions.

- 13.4** (*Catching Exceptions*) Write a program that demonstrates how various exceptions are caught with

```
catch ( Exception ex )
```

- 13.5** (*Order of Exception Handlers*) To demonstrate the importance of the order of exception handlers, write two programs, one with correct ordering of `catch` blocks (i.e., place the base-class exception handler after all derived-class exception handlers) and another with improper ordering (i.e., place the base-class exception handler before the derived-class exception handlers). What happens when you attempt to compile the second program?

**13.6 (Constructor Failure)** Exceptions can be used to indicate problems that occur when an object is being constructed. Write a program that shows a constructor passing information about constructor failure to an exception handler. The exception thrown also should contain the arguments sent to the constructor.

**13.7 (Rethrowing and Exception)** Write a program that demonstrates rethrowing an exception.

**13.8 (Not Catching Every Exception)** Write a program demonstrating that a method with its own try block does not have to catch every possible exception that occurs within the try block—some exceptions can slip through to, and be handled in, other scopes.

**13.9 (Exception from a Deeply Nested Method)** Write a program that throws an exception from a deeply nested method. The catch block should follow the try block that encloses the call chain. The exception caught should be one you defined yourself. In catching the exception, display the exception's message and stack trace.

**13.10 (FormatExceptions)** Create an app that inputs miles driven and gallons used, and calculates miles per gallon. The example should use exception handling to process the FormatExceptions that occur when converting the input strings to doubles. If invalid data is entered, display a message informing the user.

# 14

## Graphical User Interfaces with Windows Forms: Part I

*... the wisest prophets make sure  
of the event first.*

—Horace Walpole

*... The user should feel in control  
of the computer; not the other  
way around. This is achieved in  
applications that embody three  
qualities: responsiveness,  
permissiveness, and consistency.*

—Inside Macintosh, Volume 1

Apple Computer, Inc. 1985

*All the better to see you with my  
dear.*

—The Big Bad Wolf to Little Red Riding  
Hood

### Objectives

In this chapter you'll learn:

- Design principles of graphical user interfaces (GUIs).
- How to create graphical user interfaces.
- How to process events in response to user interactions with GUI controls.
- The namespaces that contain the classes for GUI controls and event handling.
- How to create and manipulate various controls.
- How to add descriptive ToolTips to GUI controls.
- How to process mouse and keyboard events.



# Outline

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>14.1</b> Introduction<br><b>14.2</b> Windows Forms<br><b>14.3</b> Event Handling <ul style="list-style-type: none"> <li><b>14.3.1</b> A Simple Event-Driven GUI</li> <li><b>14.3.2</b> Auto-Generated GUI Code</li> <li><b>14.3.3</b> Delegates and the Event-Handling Mechanism</li> <li><b>14.3.4</b> Another Way to Create Event Handlers</li> <li><b>14.3.5</b> Locating Event Information</li> </ul> <b>14.4</b> Control Properties and Layout | <b>14.5</b> Labels, TextBoxes and Buttons<br><b>14.6</b> GroupBoxes and Panels<br><b>14.7</b> CheckBoxes and RadioButtons<br><b>14.8</b> PictureBoxes<br><b>14.9</b> ToolTips<br><b>14.10</b> NumericUpDown Control<br><b>14.11</b> Mouse-Event Handling<br><b>14.12</b> Keyboard-Event Handling<br><b>14.13</b> Wrap-Up |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 14.1 Introduction

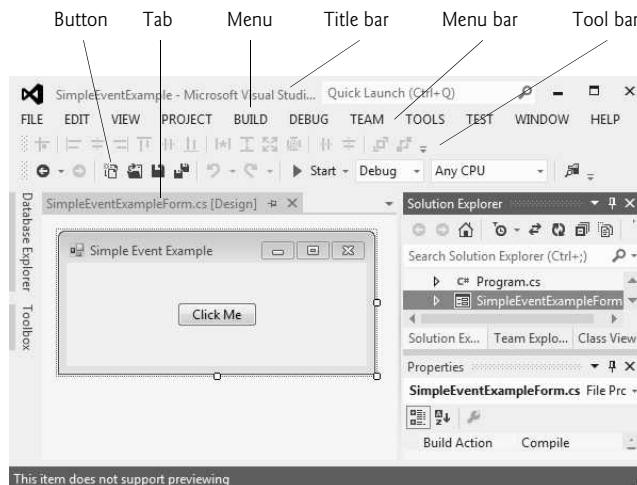
A graphical user interface (GUI) allows a user to interact *visually* with a program. A GUI (pronounced “GOO-ee”) gives a program a distinctive “look” and “feel.”



### Look-and-Feel Observation 14.1

Consistent user interfaces enable a user to learn new apps more quickly because the apps have the same “look” and “feel.”

As an example of a GUI, consider Fig. 14.1, which shows a Visual Studio Express window containing various GUI controls. Near the top, there’s a *menu bar* containing the menus FILE, EDIT, VIEW, PROJECT, BUILD, DEBUG, TEAM, TOOLS, TEST, WINDOW, and HELP. Below that is a *tool bar* of buttons, each with a defined task, such as creating a new



**Fig. 14.1** | GUI controls in the Visual Studio Express 2012 for Windows Desktop window.

project or opening an existing one. Below that is a *tab* representing a currently open file—this *tabbed view* allows users to switch between the open files. These controls form a user-friendly interface through which you have been interacting with the IDE.

GUIs are built from *GUI controls* (which are sometimes called **components** or **widg-ets**—short for **window gadgets**). GUI controls are *objects* that can display information on the screen or enable users to interact with an app via the mouse, keyboard or some other form of input (such as voice commands). Several common GUI controls are listed in Fig. 14.2—in the sections that follow and in Chapter 15, we discuss each of these in detail. Chapter 15 explores the features and properties of additional GUI controls.

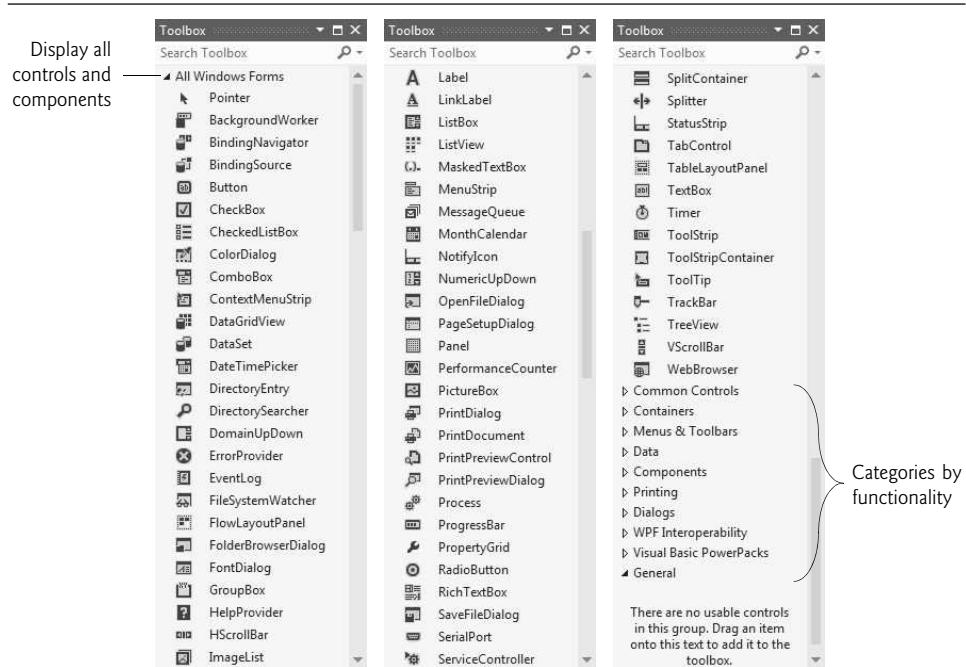
| Control       | Description                                                                                                                                             |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Label         | Displays <i>images</i> or <i>uneditable text</i> .                                                                                                      |
| TextBox       | Enables the user to <i>enter data via the keyboard</i> . It can also be used to <i>display editable or uneditable text</i> .                            |
| Button        | Triggers an <i>event</i> when clicked with the mouse.                                                                                                   |
| CheckBox      | Specifies an option that can be <i>selected</i> (checked) or <i>unselected</i> (not checked).                                                           |
| ComboBox      | Provides a <i>drop-down list</i> of items from which the user can make a <i>selection</i> either by clicking an item in the list or by typing in a box. |
| ListBox       | Provides a <i>list</i> of items from which the user can make a <i>selection</i> by clicking one or more items.                                          |
| Panel         | A <i>container</i> in which controls can be placed and organized.                                                                                       |
| NumericUpDown | Enables the user to select from a <i>range</i> of numeric input values.                                                                                 |

**Fig. 14.2** | Some basic GUI controls.

## 14.2 Windows Forms

Windows Forms is one library that can be used to create GUIs—you’ll also learn about *Windows 8 UI* and *Windows Presentation Foundation* in later chapters. A **Form** is a graphical element that appears on your computer’s desktop; it can be a dialog, a window or an **MDI window** (**m**ultiple **D**ocument **I**nterface **w**indow)—discussed in Chapter 15. A *component* is an instance of a class that implements the **IComponent** interface, which defines the behaviors that components must implement, such as how the component is loaded. A *control*, such as a **Button** or **Label**, has a graphical representation at runtime. Some components lack graphical representations (e.g., class **Timer** of namespace **System.Windows.Forms**—see Chapter 15). Such components are not visible at run time.

Figure 14.3 displays the Windows Forms controls and components from the C# **Toolbox**. The controls and components are organized into categories by functionality. Selecting the category **All Windows Forms** at the top of the **Toolbox** allows you to view all the controls and components from the other tabs in one list (as shown in Fig. 14.3). In this chapter and the next, we discuss many of these controls and components. To add a control or component to a Form, select that control or component from the **Toolbox** and drag it onto the Form. To *deselect* a control or component, select the **Pointer** item in the **Toolbox** (the icon at the top of the list). When the **Pointer** item is selected, you cannot accidentally add a new control to the Form.



**Fig. 14.3 |** Components and controls for Windows Forms.

When there are several windows on the screen, the **active window** is the *frontmost* and has a *highlighted title bar*. A window becomes the active window when the user clicks somewhere inside it. The active window is said to “have the **focus**.” For example, in Visual Studio the active window is the **Toolbox** when you’re selecting an item from it, or the **Properties** window when you’re editing a control’s properties.

A **Form** is a **container** for controls and components. When you drag items from the **Toolbox** onto the **Form**, Visual Studio generates code that creates the object and sets its basic properties. This code is updated when the control or component’s properties are modified in the IDE. Removing a control or component from the **Form** *deletes* the corresponding generated code. The IDE maintains the generated code in a separate file using **partial classes**—classes that are split among multiple files and assembled into a single class by the compiler. You could write this code yourself, but it’s much easier to allow Visual Studio to handle the details. We introduced visual programming concepts in Chapter 2. In this chapter and the next, we use visual programming to build more substantial GUIs.

Each control or component we present in this chapter is located in namespace `System.Windows.Forms`. To create a Windows Forms app, you generally create a Windows Form, set its properties, add controls to the Form, set their properties and implement event handlers (methods) that respond to events generated by the controls. Figure 14.4 lists common Form properties, common methods and a common event.

When we create controls and event handlers, Visual Studio generates much of the GUI-related code. In visual programming, the IDE maintains GUI-related code and you write the bodies of the *event handlers* to indicate what actions the program should take when particular *events* occur.

| Form properties,<br>methods and an event | Description                                                                                                                          |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>                 |                                                                                                                                      |
| AcceptButton                             | Default Button that's clicked for you when you press <i>Enter</i> .                                                                  |
| AutoScroll                               | bool value ( <i>false</i> by default) that allows or disallows <i>scrollbars</i> when needed.                                        |
| CancelButton                             | Button that's clicked when the <i>Escape</i> key is pressed.                                                                         |
| FormBorderStyle                          | <i>Border style</i> for the Form ( <i>Sizable</i> by default).                                                                       |
| Font                                     | Font of text displayed on the Form, and the <i>default font</i> for controls added to the Form.                                      |
| Text                                     | Text in the Form's title bar.                                                                                                        |
| <i>Common Methods</i>                    |                                                                                                                                      |
| Close                                    | Closes a Form and <i>releases all resources</i> , such as the memory used for the Form's contents. A closed Form cannot be reopened. |
| Hide                                     | Hides a Form, but does <i>not</i> destroy the Form or release its resources.                                                         |
| Show                                     | Displays a <i>hidden</i> Form.                                                                                                       |
| <i>Common Event</i>                      |                                                                                                                                      |
| Load                                     | Occurs before a Form is displayed to the user. You'll learn about events and event-handling in the next section.                     |

**Fig. 14.4** | Common Form properties, methods and an event.

## 14.3 Event Handling

Normally, a user interacts with an app's GUI to indicate the tasks that the app should perform. For example, when you write an e-mail in an e-mail app, clicking the **Send** button tells the app to send the e-mail to the specified e-mail addresses. GUIs are **event driven**. When the user interacts with a GUI component, the interaction—known as an **event**—drives the program to perform a task. Common events (user interactions) that might cause an app to perform a task include *clicking* a Button, *typing* in a TextBox, *selecting* an item from a menu, *closing* a window and *moving* the mouse. All GUI controls have events associated with them. Objects of other types can also have associated events as well. A method that performs a task in response to an event is called an **event handler**, and the overall process of responding to events is known as **event handling**.

### 14.3.1 A Simple Event-Driven GUI

The Form in the app of Fig. 14.5 contains a Button that a user can click to display a MessageBox. In line 6, notice the namespace declaration, which is inserted for every class you create. We've been removing these from earlier simple examples because they were unnecessary. Namespaces organize groups of related classes. Each class's name is actually a combination of its namespace name, a dot (.) and the class name. This is known as the class's **fully qualified class name**. You can use the class's **simple name** (the unqualified class name—*SimpleEventExample*) in the app. Each class name is *scoped* to the namespace in which it's defined. If you were to reuse this class in another app, you'd use the fully qual-

ified name or write a `using` directive so that you could refer to the class by its simple name. We'll use namespaces like this in Chapters 15 and 19. If another namespace also contains a class with the same name, the fully qualified class names can be used to distinguish between the classes in the app and prevent a **name conflict** (also called a **name collision**).

```

1 // Fig. 14.5: SimpleEventExampleForm.cs
2 // Simple event handling example.
3 using System;
4 using System.Windows.Forms;
5
6 namespace SimpleEventExample
7 {
8     // Form that shows a simple event handler
9     public partial class SimpleEventExampleForm : Form
10    {
11        // default constructor
12        public SimpleEventExampleForm()
13        {
14            InitializeComponent();
15        } // end constructor
16
17        // handles click event of Button clickButton
18        private void clickButton_Click( object sender, EventArgs e )
19        {
20            MessageBox.Show( "Button was clicked." );
21        } // end method clickButton_Click
22    } // end class SimpleEventExampleForm
23 } // end namespace SimpleEventExample

```



**Fig. 14.5** | Simple event-handling example.

### Renaming the `Form1.cs` File

Using the techniques presented in Chapter 2, create a `Form` containing a `Button`. First, create a new Windows Forms app. Next, rename the `Form1.cs` file to `SimpleEventExampleForm.cs` in the **Solution Explorer**. Click the `Form` in the designer, then use the **Properties** window to set the `Form`'s `Text` property to "Simple Event Example". Set the `Form`'s `Font` property to Segoe UI, 9pt. To do so, select the `Font` property in the **Properties** window, then click the *ellipsis (...)* button in the property's value field to display a font dialog.

### Adding a Button to the Form

Drag a `Button` from the **Toolbox** onto the `Form`. In the **Properties** window for the `Button`, set the `(Name)` property to `clickButton` and the `Text` property to `Click Me`. You'll notice that we use a convention in which each variable name we create for a control ends with

the control's type. For example, in the variable name `clickButton`, "Button" is the control's type.

### *Adding an Event Handler for the Button's Click Event*

When the user clicks the Button in this example, we want the app to respond by displaying a `MessageBox`. To do this, you must create an *event handler* for the Button's *Click event*. You can create this event handler by double clicking the Button on the Form, which declares the following *empty* event handler in the program code:

```
private void clickButton_Click( object sender, EventArgs e )  
{  
}
```

By convention, the IDE names the event-handler method as *objectName\_eventName* (e.g., `clickButton_Click`). The `clickButton_Click` event handler *executes* when the user *clicks* the `clickButton` control.

### *Event Handler Parameters*

Each event handler receives two parameters when it's called. The first—an `object` reference typically named `sender`—is a reference to the *object that generated the event*. The second is a reference to an `EventArgs` object (or an object of an `EventArgs` derived class), which is typically named `e`. This object contains additional information about the event that occurred. `EventArgs` is the *base class* of all classes that represent event information.

### *Displaying a MessageBox*

To display a `MessageBox` in response to the event, insert the statement

```
MessageBox.Show( "Button was clicked." );
```

in the event handler's body. The resulting event handler appears in lines 18–21 of Fig. 14.5. When you execute the app and click the Button, a `MessageBox` appears displaying the text "Button was clicked".

### **14.3.2 Auto-Generated GUI Code**

Visual Studio places the *auto-generated* GUI code in the `Designer.cs` file of the Form (`SimpleEventExampleForm.Designer.cs` in this example). You can open this file by expanding the node in the **Solution Explorer** window for the file you're currently working in (`SimpleEventExampleForm.cs`) and double clicking the file name that ends with `Designer.cs`. Figs. 14.6 and 14.7 show this file's contents. The IDE collapses the code in lines 23–57 of Fig. 14.7 by default—you can click the + icon next to line 23 to *expand* the code, then click the - icon next to that line to *collapse* it.

Now that you have studied classes and objects in detail, this code will be easier to understand. Since this code is created and maintained by Visual Studio, you generally don't need to look at it. In fact, you do not need to understand most of the code shown here to build GUI apps. However, we now take a closer look to help you understand how GUI apps work.

The auto-generated code that defines the GUI is actually part of the Form's *class*—in this case, `SimpleEventExampleForm`. Line 3 of Fig. 14.6 (and line 9 of Fig. 14.5) uses the `partial` modifier, which allows this class to be split among multiple files, including the

```

SimpleEventExampleForm.Designer.cs  SimpleEventExampleForm.cs
SimpleEventExample.SimpleEventExampleForm  components
1  namespace SimpleEventExample
2  {
3      partial class SimpleEventExampleForm
4      {
5          /// <summary>
6          /// Required designer variable.
7          /// </summary>
8          private System.ComponentModel.IContainer components = null;
9
10         /// <summary>
11         /// Clean up any resources being used.
12         /// </summary>
13         /// <param name="disposing">true if managed resources should be disposed; otherwise, false.

```

**Fig. 14.6** | First half of the Visual Studio generated code file.

```

SimpleEventExampleForm.Designer.cs  SimpleEventExampleForm.cs [Design]
SimpleEventExample.SimpleEventExampleForm  components
23  #region Windows Form Designer generated code
24
25  /// <summary>
26  /// Required method for Designer support - do not modify
27  /// the contents of this method with the code editor.
28  /// </summary>
29  private void InitializeComponent()
30  {
31      this.clickButton = new System.Windows.Forms.Button();
32      this.SuspendLayout();
33      //
34      // clickButton
35      //
36      this.clickButton.Location = new System.Drawing.Point(104, 37);
37      this.clickButton.Name = "clickButton";
38      this.clickButton.Size = new System.Drawing.Size(75, 23);
39      this.clickButton.TabIndex = 0;
40      this.clickButton.Text = "Click Me";
41      this.clickButton.UseVisualStyleBackColor = true;
42      this.clickButton.Click += new System.EventHandler(this.clickButton_Click);
43      //
44      // SimpleEventExampleForm
45      //
46      this.AutoScaleMode = System.Windows.Forms.AutoScaleMode.Font;
47      this.ClientSize = new System.Drawing.Size(282, 97);
48      this.Controls.Add(this.clickButton);
49      this.Font = new System.Drawing.Font("Segoe UI", 9F, System.Drawing.FontStyle.Regular, System.Drawing.GraphicsUnit.Point);
50      this.Name = "SimpleEventExampleForm";
51      this.Text = "Simple Event Example";
52
53      this.ResumeLayout(false);
54  }
55
56  #endregion
57
58  private System.Windows.Forms.Button clickButton;
59
60 }
61

```

**Fig. 14.7** | Second half of the Visual Studio generated code file.

files that contain auto-generated code and those in which you write your own code. Line 59 of Fig. 14.7 declares the `clickButton` that we created in **Design** mode. It's declared as

an instance variable of class `SimpleEventExampleForm`. By default, all variable declarations for controls created through C#'s *design window* have a `private` access modifier. The code also includes the *Dispose method* for *releasing resources* (Fig. 14.6, lines 14–21) and method `InitializeComponent` (Fig. 14.7, lines 29–55), which contains the code that creates the `Button`, then sets some of the `Button`'s and the `Form`'s properties. The property values correspond to the values set in the **Properties** window for each control. Visual Studio adds comments to the code that it generates, as in lines 33–35. Line 42 was generated when we created the event handler for the `Button`'s `Click` event.

Method `InitializeComponent` is called when the `Form` is created, and establishes such properties as the `Form` title, the `Form` size, control sizes and text. Visual Studio also uses the code in this method to create the GUI you see in design view. Changing the code in `InitializeComponent` may prevent Visual Studio from displaying the GUI properly.



#### Error-Prevention Tip 14.1

*The code generated by building a GUI in **Design** mode is not meant to be modified directly, which is why this code is placed in a separate file. Modifying this code can prevent the GUI from being displayed correctly in **Design** mode and might cause an app to function incorrectly. In **Design** mode, modify control properties only through the **Properties** window.*

### 14.3.3 Delegates and the Event-Handling Mechanism

The control that generates an event is known as the *event sender*. An event-handling method—known as the *event handler*—responds to a particular event that a control generates. When the event occurs, the event sender calls its event handler to perform a task (i.e., to “handle the event”).

The .NET event-handling mechanism allows you to choose your own names for event-handling methods. However, each event-handling method must declare the proper parameters to receive information about the event that it handles. Since you can choose your own method names, an event sender such as a `Button` cannot know in advance which method will respond to its events. So, we need a mechanism to indicate which method is the event handler for an event.

#### Delegates

Event handlers are connected to a control's events via special objects called **delegates**. A delegate type declaration specifies the signature of a method—in event handling, the signature specifies the return type and arguments for an event handler. GUI controls have predefined delegates that correspond to every event they can generate. For example, the delegate for a `Button`'s `Click` event is of type `EventHandler` (namespace `System`). The online help documentation declares this type as follows:

```
public delegate void EventHandler( object sender, EventArgs e );
```

This uses the `delegate` keyword to declare a delegate type named `EventHandler`, which can hold references to methods that return `void` and receive two parameters—one of type `object` (the *event sender*) and one of type `EventArgs`. If you compare the delegate declaration with `clickButton_Click`'s first line (Fig. 14.5, line 18), you'll see that this event handler returns `void` and receives the parameters specified by the `EventHandler` delegate. The preceding declaration actually creates an entire class for you. The details of this special class's declaration are handled by the compiler.

### *Indicating the Method that a Delegate Should Call*

An *event sender* calls a delegate object like a method. Since each event handler is declared as a delegate, the event sender can simply call the appropriate delegate when an event occurs—a **Button** calls the **EventHandler** delegate that corresponds to its **Click** event in response to a click. The delegate’s job is to invoke the appropriate method. To enable the **clickButton\_Click** method to be called, Visual Studio assigns **clickButton\_Click** to the **clickButton**’s **Click** **EventHandler** delegate, as shown in line 42 of Fig. 14.7. This code is added by Visual Studio when you double click the **Button** control in **Design** mode. The expression

```
new System.EventHandler(this.clickButton_Click);
```

creates an **EventHandler** delegate object and initializes it with the **clickButton\_Click** method. Line 42 uses the **+=** operator to *add* the delegate to the **Button**’s **Click** **EventHandler** delegate. This indicates that **clickButton\_Click** will respond when a user clicks the **Button**. The **+=** operator is overloaded by the delegate class that’s created by the compiler.

### *Multicast Delegates*

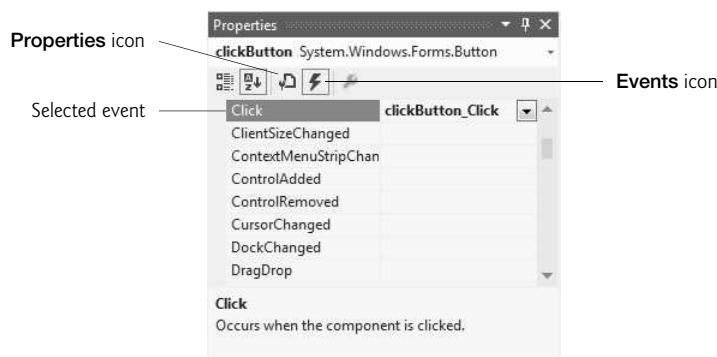
You can actually specify that several different methods should be invoked in response to an event by adding other delegates to the **Button**’s **Click** event with statements similar to line 42 of Fig. 14.7. Event delegates are **multicast**—they represent a *set of delegate objects* that all have the *same signature*. **Multicast delegates** enable several methods to be called in response to a single event. When an event occurs, the event sender calls *every* method referenced by the multicast delegate. This is known as **event multicasting**. Event delegates derive from class **MulticastDelegate**, which derives from class **Delegate** (both from namespace **System**). For most cases, you’ll specify only one event handler for a particular event on a control.

## **14.3.4 Another Way to Create Event Handlers**

For the GUI app in Fig. 14.5, you double clicked the **Button** control on the **Form** to create its event handler. This technique creates an event handler for a control’s **default event**—the event that’s most frequently used with that control. Controls can generate many different events, and each one can have its own event handler. For instance, your app can also provide an event handler for a **Button**’s **MouseHover** event, which occurs when the mouse pointer remains positioned over the **Button** for a short period of time. We now discuss how to create an event handler for an event that’s not a control’s default event.

### *Using the Properties Window to Create Event Handlers*

You can create additional event handlers through the **Properties** window. If you select a control on the **Form**, then click the **Events** icon (the lightning bolt icon in Fig. 14.8) in the **Properties** window, all the events for that control are listed in the window. You can double click an event’s name to display in the editor an existing event handler for that event, or to create the event handler if it does not yet exist in your code. You can also select an event, then use the drop-down list to its right to choose an existing method that should be used as the event handler for that event. The methods that appear in this drop-down list are the **Form** class’s methods that have the proper signature to be an event handler for the selected event. You can return to viewing the properties of a control by selecting the **Properties** icon (Fig. 14.8).

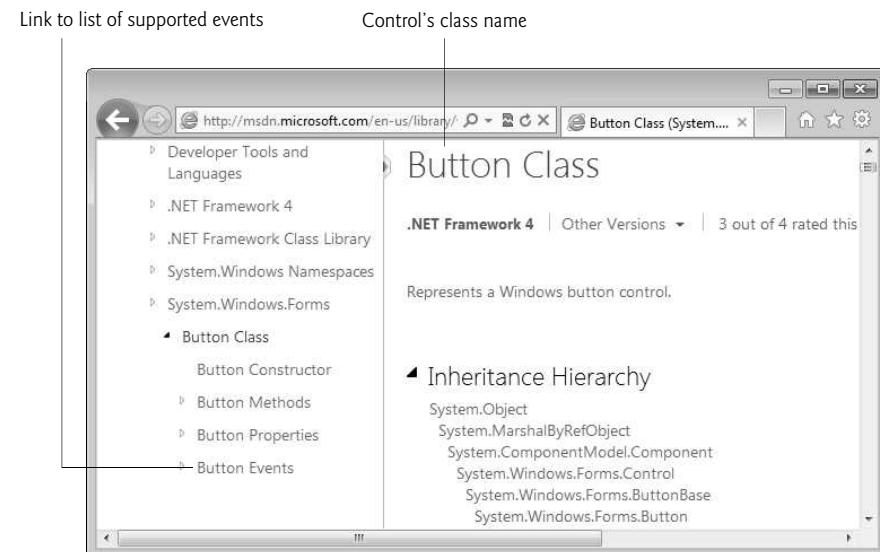


**Fig. 14.8** | Viewing events for a **Button** control in the **Properties** window.

A single method can handle events from multiple controls. For example, the `Click` events of three `Buttons` could all be handled by the same method. You can specify an event handler for multiple events by selecting multiple controls (by dragging over them or holding `Shift` and clicking each) and selecting a single method in the **Properties** window's **Events** tab. If you create a new event handler this way, you should rename it appropriately. You could also select each control individually and specify the same method for each one's event.

### 14.3.5 Locating Event Information

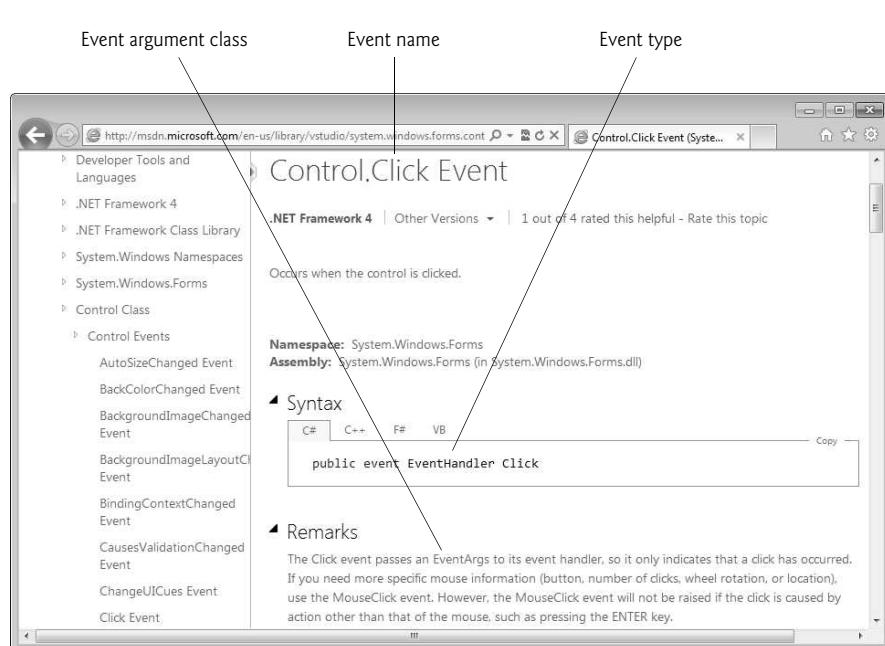
Read the Visual Studio documentation to learn about the different events raised by each control. To do this, select a control in the IDE and press the `F1` key to display that control's online help (Fig. 14.9). The web page that's displayed contains basic information



**Fig. 14.9** | Link to list of **Button** events.

about the control's class. In the left column of the page are several links to more information about the class—**Button Constructor**, **Button Methods**, **Button Properties** and **Button Events**. This list may vary by class. Each link displays a subset of the class's members. Click the link to the list of events for that control (**Button Events** in this case) to display the supported events for that control.

Next, click the name of an event to view its description and examples of its use. We selected the **Click** event to display the information in Fig. 14.10. The **Click** event is a member of class **Control**, an indirect base class of class **Button**. The **Remarks** section of the page discusses the details of the selected event. Alternatively, you could use the **Object Browser** to look up this information in the **System.Windows.Forms** namespace. The **Object Browser** shows only the members *originally* defined in a given class. The **Click** event is originally defined in class **Control** and inherited into **Button**. For this reason, you must look at class **Control** in the **Object Browser** to see the documentation for the **Click** event. See Section 10.12 for more information regarding the **Object Browser**.



**Fig. 14.10** | Click event details.

## 14.4 Control Properties and Layout

This section overviews properties that are common to many controls. Controls derive from class **Control** (namespace **System.Windows.Forms**). Figure 14.11 lists some of class **Control**'s properties and methods. The properties shown here can be set for many controls. For example, the **Text** property specifies the text that appears on a control. The location of this text varies depending on the control. In a **Form**, the text appears in the title bar, but the text of a **Button** appears on its face.

| Class Control properties and methods | Description                                                                                                                                                                                                                     |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>             |                                                                                                                                                                                                                                 |
| BackColor                            | The control's background color.                                                                                                                                                                                                 |
| BackgroundImage                      | The control's background image.                                                                                                                                                                                                 |
| Enabled                              | Specifies whether the control is <i>enabled</i> (i.e., if the user can interact with it). Typically, portions of a <i>disabled</i> control appear "grayed out" as a visual indication to the user that the control is disabled. |
| Focused                              | Indicates whether the control <i>has the focus</i> (only available at runtime).                                                                                                                                                 |
| Font                                 | The <i>Font</i> used to display the control's text.                                                                                                                                                                             |
| ForeColor                            | The control's foreground color. This usually determines the color of the text in the <i>Text</i> property.                                                                                                                      |
| TabIndex                             | The <i>tab order</i> of the control. When the <i>Tab</i> key is pressed, the focus transfers between controls based on the tab order. You can set this order.                                                                   |
| TabStop                              | If <i>true</i> , then a user can give focus to this control via the <i>Tab</i> key.                                                                                                                                             |
| Text                                 | The text associated with the control. The location and appearance of the text vary depending on the type of control.                                                                                                            |
| Visible                              | Indicates whether the control is visible.                                                                                                                                                                                       |
| <i>Common Methods</i>                |                                                                                                                                                                                                                                 |
| Hide                                 | Hides the control (sets the <i>Visible</i> property to <i>false</i> ).                                                                                                                                                          |
| Select                               | <i>Acquires the focus</i> .                                                                                                                                                                                                     |
| Show                                 | Shows the control (sets the <i>Visible</i> property to <i>true</i> ).                                                                                                                                                           |

**Fig. 14.11** | Class Control properties and methods.

The **Select** method transfers the focus to a control and makes it the **active control**. When you press the *Tab* key in an executing Windows Forms app, controls *receive the focus* in the order specified by their **TabIndex** property. This property is set by Visual Studio based on the order in which controls are added to a Form, but you can change the *tabbing order* using **VIEW > Tab Order**. **TabIndex** is helpful for users who enter information in many controls, such as a set of **TextBoxes** that represent a user's name, address and telephone number. The user can enter information, then quickly select the next control by pressing the *Tab* key.

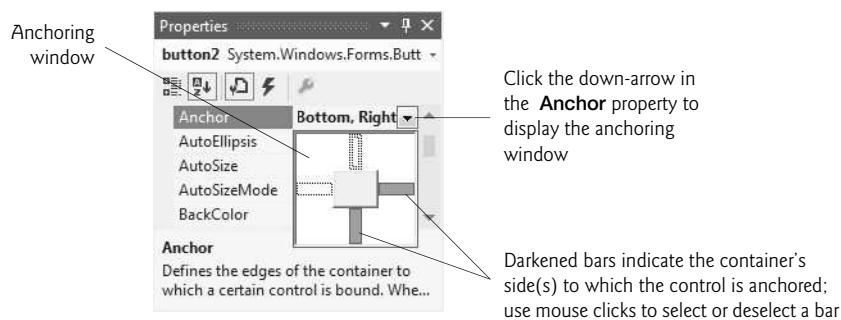
The **Enabled** property indicates whether the user can interact with a control to generate an event. Often, if a control is *disabled*, it's because an option is unavailable to the user at that time. For example, text editor apps often disable the "paste" command until the user copies some text. In most cases, a disabled control's text appears in gray (rather than in black). You can also hide a control from the user without disabling the control by setting the **Visible** property to *false* or by calling method **Hide**. In each case, the control still exists but is not visible on the Form.

### Anchoring and Docking

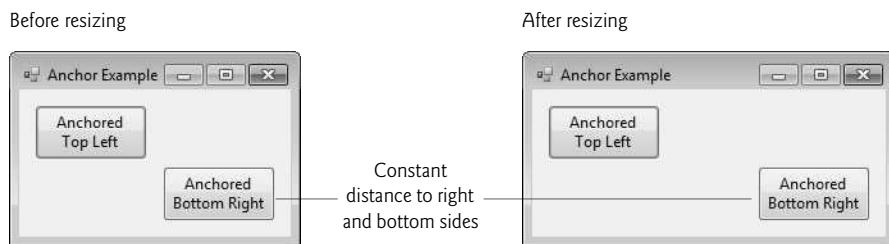
You can use anchoring and docking to specify the layout of controls inside a container (such as a Form). **Anchoring** causes controls to remain at a fixed distance from the sides of

the container even when the container is resized. Anchoring enhances the user experience. For example, if the user expects a control to appear in a particular corner of the app, anchoring ensures that the control will always be in that corner—even if the user *resizes* the Form. **Docking** attaches a control to a container such that the control stretches across an entire side or fills an entire area. For example, a button docked to the top of a container stretches across the entire top of that container, regardless of the width of the container.

When a window (or other type of *parent container* like a Panel) is resized, anchored controls are moved (and possibly resized) so that the distance from the sides to which they're anchored does not vary. By default, most controls are anchored to the top-left corner of the Form. To see the effects of anchoring a control, create a simple Windows Forms app that contains two Buttons. Anchor one control to the right and bottom sides by setting the **Anchor** property as shown in Fig. 14.12. Leave the other control with its default anchoring (top, left). Execute the app and enlarge the Form. Notice that the Button anchored to the bottom-right corner is always the same distance from the Form's bottom-right corner (Fig. 14.13), but that the other control stays its original distance from the top-left corner of the Form.



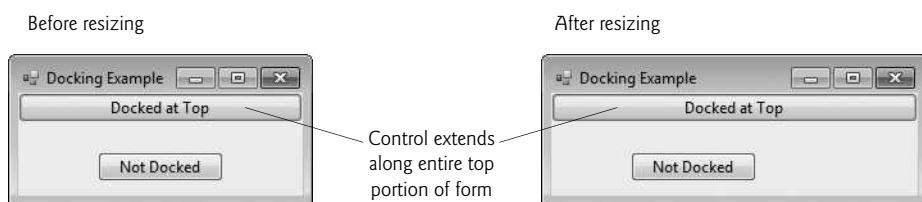
**Fig. 14.12** | Manipulating the **Anchor** property of a control.



**Fig. 14.13** | Anchoring demonstration.

Sometimes, it's desirable for a control to span an entire side of the Form, even when the Form is resized. For example, a control such as a status bar typically should remain at the bottom of the Form. Docking allows a control to *span an entire side* (left, right, top or bottom) of its parent container or to *fill the entire container*. When the parent control is

resized, the docked control resizes as well. In Fig. 14.14, a Button is docked at the top of the Form (spanning the top portion). When the Form is resized, the Button is resized to the Form's new width. Forms have a **Padding** property that specifies the distance between the docked controls and the Form edges. This property specifies four values (one for each side), and each value is set to 0 by default. Some common control layout properties are summarized in Fig. 14.15.



**Fig. 14.14** | Docking a Button to the top of a Form.

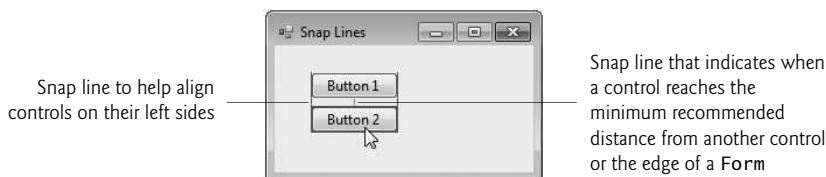
| Control layout properties | Description                                                                                                                                       |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Anchor                    | Causes a control to remain at a fixed distance from the side(s) of the container even when the container is resized.                              |
| Dock                      | Allows a control to span one side of its container or to fill the remaining space in the container.                                               |
| Padding                   | Sets the space between a container's edges and docked controls. The default is 0, causing the control to appear flush with the container's sides. |
| Location                  | Specifies the location (as a set of coordinates) of the upper-left corner of the control, in relation to its container's upper-left corner.       |
| Size                      | Specifies the size of the control in pixels as a <b>Size</b> object, which has properties <b>Width</b> and <b>Height</b> .                        |
| MinimumSize, MaximumSize  | Indicates the minimum and maximum size of a <b>Control</b> , respectively.                                                                        |

**Fig. 14.15** | Control layout properties.

The **Anchor** and **Dock** properties of a **Control** are set with respect to the **Control**'s parent container, which could be a **Form** or another parent container (such as a **Panel**; discussed in Section 14.6). The minimum and maximum **Form** (or other **Control**) sizes can be set via properties **MinimumSize** and **MaximumSize**, respectively. Both are of type **Size**, which has properties **Width** and **Height** to specify the size of the **Form**. Properties **MinimumSize** and **MaximumSize** allow you to design the GUI layout for a given size range. The user cannot make a **Form** smaller than the size specified by property **MinimumSize** and cannot make a **Form** larger than the size specified by property **MaximumSize**. To set a **Form** to a *fixed* size (where the **Form** cannot be resized by the user), set its minimum and maximum size to the same value.

### Using Visual Studio To Edit a GUI's Layout

Visual Studio helps you with GUI layout. When you drag a control across a Form, blue snap lines appear to help you position the control with respect to others (Fig. 14.16) and the Form's edges. This feature makes the control you're dragging appear to “snap into place” alongside other controls. Visual Studio also provides the **FORMAT** menu, which contains options for modifying your GUI's layout. The **FORMAT** menu does not appear in the IDE unless you select one or more controls in design view. When you select multiple controls, you can align them with the **FORMAT** menu's **Align** submenu. The **FORMAT** menu also enables you to modify the space between controls or to center a control on the Form.



**Fig. 14.16** | Snap lines for aligning controls.

## 14.5 Labels, TextBoxes and Buttons

Labels provide text information (as well as optional images) and are defined with class `Label` (a derived class of `Control`). A `Label` displays text that the *user cannot directly modify*. A `Label`'s text can be changed programmatically by modifying the `Label`'s `Text` property. Figure 14.17 lists common `Label` properties.

| Common Label properties | Description                                                                                                                                                           |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>Font</code>       | The font of the text on the <code>Label</code> .                                                                                                                      |
| <code>Text</code>       | The text on the <code>Label</code> .                                                                                                                                  |
| <code> TextAlign</code> | The alignment of the <code>Label</code> 's text on the control—horizontally (left, center or right) and vertically (top, middle or bottom). The default is top, left. |

**Fig. 14.17** | Common `Label` properties.

A **textbox** (class `TextBox`) is an area in which either text can be displayed by a program or the user can type text via the keyboard. A **password TextBox** is a `TextBox` that hides the information entered by the user. As the user types characters, the password `TextBox` masks the user input by displaying a password character. If you set the property `UseSystemPasswordChar` to `true`, the `TextBox` becomes a password `TextBox`. Users often encounter both types of `TextBoxes`, when logging into a computer or website—the username `TextBox` allows users to input their usernames; the password `TextBox` allows users to enter their passwords. Figure 14.18 lists the common properties and a common event of `TextBoxes`.

| TextBox properties and an event | Description                                                                                                                                                                                                                                                                                                                 |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>        |                                                                                                                                                                                                                                                                                                                             |
| AcceptsReturn                   | If <code>true</code> in a multiline TextBox, pressing <code>Enter</code> in the TextBox creates a new line. If <code>false</code> (the default), pressing <code>Enter</code> is the same as pressing the default Button on the Form. The default Button is the one assigned to a Form's <code>AcceptButton</code> property. |
| Multiline                       | If <code>true</code> , the TextBox can span multiple lines. The default value is <code>false</code> .                                                                                                                                                                                                                       |
| ReadOnly                        | If <code>true</code> , the TextBox has a gray background, and its text cannot be edited. The default value is <code>false</code> .                                                                                                                                                                                          |
| ScrollBars                      | For multiline textboxes, this property indicates which scrollbars appear (None—the default, Horizontal, Vertical or Both).                                                                                                                                                                                                  |
| Text                            | The TextBox's text content.                                                                                                                                                                                                                                                                                                 |
| UseSystemPasswordChar           | When <code>true</code> , the TextBox becomes a password TextBox, and the system-specified character masks each character the user types.                                                                                                                                                                                    |
| <i>Common Event</i>             |                                                                                                                                                                                                                                                                                                                             |
| TextChanged                     | Generated when the text changes in a TextBox (i.e., when the user adds or deletes characters). When you double click the TextBox control in Design mode, an empty event handler for this event is generated.                                                                                                                |

**Fig. 14.18** | TextBox properties and an event.

A button is a control that the user clicks to trigger a specific action or to select an option in a program. As you'll see, a program can use several types of buttons, such as **checkboxes** and **radio buttons**. All the button classes derive from class **ButtonBase** (namespace `System.Windows.Forms`), which defines common button features. In this section, we discuss class **Button**, which typically enables a user to issue a command to an app. Figure 14.19 lists common properties and a common event of class **Button**.

| Button properties and an event | Description                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>       |                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Text                           | Specifies the text displayed on the Button face.                                                                                                                                                                                                                                                                                                                                                                       |
| FlatStyle                      | Modifies a Button's appearance— <code>Flat</code> (for the Button to display without a three-dimensional appearance), <code>Popup</code> (for the Button to appear flat until the user moves the mouse pointer over the Button), <code>Standard</code> (three-dimensional) and <code>System</code> , where the Button's appearance is controlled by the operating system. The default value is <code>Standard</code> . |
| <i>Common Event</i>            |                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Click                          | Generated when the user clicks the Button. When you double click a Button in design view, an empty event handler for this event is created.                                                                                                                                                                                                                                                                            |

**Fig. 14.19** | Button properties and an event.

Figure 14.20 uses a **TextBox**, a **Button** and a **Label**. The user enters text into a password box and clicks the **Button**, causing the text input to be displayed in the **Label**. Normally, we would not display this text—the purpose of password **TextBoxes** is to hide the text being entered by the user. When the user clicks the **Show Me** **Button**, this app retrieves the text that the user typed in the password **TextBox** and displays it in a **Label**.

```

1 // Fig. 14.20: LabelTextBoxButtonTestForm.cs
2 // Using a TextBox, Label and Button to display
3 // the hidden text in a password TextBox.
4 using System;
5 using System.Windows.Forms;
6
7 namespace LabelTextBoxButtonTest
8 {
9     // Form that creates a password TextBox and
10    // a Label to display TextBox contents
11    public partial class LabelTextBoxButtonTestForm : Form
12    {
13        // default constructor
14        public LabelTextBoxButtonTestForm()
15        {
16            InitializeComponent();
17        } // end constructor
18
19        // display user input in Label
20        private void displayPasswordButton_Click(
21            object sender, EventArgs e )
22        {
23            // display the text that the user typed
24            displayPasswordLabel.Text = inputPasswordTextBox.Text;
25        } // end method displayPasswordButton_Click
26    } // end class LabelTextBoxButtonTestForm
27 } // end namespace LabelTextBoxButtonTest

```



**Fig. 14.20** | Program to display hidden text in a password box.

First, create the GUI by dragging the controls (a **TextBox**, a **Button** and a **Label**) onto the **Form**. Once the controls are positioned, change their names in the **Properties** window from the default values—**textBox1**, **button1** and **label1**—to the more descriptive **displayPasswordLabel**, **displayPasswordButton** and **inputPasswordTextBox**. The **(Name)** property in the **Properties** window enables us to change the variable name for a control. Visual Studio creates the necessary code and places it in method **InitializeComponent** of the partial class in the file **LabelTextBoxButtonTestForm.Designer.cs**.

We set `displayPasswordButton`'s `Text` property to "Show Me" and clear the `Text` of `displayPasswordLabel` so that it's blank when the program begins executing. The `BorderStyle` property of `displayPasswordLabel` is set to `Fixed3D`, giving our `Label` a three-dimensional appearance. We also changed its  `TextAlign` property to `MiddleLeft` so that the `Label`'s text is displayed centered between its top and bottom. The password character for `inputPasswordTextBox` is determined by the user's system settings when you set `UserSystemPasswordChar` to `true`.

We create an event handler for `displayPasswordButton` by double clicking this control in **Design** mode. We added line 24 to the event handler's body. When the user clicks the **Show Me** Button in the executing app, line 24 obtains the text entered by the user in `inputPasswordTextBox` and displays the text in `displayPasswordLabel`.

## 14.6 GroupBoxes and Panels

**GroupBoxes** and **Panels** arrange controls on a GUI. **GroupBoxes** and **Panels** are typically used to group several controls of similar functionality or several controls that are related in a GUI. All of the controls in a **GroupBox** or **Panel** move together when the **GroupBox** or **Panel** is moved. Furthermore, a **GroupBoxes** and **Panels** can also be used to show or hide a set of controls at once. When you modify a container's `Visible` property, it toggles the visibility of all the controls within it.

The primary difference between these two controls is that **GroupBoxes** can display a caption (i.e., text) and do *not* include scrollbars, whereas **Panels** can include scrollbars and do not include a caption. **GroupBoxes** have thin borders by default; **Panels** can be set so that they also have borders by changing their `BorderStyle` property. Figures 14.21–14.22 list the common properties of **GroupBoxes** and **Panels**, respectively.

| <b>Look-and-Feel Observation 14.2</b> |                                                                                                |
|---------------------------------------|------------------------------------------------------------------------------------------------|
|                                       | <i>Panels and GroupBoxes can contain other Panels and GroupBoxes for more complex layouts.</i> |

| GroupBox properties   | Description                                                              |
|-----------------------|--------------------------------------------------------------------------|
| <code>Controls</code> | The set of controls that the <b>GroupBox</b> contains.                   |
| <code>Text</code>     | Specifies the caption text displayed at the top of the <b>GroupBox</b> . |

**Fig. 14.21** | **GroupBox** properties.

| Panel properties         | Description                                                                                                                                          |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>AutoScroll</code>  | Indicates whether scrollbars appear when the <b>Panel</b> is too small to display all of its controls. The default value is <code>false</code> .     |
| <code>BorderStyle</code> | Sets the border of the <b>Panel</b> . The default value is <code>None</code> ; other options are <code>Fixed3D</code> and <code>FixedSingle</code> . |
| <code>Controls</code>    | The set of controls that the <b>Panel</b> contains.                                                                                                  |

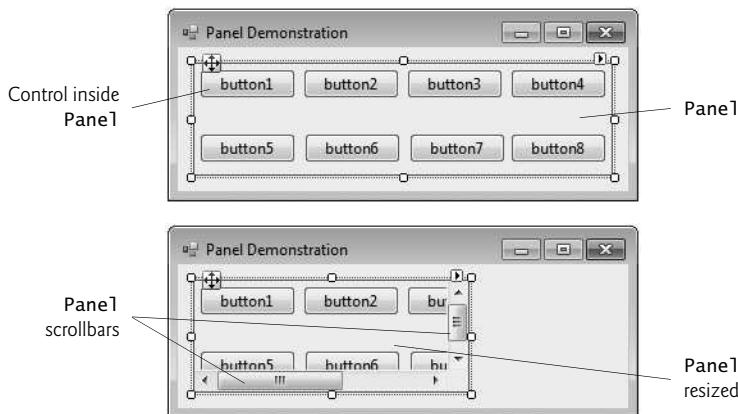
**Fig. 14.22** | **Panel** properties.

**Look-and-Feel Observation 14.3**

You can organize a GUI by anchoring and docking controls inside a **GroupBox** or **Panel**. The **GroupBox** or **Panel** then can be anchored or docked inside a **Form**. This divides controls into functional “groups” that can be arranged easily.

To create a **GroupBox**, drag its icon from the **Toolbox** onto a **Form**. Then, drag new controls from the **Toolbox** into the **GroupBox**. These controls are added to the **GroupBox**’s **Controls** property and become part of the **GroupBox**. The **GroupBox**’s **Text** property specifies the caption at the top of the **GroupBox**.

To create a **Panel**, drag its icon from the **Toolbox** onto the **Form**. You can then add controls directly to the **Panel** by dragging them from the **Toolbox** onto the **Panel**. To enable the scrollbars, set the **Panel**’s **AutoScroll** property to **true**. If the **Panel** is resized and cannot display all of its controls, scrollbars appear (Fig. 14.23). The scrollbars can be used to view *all* the controls in the **Panel**—at design time *and* at execution time. In Fig. 14.23, we set the **Panel**’s **BorderStyle** property to **FixedSingle** so that you can see the **Panel** in the **Form**.



**Fig. 14.23** | Creating a **Panel** with scrollbars.

**Look-and-Feel Observation 14.4**

Use **Panels** with scrollbars to avoid cluttering a GUI and to reduce the GUI’s size.

The program in Fig. 14.24 uses a **GroupBox** and a **Panel** to arrange **Buttons**. When these **Buttons** are clicked, their event handlers change the text on a **Label**.

```

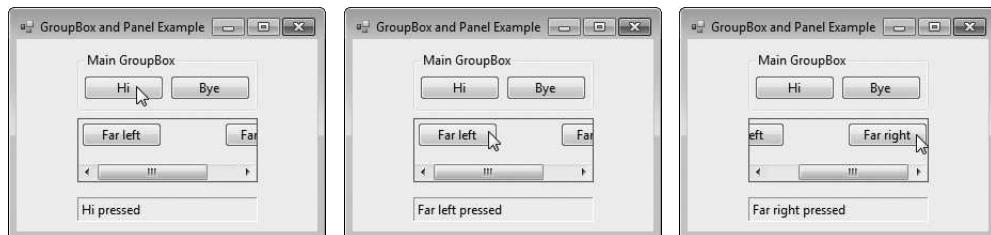
1 // Fig. 14.24: GroupBoxPanelExampleForm.cs
2 // Using GroupBoxes and Panels to arrange Buttons.
3 using System;
4 using System.Windows.Forms;
```

**Fig. 14.24** | Using **GroupBoxes** and **Panels** to arrange **Buttons**. (Part 1 of 2.)

```

5   namespace groupBoxPanelExample
6   {
7       // Form that displays a GroupBox and a Panel
8       public partial class groupBoxPanelExampleForm : Form
9       {
10           // default constructor
11           public groupBoxPanelExampleForm()
12           {
13               InitializeComponent();
14           } // end constructor
15
16
17           // event handler for Hi Button
18           private void hiButton_Click( object sender, EventArgs e )
19           {
20               messageLabel.Text = "Hi pressed"; // change text in Label
21           } // end method hiButton_Click
22
23           // event handler for Bye Button
24           private void byeButton_Click( object sender, EventArgs e )
25           {
26               messageLabel.Text = "Bye pressed"; // change text in Label
27           } // end method byeButton_Click
28
29           // event handler for Far Left Button
30           private void leftButton_Click( object sender, EventArgs e )
31           {
32               messageLabel.Text = "Far left pressed"; // change text in Label
33           } // end method leftButton_Click
34
35           // event handler for Far Right Button
36           private void rightButton_Click( object sender, EventArgs e )
37           {
38               messageLabel.Text = "Far right pressed"; // change text in Label
39           } // end method rightButton_Click
40       } // end class groupBoxPanelExampleForm
41   } // end namespace groupBoxPanelExample

```



**Fig. 14.24** | Using GroupBoxes and Panels to arrange Buttons. (Part 2 of 2.)

The `mainGroupBox` has two Buttons—`hiButton` (which displays the text `Hi`) and `byeButton` (which displays the text `Bye`). The `Panel` (named `mainPanel`) also has two Buttons, `leftButton` (which displays the text `Far Left`) and `rightButton` (which displays the text `Far Right`). The `mainPanel` has its `AutoScroll` property set to `true`, allowing scrollbars to appear

when the contents of the Panel require more space than the Panel's visible area. The Label (named `messageLabel1`) is initially blank. To add controls to `mainGroupBox` or `mainPanel1`, Visual Studio calls method `Add` of each container's `Controls` property. This code is placed in the partial class located in the file `GroupBoxPanelExample.Designer.cs`.

The event handlers for the four Buttons are located in lines 18–39. Lines 20, 26, 32 and 38 change the text of `messageLabel1` to indicate which Button the user pressed.

## 14.7 Check Boxes and Radio Buttons

C# has two types of **state buttons** that can be in the on/off or true/false states—**Check Boxes** and **RadioButtons**. Like class `Button`, classes `CheckBox` and `RadioButton` are derived from class `ButtonBase`.

### **Check Boxes**

A `CheckBox` is a small square that either is blank or contains a check mark. When the user clicks a `CheckBox` to select it, a check mark appears in the box. If the user clicks the `CheckBox` again to deselect it, the check mark is removed. You can also configure a `CheckBox` to toggle between three states (*checked*, *unchecked* and *indeterminate*) by setting its **Three-State** property to `true`. Any number of `CheckBoxes` can be selected at a time. A list of common `CheckBox` properties and events appears in Fig. 14.25.

| CheckBox properties and events | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Appearance                     | By default, this property is set to <code>Normal</code> , and the <code>CheckBox</code> displays as a traditional checkbox. If it's set to <code>Button</code> , the <code>CheckBox</code> displays as a Button that looks pressed when the <code>CheckBox</code> is checked.                                                                                                                                                                                                   |
| Checked                        | Indicates whether the <code>CheckBox</code> is <i>checked</i> (contains a check mark) or <i>unchecked</i> (blank). This property returns a <code>bool</code> value. The default is <code>false</code> ( <i>unchecked</i> ).                                                                                                                                                                                                                                                     |
| CheckState                     | Indicates whether the <code>CheckBox</code> is <i>checked</i> or <i>unchecked</i> with a value from the <code>CheckState</code> enumeration ( <code>Checked</code> , <code>Unchecked</code> or <code>Indeterminate</code> ). <code>Indeterminate</code> is used when it's unclear whether the state should be <code>Checked</code> or <code>Unchecked</code> . When <code>CheckState</code> is set to <code>Indeterminate</code> , the <code>CheckBox</code> is usually shaded. |
| Text                           | Specifies the text displayed to the right of the <code>CheckBox</code> .                                                                                                                                                                                                                                                                                                                                                                                                        |
| ThreeState                     | When this property is <code>true</code> , the <code>CheckBox</code> has three states— <i>checked</i> , <i>unchecked</i> and <i>indeterminate</i> . By default, this property is <code>false</code> and the <code>CheckBox</code> has only two states— <i>checked</i> and <i>unchecked</i> .                                                                                                                                                                                     |
| <i>Common Events</i>           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| CheckedChanged                 | Generated when the <code>Checked</code> or <code>CheckState</code> property changes. This is a <code>CheckBox</code> 's default event. When a user double-clicks the <code>CheckBox</code> control in design view, an empty event handler for this event is generated.                                                                                                                                                                                                          |
| CheckStateChanged              | Generated when the <code>Checked</code> or <code>CheckState</code> property changes.                                                                                                                                                                                                                                                                                                                                                                                            |

**Fig. 14.25** | `CheckBox` properties and events.

The program in Fig. 14.26 allows the user to select CheckBoxes to change a Label's font style. The event handler for one CheckBox applies bold and the event handler for the other applies italic. If both CheckBoxes are selected, the font style is set to bold and italic. Initially, neither CheckBox is checked.

```

1 // Fig. 14.26: CheckBoxTestForm.cs
2 // Using CheckBoxes to toggle italic and bold styles.
3 using System;
4 using System.Drawing;
5 using System.Windows.Forms;
6
7 namespace CheckBoxTest
8 {
9     // Form contains CheckBoxes to allow the user to modify sample text
10    public partial class CheckBoxTestForm : Form
11    {
12        // default constructor
13        public CheckBoxTestForm()
14        {
15            InitializeComponent();
16        } // end constructor
17
18        // toggle the font style between bold and
19        // not bold based on the current setting
20        private void boldCheckBox_CheckedChanged(
21            object sender, EventArgs e )
22        {
23            outputLabel.Font = new Font( outputLabel.Font,
24                outputLabel.Font.Style ^ FontStyle.Bold );
25        } // end method boldCheckBox_CheckedChanged
26
27        // toggle the font style between italic and
28        // not italic based on the current setting
29        private void italicCheckBox_CheckedChanged(
30            object sender, EventArgs e )
31        {
32            outputLabel.Font = new Font( outputLabel.Font,
33                outputLabel.Font.Style ^ FontStyle.Italic );
34        } // end method italicCheckBox_CheckedChanged
35    } // end class CheckBoxTestForm
36 } // end namespace CheckBoxTest

```



**Fig. 14.26** | Using CheckBoxes to change font styles.

The boldCheckBox has its Text property set to Bold. The italicCheckBox has its Text property set to Italic. The Text property of outputLabel is set to Watch the font style change. After creating the controls, we define their event handlers. Double clicking the CheckBoxes at design time creates empty CheckedChanged event handlers.

To change a Label's font style, set its `Font` property to a new `Font` object (lines 23–24 and 32–33). Class `Font` is in the `System.Drawing` namespace. The `Font` constructor that we use here takes the current font and new style as arguments. The first argument—`outputLabel.Font`—uses `outputLabel`'s original font name and size. The style is specified with a member of the `FontStyle` enumeration, which contains `Regular`, `Bold`, `Italic`, `Strikeout` and `Underline`. (The `Strikeout` style displays text with a line through it.) A `Font` object's `Style` property is read-only, so it can be set only when the `Font` object is created.

### *Combining Font Styles with Bitwise Operators*

Styles can be combined via **bitwise operators**—operators that perform manipulation on bits of information. Recall from Chapter 1 that all data is represented in the computer as combinations of 0s and 1s. Each 0 or 1 represents a bit. The `FontStyle` (namespace `System.Drawing`) is represented as a set of bits that are selected in a way that allows us to combine different `FontStyle` elements to create compound styles, using bitwise operators. These styles are *not mutually exclusive*, so we can combine different styles and remove them without affecting the combination of previous `FontStyle` elements. We can combine these various font styles, using either the *logical OR* (`|`) operator or the *logical exclusive OR* (`^`) operator (also called XOR). When the *logical OR* operator is applied to two bits, if at least one bit of the two has the value 1, then the result is 1. Combining styles using the *logical OR* operator works as follows. Assume that `FontStyle.Bold` is represented by bits 01 and that `FontStyle.Italic` is represented by bits 10. When we use the *logical OR* (`|`) to combine the styles, we obtain the bits 11.

```
01 = Bold
10 = Italic
--
11 = Bold and Italic
```

The *logical OR* operator helps create style combinations. However, what happens if we want to *undo* a style combination, as we did in Fig. 14.26?

The *logical exclusive OR* operator enables us to combine styles and to *undo* existing style settings. When *logical exclusive OR* is applied to two bits, if both bits have the same value, then the result is 0. If both bits are different, then the result is 1.

Combining styles using *logical exclusive OR* works as follows. Assume, again, that `FontStyle.Bold` is represented by bits 01 and that `FontStyle.Italic` is represented by bits 10. When we use *logical exclusive OR* (`^`) on both styles, we obtain the bits 11.

```
01 = Bold
10 = Italic
--
11 = Bold and Italic
```

Now, suppose that we would like to *remove* the `FontStyle.Bold` style from the previous combination of `FontStyle.Bold` and `FontStyle.Italic`. The easiest way to do so is to reapply the *logical exclusive OR* (`^`) operator to the compound style and `FontStyle.Bold`.

```
11 = Bold and Italic
01 = Bold
--
10 = Italic
```

This is a simple example. The advantages of using bitwise operators to combine `FontStyle` values become more evident when we consider that there are five `FontStyle` values (`Bold`, `Italic`, `Regular`, `Strikeout` and `Underline`), resulting in 16 `FontStyle` combinations. Using bitwise operators to combine font styles greatly reduces the amount of code required to check all possible font combinations.

In Fig. 14.26, we need to set the `FontStyle` so that the text appears in bold if it was not bold originally, and vice versa. Line 24 uses the *bitwise logical exclusive OR operator* to do this. If `outputLabel1.Font.Style` is bold, then the resulting style is not bold. If the text is originally italic, the resulting style is bold and italic, rather than just bold. The same applies for `FontStyle.Italic` in line 33.

If we didn't use bitwise operators to compound `FontStyle` elements, we'd have to test for the current style and change it accordingly. In `boldCheckBox_CheckedChanged`, we could test for the regular style and make it bold, test for the bold style and make it regular, test for the italic style and make it bold italic and test for the italic bold style and make it italic. This is cumbersome because, for every new style we add, we double the number of combinations. Adding a `CheckBox` for underline would require testing eight additional styles. Adding a `CheckBox` for strikeout would require testing 16 additional styles.

### **RadioButtons**

Radio buttons (defined with class `RadioButton`) are similar to `Checkboxes` in that they also have two states—**selected** and **not selected** (also called **deselected**). However, `RadioButtons` normally appear as a **group**, in which only one `RadioButton` can be selected at a time. Selecting one `RadioButton` in the group forces all the others to be deselected. Therefore, `RadioButtons` are used to represent a set of **mutually exclusive** options (i.e., a set in which multiple options *cannot* be selected at the same time).



#### **Look-and-Feel Observation 14.5**

*Use `RadioButtons` when the user should choose only one option in a group. Use `Checkboxes` when the user should be able to choose multiple options in a group.*

All `RadioButtons` added to a container become part of the same group. To divide `RadioButtons` into several groups, they must be added to *separate* containers, such as `GroupBoxes` or `Panels`. The common properties and a common event of class `RadioButton` are listed in Fig. 14.27.

| RadioButton<br>properties and an event | Description                                                                                                                                                                                             |
|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>               |                                                                                                                                                                                                         |
| <code>Checked</code>                   | Indicates whether the <code>RadioButton</code> is checked.                                                                                                                                              |
| <code>Text</code>                      | Specifies the <code>RadioButton</code> 's text.                                                                                                                                                         |
| <i>Common Event</i>                    |                                                                                                                                                                                                         |
| <code>CheckedChanged</code>            | Generated every time the <code>RadioButton</code> is checked or unchecked. When you double click a <code>RadioButton</code> control in design view, an empty event handler for this event is generated. |

**Fig. 14.27** | `RadioButton` properties and an event.



### Software Engineering Observation 14.1

*Forms, GroupBoxes, and Panels can act as logical groups for RadioButtons. The RadioButtons within each group are mutually exclusive to each other, but not to RadioButtons in different logical groups.*

The program in Fig. 14.28 uses RadioButtons to enable users to select options for a MessageBox. After selecting the desired attributes, the user presses the **Display** Button to display the MessageBox. A Label in the lower-left corner shows the result of the MessageBox (i.e., which Button the user clicked—**Yes**, **No**, **Cancel**, etc.).

```

1 // Fig. 14.28: RadioButtonsTestForm.cs
2 // Using RadioButtons to set message window options.
3 using System;
4 using System.Windows.Forms;
5
6 namespace RadioButtonsTest
7 {
8     // Form contains several RadioButtons--user chooses one
9     // from each group to create a custom MessageBox
10    public partial class RadioButtonsTestForm : Form
11    {
12        // create variables that store the user's choice of options
13        private MessageBoxIcon iconType;
14        private MessageBoxButtons buttonType;
15
16        // default constructor
17        public RadioButtonsTestForm()
18        {
19            InitializeComponent();
20        } // end constructor
21
22        // change Buttons based on option chosen by sender
23        private void buttonType_CheckedChanged(
24            object sender, EventArgs e )
25        {
26            if ( sender == okRadioButton ) // display OK Button
27                buttonType = MessageBoxButtons.OK;
28
29            // display OK and Cancel Buttons
30            else if ( sender == okCancelRadioButton )
31                buttonType = MessageBoxButtons.OKCancel;
32
33            // display Abort, Retry and Ignore Buttons
34            else if ( sender == abortRetryIgnoreRadioButton )
35                buttonType = MessageBoxButtons.AbortRetryIgnore;
36
37            // display Yes, No and Cancel Buttons
38            else if ( sender == yesNoCancelRadioButton )
39                buttonType = MessageBoxButtons.YesNoCancel;
40

```

**Fig. 14.28** | Using RadioButtons to set message-window options. (Part I of 4.)

```
41         // display Yes and No Buttons
42     else if ( sender == yesNoRadioButton )
43         buttonType = MessageBoxButtons.YesNo;
44
45     // only one option left--display Retry and Cancel Buttons
46     else
47         buttonType = MessageBoxButtons.RetryCancel;
48 } // end method buttonType_CheckedChanged
49
50 // change Icon based on option chosen by sender
51 private void iconType_CheckedChanged( object sender, EventArgs e )
52 {
53     if ( sender == asteriskRadioButton ) // display asterisk Icon
54         iconType = MessageBoxIcon.Asterisk;
55
56     // display error Icon
57     else if ( sender == errorRadioButton )
58         iconType = MessageBoxIcon.Error;
59
60     // display exclamation point Icon
61     else if ( sender == exclamationRadioButton )
62         iconType = MessageBoxIcon.Exclamation;
63
64     // display hand Icon
65     else if ( sender == handRadioButton )
66         iconType = MessageBoxIcon.Hand;
67
68     // display information Icon
69     else if ( sender == informationRadioButton )
70         iconType = MessageBoxIcon.Information;
71
72     // display question mark Icon
73     else if ( sender == questionRadioButton )
74         iconType = MessageBoxIcon.Question;
75
76     // display stop Icon
77     else if ( sender == stopRadioButton )
78         iconType = MessageBoxIcon.Stop;
79
80     // only one option left--display warning Icon
81     else
82         iconType = MessageBoxIcon.Warning;
83 } // end method iconType_CheckedChanged
84
85 // display MessageBox and Button user pressed
86 private void displayButton_Click( object sender, EventArgs e )
87 {
88     // display MessageBox and store
89     // the value of the Button that was pressed
90     DialogResult result = MessageBox.Show(
91         "This is your Custom MessageBox.", "Custom MessageBox",
92         buttonType, iconType );
93 }
```

Fig. 14.28 | Using RadioButtons to set message-window options. (Part 2 of 4.)

```

94         // check to see which Button was pressed in the MessageBox
95         // change text displayed accordingly
96         switch (result)
97         {
98             case DialogResult.OK:
99                 displayLabel.Text = "OK was pressed.";
100                break;
101            case DialogResult.Cancel:
102                 displayLabel.Text = "Cancel was pressed.";
103                break;
104            case DialogResult.Abort:
105                 displayLabel.Text = "Abort was pressed.";
106                break;
107            case DialogResult.Retry:
108                 displayLabel.Text = "Retry was pressed.";
109                break;
110            case DialogResult.Ignore:
111                 displayLabel.Text = "Ignore was pressed.";
112                break;
113            case DialogResult.Yes:
114                 displayLabel.Text = "Yes was pressed.";
115                break;
116            case DialogResult.No:
117                 displayLabel.Text = "No was pressed.";
118                break;
119         } // end switch
120     } // end method displayButton_Click
121 } // end class RadioButtonsTestForm
122 } // end namespace RadioButtonsTest

```

a) GUI for testing RadioButtons



b) AbortRetryIgnore button type

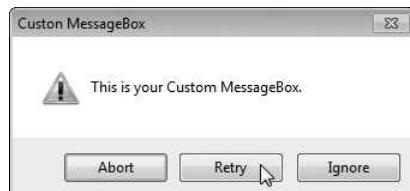


Fig. 14.28 | Using RadioButtons to set message-window options. (Part 3 of 4.)

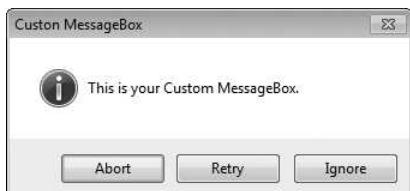
c) OKCancel button type



d) OK button type



e) AbortRetryIgnore button type



f) YesNoCancel button type



g) YesNo button type



h) RetryCancel button type

**Fig. 14.28** | Using RadioButtons to set message-window options. (Part 4 of 4.)

We store the user's choices in `iconType` and `buttonType` (declared in lines 13–14). Object `iconType` is of type `MessageBoxIcon`, and can have values `Asterisk`, `Error`, `Exclamation`, `Hand`, `Information`, `None`, `Question`, `Stop` and `Warning`. The sample output shows only `Error`, `Exclamation`, `Information` and `Question` icons.

Object `buttonType` is of type `MessageBoxButtons`, and can have values `AbortRetryIgnore`, `OK`, `OKCancel`, `RetryCancel`, `YesNo` and `YesNoCancel`. The name indicates the options that are presented to the user in the `MessageBox`. The sample output windows show `MessageBoxes` for all of the `MessageBoxButtons` enumeration values.

We created two `GroupBoxes`, one for each set of enumeration values. The `GroupBox` captions are **Button Type** and **Icon**. The `GroupBoxes` contain `RadioButtons` for the corresponding enumeration options, and the `RadioButtons`' `Text` properties are set appropriately. Because the `RadioButtons` are grouped, only one `RadioButton` can be selected from each `GroupBox`. There's also a `Button` (`displayButton`) labeled **Display**. When a user clicks this `Button`, a customized `MessageBox` is displayed. A `Label` (`displayLabel`) displays which `Button` the user pressed within the `MessageBox`.

The event handler for the `RadioButtons` handles the `CheckedChanged` event of each `RadioButton`. When a `RadioButton` contained in the **Button Type** `GroupBox` is checked, the corresponding event handler sets `buttonType` to the appropriate value. Lines 23–48 contain the event handling for these `RadioButtons`. Similarly, when the user checks the

RadioButtons belonging to the **Icon** GroupBox, the corresponding event handler associated with these events (lines 51–83) sets `iconType` to the appropriate value.

The `Click` event handler for `displayButton` (lines 86–120) creates a `MessageBox` (lines 90–92). The `MessageBox` options are specified with the values stored in `iconType` and `buttonType`. When the user clicks one of the `MessageBox`'s buttons, the result of the message box is returned to the app. This result is a value from the **DialogResult** enumeration that contains `Abort`, `Cancel`, `Ignore`, `No`, `None`, `OK`, `Retry` or `Yes`. The switch statement in lines 96–119 tests for the result and sets `displayLabel.Text` appropriately.

## 14.8 PictureBoxes

A `PictureBox` displays an image. The image can be one of several formats, such as bitmap, PNG (Portable Network Graphics), GIF (Graphics Interchange Format) and JPEG. A `PictureBox`'s `Image` property specifies the image that's displayed, and the `SizeMode` property indicates how the image is displayed (`Normal`, `StretchImage`, `AutoSize`, `CenterImage` or `Zoom`). Figure 14.29 describes common `PictureBox` properties and a common event.

Figure 14.30 uses a `PictureBox` named `imagePictureBox` to display one of three bitmap images—`image0.bmp`, `image1.bmp` or `image2.bmp`. These images are provided in the `Images` subdirectory of this chapter's examples directory. Whenever a user clicks the **Next Image** Button, the image changes to the next image in sequence. When the last image is displayed and the user clicks the **Next Image** Button, the first image is displayed again.

| <b>PictureBox</b> properties<br>and an event | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <code>Image</code>                           | Sets the image to display in the <code>PictureBox</code> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <code>SizeMode</code>                        | Enumeration that controls image sizing and positioning. Values are <code>Normal</code> (default), <code>StretchImage</code> , <code>AutoSize</code> , <code>CenterImage</code> , and <code>Zoom</code> . <code>Normal</code> places the image in the <code>PictureBox</code> 's top-left corner, and <code>CenterImage</code> puts the image in the middle. These two options truncate the image if it's too large. <code>StretchImage</code> resizes the image to fit in the <code>PictureBox</code> . <code>AutoSize</code> resizes the <code>PictureBox</code> to hold the image. <code>Zoom</code> resizes the image to fit the <code>PictureBox</code> but maintains the original aspect ratio. |
| <i>Common Event</i>                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <code>Click</code>                           | Occurs when the user clicks a control. When you double click this control in the designer, an event handler is generated for this event.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

**Fig. 14.29** | `PictureBox` properties and an event.

---

```

1 // Fig. 14.30: PictureBoxTestForm.cs
2 // Using a PictureBox to display images.
3 using System;

```

**Fig. 14.30** | Using a `PictureBox` to display images. (Part 1 of 2.)

```
4  using System.Drawing;
5  using System.Windows.Forms;
6
7  namespace PictureBoxTest
8  {
9      // Form to display different images when PictureBox is clicked
10     public partial class PictureBoxTestForm : Form
11     {
12         private int imageNum = -1; // determines which image is displayed
13
14         // default constructor
15         public PictureBoxTestForm()
16         {
17             InitializeComponent();
18         } // end constructor
19
20         // change image whenever Next Button is clicked
21         private void nextButton_Click( object sender, EventArgs e )
22         {
23             imageNum = ( imageNum + 1 ) % 3; // imageNum cycles from 0 to 2
24
25             // retrieve image from resources and load into PictureBox
26             imagePictureBox.Image = ( Image )
27                 ( Properties.Resources.ResourceManager.GetObject(
28                     string.Format( "image{0}", imageNum ) ) );
29         } // end method nextButton_Click
30     } // end class PictureBoxTestForm
31 } // end namespace PictureBoxTest
```



Fig. 14.30 | Using a PictureBox to display images. (Part 2 of 2.)

### *Using Resources Programmatically*

In this example, we added the images to the project as **resources**. This causes the compiler to embed the images in the app's executable file and enables the app to access the images through the project's **Properties** namespace. By embedding the images in the app, you don't need to worry about wrapping the images with the app when you move it to another location or computer.

If you're creating a new project, use the following steps to add images to the project as resources:

1. After creating your project, right click the project's **Properties** node in the **Solution Explorer** and select **Open** to display the project's properties.
2. From the tabs on the left, click the **Resources** tab.
3. At the top of the **Resources** tab, click the down arrow next to **Add Resource** and select **Add Existing File...** to display the **Add existing file to resources** dialog.
4. Locate the image files you wish to add as resources and click the **Open** button. We provided three sample images in the **Images** folder with this chapter's examples.
5. Save your project.

The files now appear in a folder named **Resources** in the **Solution Explorer**. We'll use this technique in most examples that use images going forward.

A project's resources are stored in its **Resources** class (of the project's **Properties** namespace). The **Resources** class contains a **ResourceManager** object for interacting with the resources programmatically. To access an image, you can use the method **GetObject**, which takes as an argument the resource name as it appears in the **Resources** tab (e.g., "image0") and returns the resource as an **Object**. Lines 27–28 invoke **GetObject** with the result of the expression

```
string.Format("image{0}", imageNum)
```

which builds the name of the resource by placing the index of the next picture (**imageNum**, which was obtained earlier in line 23) at the end of the word "image". You must convert this **Object** to type **Image** (namespace **System.Drawing**) to assign it to the **PictureBox**'s **Image** property (line 26).

The **Resources** class also provides direct access to the resources you define with expressions of the form **Resources.resourceName**, where **resourceName** is the name you provided to the resource when you created it. When using such an expression, the resource returned already has the appropriate type. For example, **Properties.Resources.image0** is an **Image** object representing the first image.

## 14.9 ToolTips

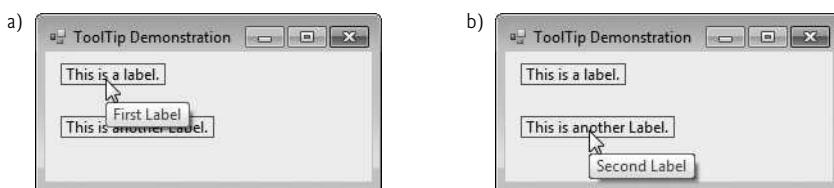
In Chapter 2, we demonstrated *tool tips*—the helpful text that appears when the mouse hovers over an item in a GUI. Recall that the tool tips displayed in Visual Studio help you become familiar with the IDE's features and serve as useful reminders for each toolbar icon's functionality. Many programs use tool tips to remind users of each control's purpose. For example, Microsoft Word has tool tips that help users determine the purpose of the app's icons. This section demonstrates how to use the **ToolTip** component to add tool

tips to your apps. Figure 14.31 describes common properties and a common event of class `ToolTip`.

| ToolTip properties and an event | Description                                                                                                                              |
|---------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>        |                                                                                                                                          |
| <code>AutoPopDelay</code>       | The amount of time (in milliseconds) that the tool tip appears while the mouse is over a control.                                        |
| <code>InitialDelay</code>       | The amount of time (in milliseconds) that a mouse must hover over a control before a tool tip appears.                                   |
| <code>ReshowDelay</code>        | The amount of time (in milliseconds) between which two different tool tips appear (when the mouse is moved from one control to another). |
| <i>Common Event</i>             |                                                                                                                                          |
| <code>Draw</code>               | Raised when the tool tip is displayed. This event allows programmers to modify the appearance of the tool tip.                           |

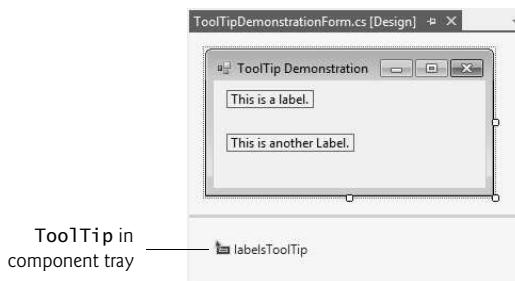
**Fig. 14.31** | `ToolTip` properties and an event.

When you add a `ToolTip` component from the **Toolbox**, it appears in the **component tray**—the region below the **Form** in **Design** mode. Once a `ToolTip` is added to a **Form**, a new property appears in the **Properties** window for the **Form**'s other controls. This property appears in the **Properties** window as **ToolTip on**, followed by the name of the `ToolTip` component. For instance, if our **Form**'s `ToolTip` were named `helpfulToolTip`, you would set a control's **ToolTip on helpfulToolTip** property value to specify the control's tool tip text. Figure 14.32 demonstrates the `ToolTip` component. For this example, we create a GUI containing two `Labels`, so we can demonstrate different tool tip text for each `Label`. To make the sample outputs clearer, we set the **BorderStyle** property of each `Label` to **FixedSingle**, which displays a solid border. Since there's no event-handling code in this example, we do not show you the code for the `Form` class.

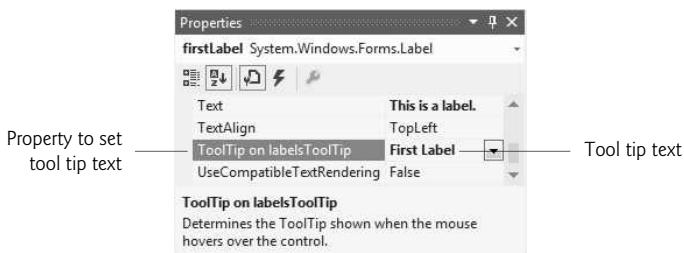


**Fig. 14.32** | Demonstrating the `ToolTip` component.

In this example, we named the `ToolTip` component `labelsToolTip`. Figure 14.33 shows the `ToolTip` in the component tray. We set the tool tip text for the first `Label` to "First Label" and the tool tip text for the second `Label` to "Second Label". Figure 14.34 demonstrates setting the tool tip text for the first `Label`.



**Fig. 14.33** | Demonstrating the component tray.



**Fig. 14.34** | Setting a control's tool tip text.

## 14.10 NumericUpDown Control

At times, you'll want to restrict a user's input choices to a specific *range of numeric values*. This is the purpose of the **NumericUpDown** control. This control appears as a TextBox, with two small Buttons on the right side—one with an up arrow and one with a down arrow. By default, a user can type numeric values into this control as if it were a TextBox or click the up and down arrows to increase or decrease the value in the control, respectively. The largest and smallest values in the range are specified with the **Maximum** and **Minimum** properties, respectively (both of type `decimal`). The **Increment** property (also of type `decimal`) specifies by how much the current value changes when the user clicks the arrows. Property **DecimalPlaces** specifies the number of decimal places that the control should display as an integer. Figure 14.35 describes common **NumericUpDown** properties and an event.

| NumericUpDown properties and an event | Description                                                                                                            |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>              |                                                                                                                        |
| <b>DecimalPlaces</b>                  | Specifies how many decimal places to display in the control.                                                           |
| <b>Increment</b>                      | Specifies by how much the current number in the control changes when the user clicks the control's up and down arrows. |

**Fig. 14.35** | **NumericUpDown** properties and an event. (Part 1 of 2.)

| NumericUpDown<br>properties and an event | Description                                                                                                                                                                           |
|------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Maximum                                  | Largest value in the control's range.                                                                                                                                                 |
| Minimum                                  | Smallest value in the control's range.                                                                                                                                                |
| UpDownAlign                              | Modifies the alignment of the up and down Buttons on the NumericUpDown control. This property can be used to display these Buttons either to the left or to the right of the control. |
| Value                                    | The numeric value currently displayed in the control.                                                                                                                                 |
| <i>Common Event</i>                      |                                                                                                                                                                                       |
| ValueChanged                             | This event is raised when the value in the control is changed.<br>This is the default event for the NumericUpDown control.                                                            |

**Fig. 14.35** | NumericUpDown properties and an event. (Part 2 of 2.)

Figure 14.36 demonstrates a NumericUpDown control in a GUI that calculates interest rate. The calculations performed in this app are similar to those in Fig. 6.6. TextBoxes are used to input the principal and interest rate amounts, and a NumericUpDown control is used to input the number of years for which we want to calculate interest.

---

```

1 // Fig. 14.36: InterestCalculatorForm.cs
2 // Demonstrating the NumericUpDown control.
3 using System;
4 using System.Windows.Forms;
5
6 namespace NumericUpDownTest
7 {
8     public partial class InterestCalculatorForm : Form
9     {
10         // default constructor
11         public InterestCalculatorForm()
12         {
13             InitializeComponent();
14         } // end constructor
15
16         private void calculateButton_Click(
17             object sender, EventArgs e )
18         {
19             // declare variables to store user input
20             decimal principal; // store principal
21             double rate; // store interest rate
22             int year; // store number of years
23             decimal amount; // store amount
24             string output; // store output
25
26             // retrieve user input
27             principal = Convert.ToDecimal( principalTextBox.Text );

```

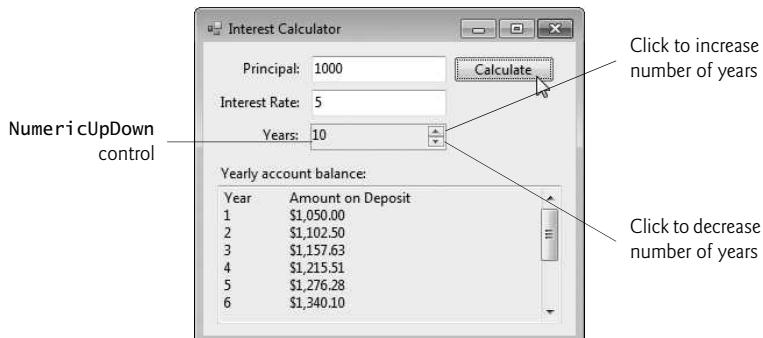
---

**Fig. 14.36** | Demonstrating the NumericUpDown control. (Part 1 of 2.)

```

28     rate = Convert.ToDouble( interestTextBox.Text );
29     year = Convert.ToInt32( yearUpDown.Value );
30
31     // set output header
32     output = "Year\tAmount on Deposit\r\n";
33
34     // calculate amount after each year and append to output
35     for ( int yearCounter = 1; yearCounter <= year; ++yearCounter )
36     {
37         amount = principal *
38             ( ( decimal ) Math.Pow( 1 + rate / 100, yearCounter ) );
39         output += ( yearCounter + "\t" +
40             string.Format( "{0:C}", amount ) + "\r\n" );
41     } // end for
42
43     displayTextBox.Text = output; // display result
44 } // end method calculateButton_Click
45 } // end class InterestCalculatorForm
46 } // end namespace NumericUpDownTest

```



**Fig. 14.36** | Demonstrating the `NumericUpDown` control. (Part 2 of 2.)

For the `NumericUpDown` control named `yearUpDown`, we set the `Minimum` property to 1 and the `Maximum` property to 10. We left the `Increment` property set to 1, its default value. These settings specify that users can enter a number of years in the range 1 to 10 in increments of 1. If we had set the `Increment` to 0.5, we could also input values such as 1.5 or 2.5. If you don't modify the `DecimalPlaces` property (0 by default), 1.5 and 2.5 display as 2 and 3, respectively. We set the `NumericUpDown`'s `ReadOnly` property to true to indicate that the user cannot type a number into the control to make a selection. Thus, the user must click the up and down arrows to modify the value in the control. By default, the `ReadOnly` property is set to `false`. The output for this app is displayed in a multiline read-only `TextBox` with a vertical scrollbar, so the user can scroll through the entire output.

## 14.11 Mouse-Event Handling

This section explains how to handle **mouse events**, such as **clicks** and **moves**, which are generated when the user interacts with a control via the mouse. Mouse events can be han-

dled for any control that derives from class `System.Windows.Forms.Control`. For most mouse events, information about the event is passed to the event-handling method through an object of class `MouseEventArgs`, and the delegate used to create the mouse-event handlers is `MouseEventHandler`. Each mouse-event-handling method for these events requires an object and a `MouseEventArgs` object as arguments.

Class `MouseEventArgs` contains information related to the mouse event, such as the mouse pointer's *x*- and *y*-coordinates, the mouse button pressed (Right, Left or Middle) and the number of times the mouse was clicked. The *x*- and *y*-coordinates of the `MouseEventArgs` object are relative to the control that generated the event—i.e., point (0,0) represents the upper-left corner of the control where the mouse event occurred. Several common mouse events and event arguments are described in Fig. 14.37.

| Mouse events and event arguments                               |                                                                                  |
|----------------------------------------------------------------|----------------------------------------------------------------------------------|
| <i>Mouse Events with Event Argument of Type EventArgs</i>      |                                                                                  |
| <code>MouseEnter</code>                                        | Mouse cursor enters the control's boundaries.                                    |
| <code>MouseHover</code>                                        | Mouse cursor hovers within the control's boundaries.                             |
| <code>MouseLeave</code>                                        | Mouse cursor leaves the control's boundaries.                                    |
| <i>Mouse Events with Event Argument of Type MouseEventArgs</i> |                                                                                  |
| <code>MouseDown</code>                                         | Mouse button is pressed while the mouse cursor is within a control's boundaries. |
| <code>MouseMove</code>                                         | Mouse cursor is moved while in the control's boundaries.                         |
| <code>MouseUp</code>                                           | Mouse button is released when the cursor is over the control's boundaries.       |
| <code>MouseWheel</code>                                        | Mouse wheel is moved while the control has the focus.                            |
| <i>Class MouseEventArgs Properties</i>                         |                                                                                  |
| <code>Button</code>                                            | Specifies which mouse button was pressed (Left, Right, Middle or None).          |
| <code>Clicks</code>                                            | The number of times that the mouse button was clicked.                           |
| <code>X</code>                                                 | The <i>x</i> -coordinate within the control where the event occurred.            |
| <code>Y</code>                                                 | The <i>y</i> -coordinate within the control where the event occurred.            |

**Fig. 14.37** | Mouse events and event arguments.

Figure 14.38 uses mouse events to draw on a Form. Whenever the user *drags* the mouse (i.e., moves the mouse while a mouse button is pressed), small circles appear on the Form at the position where each mouse event occurs during the drag operation.

---

```

1 // Fig. 14.38: PainterForm.cs
2 // Using the mouse to draw on a Form.
3 using System;
4 using System.Drawing;
5 using System.Windows.Forms;
6
7 namespace Painter
8 {

```

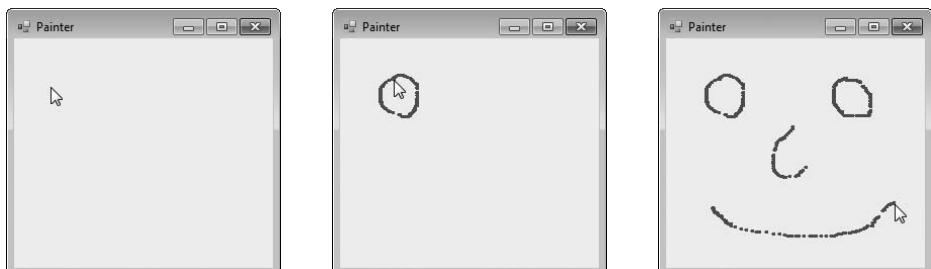
---

**Fig. 14.38** | Using the mouse to draw on a Form. (Part 1 of 2.)

```

9   // creates a Form that's a drawing surface
10  public partial class PainterForm : Form
11  {
12      bool shouldPaint = false; // determines whether to paint
13
14      // default constructor
15      public PainterForm()
16      {
17          InitializeComponent();
18      } // end constructor
19
20      // should paint when mouse button is pressed down
21      private void PainterForm_MouseDown(
22          object sender, MouseEventArgs e )
23      {
24          // indicate that user is dragging the mouse
25          shouldPaint = true;
26      } // end method PainterForm_MouseDown
27
28      // stop painting when mouse button is released
29      private void PainterForm_MouseUp( object sender, MouseEventArgs e )
30      {
31          // indicate that user released the mouse button
32          shouldPaint = false;
33      } // end method PainterForm_MouseUp
34
35      // draw circle whenever mouse moves with its button held down
36      private void PainterForm_MouseMove(
37          object sender, MouseEventArgs e )
38      {
39          if ( shouldPaint ) // check if mouse button is being pressed
40          {
41              // draw a circle where the mouse pointer is present
42              using ( Graphics graphics = CreateGraphics() )
43              {
44                  graphics.FillEllipse(
45                      new SolidBrush( Color.BlueViolet ), e.X, e.Y, 4, 4 );
46              } // end using; calls graphics.Dispose()
47          } // end if
48      } // end method PainterForm_MouseMove
49  } // end class PainterForm
50 } // end namespace Painter

```



**Fig. 14.38** | Using the mouse to draw on a Form. (Part 2 of 2.)

In line 12, the program declares variable `shouldPaint`, which determines whether to draw on the Form. We want the program to draw only while the mouse button is pressed (i.e., held down). Thus, when the user clicks or holds down a mouse button, the system generates a `MouseDown` event, and the event handler (lines 21–26) sets `shouldPaint` to `true`. When the user releases the mouse button, the system generates a `MouseUp` event, `shouldPaint` is set to `false` in the `PainterForm_MouseUp` event handler (lines 29–33) and the program stops drawing. Unlike `MouseMove` events, which occur continuously as the user moves the mouse, the system generates a `MouseDown` event only when a mouse button is first *pressed* and generates a `MouseUp` event only when a mouse button is *released*.

Whenever the mouse moves over a control, the `MouseMove` event for that control occurs. Inside the `PainterForm_MouseMove` event handler (lines 36–48), the program draws only if `shouldPaint` is `true` (i.e., a mouse button is pressed). In the `using` statement, line 42 calls inherited `Form` method `CreateGraphics` to create a `Graphics` object that allows the program to draw on the `Form`. Class `Graphics` provides methods that draw various shapes. For example, lines 44–45 use method `FillEllipse` to draw a circle. The first parameter to method `FillEllipse` in this case is an object of class `SolidBrush`, which specifies the solid color that will fill the shape. The color is provided as an argument to class `SolidBrush`'s constructor. Type `Color` contains numerous predefined color constants—we selected `Color.BlueViolet`. `FillEllipse` draws an oval in a bounding rectangle that's specified by the *x*- and *y*-coordinates of its upper-left corner, its width and its height—the final four arguments to the method. The *x*- and *y*-coordinates represent the location of the mouse event and can be taken from the mouse-event arguments (`e.X` and `e.Y`). To draw a circle, we set the width and height of the bounding rectangle so that they're equal—in this example, both are 4 pixels. `Graphics`, `SolidBrush` and `Color` are all part of the namespace `System.Drawing`. Recall from Chapter 13 that the `using` statement automatically calls `Dispose` on the object that was created in the parentheses following keyword `using`. This is important because `Graphics` objects are a limited resource. Calling `Dispose` on a `Graphics` object ensures that its resources are returned to the system for reuse.

## 14.12 Keyboard-Event Handling

Key events occur when keyboard keys are pressed and released. Such events can be handled for any control that inherits from `System.Windows.Forms.Control`. There are three key events—`KeyPress`, `KeyUp` and `KeyDown`. The `KeyPress` event occurs when the user presses a key that represents an ASCII character. The specific key can be determined with property `KeyChar` of the event handler's `KeyPressEventArgs` argument. ASCII is a 128-character set of alphanumeric symbols, a full listing of which can be found in Appendix C.

The `KeyPress` event does *not* indicate whether **modifier keys** (e.g., `Shift`, `Alt` and `Ctrl`) were pressed when a key event occurred. If this information is important, the `KeyUp` or `KeyDown` events can be used. The `KeyEventEventArgs` argument for each of these events contains information about modifier keys. Figure 14.39 lists important key event information. Several properties return values from the `Keys` enumeration, which provides constants that specify the various keys on a keyboard. Like the `FontStyle` enumeration (Section 14.7), the `Keys` enumeration is represented with a set of bits, so the enumeration's constants can be combined with the bitwise operators to indicate *multiple keys* pressed at the same time.

**Keyboard events and event arguments**

*Key Events with Event Arguments of Type KeyEventArgs*

**KeyDown** Generated when a key is initially pressed.

**KeyUp** Generated when a key is released.

*Key Event with Event Argument of Type KeyPressEventArgs*

**KeyPress** Generated when a key is pressed. Raised after KeyDown and before KeyUp.

*Class KeyPressEventArgs Properties*

**KeyChar** Returns the ASCII character for the key pressed.

*Class KeyEventArgs Properties*

**Alt** Indicates whether the *Alt* key was pressed.

**Control** Indicates whether the *Ctrl* key was pressed.

**Shift** Indicates whether the *Shift* key was pressed.

**KeyCode** Returns the key code for the key as a value from the **Keys** enumeration. This does not include modifier-key information. It's used to test for a specific key.

**KeyData** Returns the key code for a key combined with modifier information as a **Keys** value. This property contains all information about the pressed key.

**KeyValue** Returns the key code as an **int**, rather than as a value from the **Keys** enumeration. This property is used to obtain a numeric representation of the pressed key. The **int** value is known as a Windows virtual key code.

**Modifiers** Returns a **Keys** value indicating any pressed modifier keys (*Alt*, *Ctrl* and *Shift*). This property is used to determine modifier-key information only.

**Fig. 14.39** | Keyboard events and event arguments.

Figure 14.40 demonstrates the use of the key-event handlers to display a key pressed by a user. The program is a **Form** with two **Labels** that displays the pressed key on one **Label** and modifier key information on the other.

---

```

1 // Fig. 14.40: KeyDemo.cs
2 // Displaying information about the key the user pressed.
3 using System;
4 using System.Windows.Forms;
5
6 namespace KeyDemo
7 {
8     // Form to display key information when key is pressed
9     public partial class KeyDemo : Form
10    {
11        // default constructor
12        public KeyDemo()
13        {

```

---

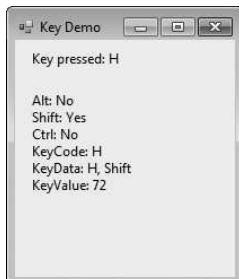
**Fig. 14.40** | Demonstrating keyboard events. (Part 1 of 2.)

```

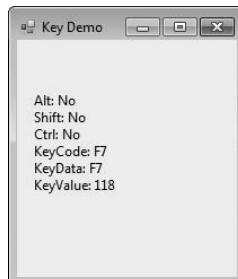
14         InitializeComponent();
15     } // end constructor
16
17     // display the character pressed using KeyChar
18     private void KeyDemo_KeyPress(object sender, KeyPressEventArgs e)
19     {
20         charLabel.Text = "Key pressed: " + e.KeyChar;
21     } // end method KeyDemo_KeyPress
22
23
24     // display modifier keys, key code, key data and key value
25     private void KeyDemo_KeyDown( object sender, KeyEventArgs e )
26     {
27         keyInfoLabel.Text =
28             "Alt: " + ( e.Alt ? "Yes" : "No" ) + '\n' +
29             "Shift: " + ( e.Shift ? "Yes" : "No" ) + '\n' +
30             "Ctrl: " + ( e.Control ? "Yes" : "No" ) + '\n' +
31             "KeyCode: " + e.KeyCode + '\n' +
32             "KeyData: " + e.KeyData + '\n' +
33             "KeyValue: " + e.KeyValue;
34     } // end method KeyDemo_KeyDown
35
36     // clear Labels when key released
37     private void KeyDemo_KeyUp( object sender, KeyEventArgs e )
38     {
39         charLabel.Text = "";
40         keyInfoLabel.Text = "";
41     } // end method KeyDemo_KeyUp
42 } // end class KeyDemo
43 } // end namespace KeyDemo

```

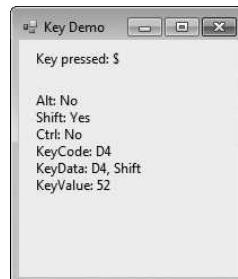
a) H pressed



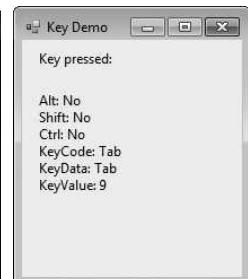
b) F7 pressed



c) \$ pressed



d) Tab pressed

**Fig. 14.40** | Demonstrating keyboard events. (Part 2 of 2.)

Control `charLabel` displays the character value of the key pressed, whereas `keyInfoLabel` displays information relating to the pressed key. Because the `KeyDown` and `KeyPress` events convey different information, the Form (`KeyDemo`) handles both.

The `KeyPress` event handler (lines 18–22) accesses the `KeyChar` property of the `KeyPressEventArgs` object. This returns the pressed key as a `char`, which we then display in `charLabel` (line 21). If the pressed key is not an ASCII character, then the `KeyPress` event will not occur, and `charLabel` will not display any text. ASCII is a common encoding

format for letters, numbers, punctuation marks and other characters. It does not support keys such as the **function keys** (like *F1*) or the modifier keys (*Alt*, *Ctrl* and *Shift*).

The `KeyDown` event handler (lines 25–34) displays information from its `KeyEventArgs` object. The event handler tests for the *Alt*, *Shift* and *Ctrl* keys by using the `Alt`, `Shift` and `Control` properties, each of which returns a `bool` value—`true` if the corresponding key is pressed and `false` otherwise. The event handler then displays the `KeyCode`, `KeyData` and `KeyValue` properties.

The `KeyCode` property returns a `Keys` enumeration value (line 31). The `KeyCode` property returns the pressed key, but does not provide any information about modifier keys. Thus, both a capital and a lowercase “a” are represented as the *A* key.

The `KeyData` property (line 32) also returns a `Keys` enumeration value, but this property includes data about modifier keys. Thus, if “A” is input, the `KeyData` shows that both the *A* key and the *Shift* key were pressed. Lastly, `KeyValue` (line 33) returns an `int` representing a pressed key. This `int` is the **key code**. The key code is useful when testing for non-ASCII keys like *F12*.

The `KeyUp` event handler (lines 37–41) clears both `Labels` when the key is released. As we can see from the output, non-ASCII keys are not displayed in `charLabel`, because the `KeyPress` event is not generated. For example, `charLabel` does not display any text when you press the *F7* or *Tab* keys, as shown in Fig. 14.40(b) and (d). However, the `KeyDown` event still is generated, and `keyInfoLabel` displays information about the key that’s pressed. The `Keys` enumeration can be used to test for specific keys by comparing the `KeyCode` of the pressed key to values in the `Keys` enumeration.



### Software Engineering Observation 14.2

*To cause a control to react when a particular key is pressed (such as Enter), handle a key event and test for the pressed key. To cause a Button to be clicked when the Enter key is pressed on a Form, set the Form’s AcceptButton property.*

By default, a keyboard event is handled by the control that currently has the focus. Sometimes it’s appropriate to have the `Form` handle these events. This can be accomplished by setting the `Form`’s `KeyPreview` property to `true`, which makes the `Form` receive keyboard events before they’re passed to another control. For example, a key press would raise the `Form`’s `KeyPress`, even if a control within the `Form` has the focus instead of the `Form` itself.

## 14.13 Wrap-Up

This chapter introduced several common GUI controls. We discussed event handling in detail, and showed how to create event handlers. We showed how delegates are used to connect event handlers to the events of specific controls. You learned how to use a control’s properties and Visual Studio to specify the layout of your GUI. We then demonstrated several controls, beginning with `Labels`, `Buttons` and `TextBoxes`. You learned how to use `GroupBoxes` and `Panels` to organize other controls. We then demonstrated `CheckBoxes` and `RadioButtons`, which are state buttons that allow users to select among several options. We displayed images in `PictureBox` controls, displayed helpful text on a GUI with `ToolTip` components and specified a range of numeric input values for users with a `NumericUpDown` control. We then demonstrated how to handle mouse and keyboard events. The next chapter introduces additional GUI controls. You’ll learn how to add menus to your GUIs and create Windows Forms apps that display multiple `Forms`.

## Summary

### Section 14.1 Introduction

- A graphical user interface (GUI) allows a user to interact visually with a program.
- GUIs are built from GUI controls.
- GUI controls are objects that can display information on the screen or enable users to interact with an app via the mouse, keyboard or some other form of input.

### Section 14.2 Windows Forms

- Windows Forms are used to create the GUIs for programs.
- A **Form** is a graphical element that appears on the desktop; it can be a dialog, a window or an MDI (multiple document interface) window.
- A component is an instance of a class that implements the `IComponent` interface, which defines the behaviors that components must implement, such as how the component is loaded.
- A control has a graphical representation at runtime.
- Some components lack graphical representations (e.g., class `Timer` of namespace `System.Windows.Forms`). Such components are not visible at runtime.
- When there are several windows on the screen, the active window is the frontmost and has a highlighted title bar. A window becomes the active window when the user clicks somewhere inside it.
- The active window is said to “have the focus.”
- A **Form** is a container for controls and components.

### Section 14.3 Event Handling

- Normally, a user interacts with an app’s GUI to indicate the tasks that the app should perform.
- GUIs are event driven.
- When the user interacts with a GUI component, the interaction—known as an event—drives the program to perform a task. Common events include clicking a `Button`, typing in a `TextBox`, selecting an item from a menu, closing a window and moving the mouse.
- A method that performs a task in response to an event is called an event handler, and the overall process of responding to events is known as event handling.

#### Section 14.3.1 A Simple Event-Driven GUI

- An event handler executes only when the user performs the specific event.
- Each event handler receives two parameters when it’s called. The first—an `object` reference typically named `sender`—is a reference to the object that generated the event. The second is a reference to an `EventArgs` object of type `EventArgs` (or one of its derived classes), which is typically named `e`. This object contains additional information about the event that occurred.
- `EventArgs` is the base class of all classes that represent event information.

#### Section 14.3.2 Auto-Generated GUI Code

- Visual Studio generates the code that creates and initializes the GUI that you build in the GUI design window. This auto-generated code is placed in the `Designer.cs` file of the `Form`.
- The auto-generated code that defines the GUI is part of the `Form`’s class. The use of the `partial` modifier in the class declaration allows the class to be split among multiple files.
- The `Designer.cs` file declares the controls you create in **Design** mode. By default, all variable declarations for controls created through C#’s design window have a `private` access modifier.

- The `Designer.cs` file includes the `Dispose` method for releasing resources and method `InitializeComponent`, which sets the properties of the `Form` and its controls.
- Visual Studio uses the code in `InitializeComponent` to create the GUI you see in design view. Changing the code in this method may prevent Visual Studio from displaying the GUI properly.

#### ***Section 14.3.3 Delegates and the Event-Handling Mechanism***

- The control that generates an event is known as the event sender.
- An event-handling method—known as the event handler—responds to a particular event that a control generates.
- When an event occurs, the event sender calls its event handler to perform a task.
- The .NET event-handling mechanism allows you to choose your own names for event-handling methods. However, each event-handling method must declare the proper parameters to receive information about the event that it handles.
- Event handlers are connected to a control's events via special objects called delegates.
- A delegate object holds a reference to a method with a signature specified by the delegate type's declaration.
- GUI controls have predefined delegates that correspond to every event they can generate.
- An event sender calls a delegate object like a method.
- Since each event handler is declared as a delegate, the event sender can simply call the appropriate delegate when an event occurs. The delegate's job is to invoke the appropriate method.
- Event delegates represent a set of delegate objects that all have the same signature.
- When an event occurs, its sender calls every method referenced by a multicast delegate. Multicast delegates enable several methods to be called in response to a single event.
- Event delegates derive from class `MulticastDelegate`, which derives from class `Delegate` (both from namespace `System`).

#### ***Section 14.3.4 Another Way to Create Event Handlers***

- Double-clicking a control on the `Form` in the designer creates an event handler for a control's default event.
- Typically, controls can generate many different events, and each can have its own event handler.
- You can create additional event handlers through the **Properties** window.
- If you select a control on the `Form`, then click the **Events** icon (the lightning bolt icon) in the **Properties** window, all the events for that control are listed in the window. You can double click an event's name to display the event handler in the editor, if the event handler already exists, or to create the corresponding event handler.
- You can select an event, then use the drop-down list to its right to choose an existing method that should be used as the event handler for that event. The methods that appear in this drop-down list are the `Form` class's methods that have the proper signature to be an event handler for the selected event.
- A single event handler can handle multiple events from multiple controls.

#### ***Section 14.3.5 Locating Event Information***

- Read the Visual Studio documentation to learn about the different events raised by each control. To do this, select a control in the IDE and press the *F1* key to display that control's online help. The web page that's displayed contains basic information about the control's class. Click the link to the list of events for that control to display the supported events for that control.

***Section 14.4 Control Properties and Layout***

- Controls derive from class `Control` (of namespace `System.Windows.Forms`).
- The `Select` method transfers the focus to a control and makes it the active control.
- The `Enabled` property indicates whether the user can interact with a control to generate an event.
- A programmer can hide a control from the user without disabling the control by setting the `Visible` property to `false` or by calling method `Hide`.
- Anchoring causes controls to remain at a fixed distance from the sides of the container even when the control is resized.
- Docking attaches a control to a container such that the control stretches across an entire side or fills all the remaining space.
- Forms have a `Padding` property that specifies the distance between the docked controls and the `Form` edges.
- The `Anchor` and `Dock` properties of a `Control` are set with respect to the `Control`'s parent container, which could be a `Form` or other parent container (such as a `Panel`).
- The minimum and maximum `Form` (or other `Control`) sizes can be set via properties `MinimumSize` and `MaximumSize`, respectively.
- When dragging a control across a `Form`, blue lines (known as snap lines) appear to help you position the control with respect to other controls and the `Form`'s edges.
- Visual Studio also provides the `FORMAT` menu, which contains several options for modifying your GUI's layout.

***Section 14.5 Labels, TextBoxes and Buttons***

- Labels provide text information (as well as optional images) that the user cannot directly modify.
- A textbox (class `TextBox`) is an area in which text either can be displayed by a program or in which the user can type text via the keyboard.
- A password `TextBox` is a `TextBox` that hides the information entered by the user. As the user types, the password `TextBox` masks the user input by displaying a password character (usually \*). If you set the `UseSystemPasswordChar` property to `true`, the `TextBox` becomes a password `TextBox`.
- A button is a control that the user clicks to trigger an action in a program or to select an option.
- All the button classes derive from class `ButtonBase` (namespace `System.Windows.Forms`), which defines common button features.

***Section 14.6 GroupBoxes and Panels***

- `GroupBoxes` and `Panels` arrange controls on a GUI.
- `GroupBoxes` and `Panels` are typically used to group several controls of similar functionality or several controls that are related in a GUI.
- `GroupBoxes` can display a caption (i.e., text) and do not include scrollbars, whereas `Panels` can include scrollbars and do not include a caption.
- `GroupBoxes` have thin borders by default; `Panels` can be set so that they also have borders, by changing their `BorderStyle` property.
- The controls of a `GroupBox` or `Panel` are added to their `Controls` properties.
- To enable a `Panel`'s scrollbars, set the `Panel`'s `AutoScroll` property to `true`. If the `Panel` is resized and cannot display all of its controls, scrollbars appear.

***Section 14.7 CheckBoxes and RadioButtons***

- `CheckBoxes` and `RadioButtons` can be in the on/off or true/false states.

- Classes `CheckBox` and `RadioButton` are derived from class `ButtonBase`.
- A `CheckBox` is a small square that either is blank or contains a check mark. When a `CheckBox` is selected, a check mark appears in the box. Any number of `CheckBoxes` can be selected at a time.
- A `CheckBox` can be configured to have three states—checked, unchecked, and indeterminate—by setting its `ThreeState` property to `true`.
- Font styles can be combined via bitwise operators, such as the logical OR (`|`) operator or the logical exclusive OR (`^`) operator.
- `RadioButtons` (defined with class `RadioButton`) are similar to `CheckBoxes` in that they also have two states: selected and not selected (also called deselected).
- `RadioButtons` normally appear as a group, in which only one `RadioButton` can be selected at a time. The selection of one `RadioButton` in the group forces all the others to be deselected. Therefore, `RadioButtons` are used to represent a set of mutually exclusive options.
- All `RadioButtons` added to a container become part of the same group.

### **Section 14.8 Picture Boxes**

- A `PictureBox` displays an image.
- The `Image` property specifies the image that's displayed
- The `SizeMode` property indicates how the image is displayed (`Normal`, `StretchImage`, `AutoSize`, `CenterImage`, or `Zoom`).
- You can embed images into a project as resources.
- Embedded image files appear in a folder named **Resources** in the **Solution Explorer**.
- The **Resources** class (of a project's **Properties** namespace) stores a project's resources.
- Class `ResourceManager` provides methods for programmatically accessing a project's resources.
- To access an image (or any other resource) in the project's resources, you use the method `GetObject` of class `ResourceManager`, which takes as an argument the resource name as it appears in the **Resources** tab and returns the resource as an `Object`.
- The **Resources** class also provides direct access to the resources you define with expressions of the form `Resources.resourceName`, where `resourceName` is the name you provided to the resource when you created it. When using such an expression, the resource returned already has the appropriate type.

### **Section 14.9 Tool Tips**

- Tool tips help you become familiar with a `Form`'s features and serve as useful reminders for each control's functionality. In the **Properties** window, you can specify a tool tip for a control by setting the `ToolTip` on `componentName` entry, where `componentName` is the name of the `ToolTip` component.
- The `ToolTip` component can be used to add tool tips to your app.
- The `ToolTip` component is placed in the component tray—the gray region below the `Form` in **Design** mode.

### **Section 14.10 NumericUpDown Control**

- At times you'll want to restrict a user's input choices to a specific range of numeric values. This is the purpose of the `NumericUpDown` control.
- The `NumericUpDown` control appears as a `TextBox`, with two small `Buttons` on the right side, one with an up arrow and one with a down arrow. By default, a user can type numeric values into this control as if it were a `TextBox` or click the up and down arrows to increase or decrease the value in the control, respectively.

- The largest and smallest values in the range are specified with the `Maximum` and `Minimum` properties, respectively (both are of type `decimal`).
- The `Increment` property (of type `decimal`) specifies by how much the current number in the control changes when the user clicks the control's up and down arrows.
- Setting a `NumericUpDown` control's `ReadOnly` property to `true` specifies that the user can only use the up and down arrows to modify the value in the `NumericUpDown` control.

### ***Section 14.11 Mouse-Event Handling***

- Mouse events, such as clicks and moves, are generated when the mouse interacts with a control.
- Mouse events can be handled for any subclass of `System.Windows.Forms.Control`.
- Class `MouseEventArgs` contains information related to the mouse event, such as the *x*- and *y*-coordinates of the mouse pointer, the mouse button pressed (Right, Left or Middle) and the number of times the mouse was clicked.
- Whenever the user clicks or holds down a mouse button, the system generates a `MouseDown` event.
- When the user releases the mouse button (to complete a “click” operation), the system generates a single `MouseUp` event.
- Whenever the mouse moves over a control, the `MouseMove` event for that control is raised.

### ***Section 14.12 Keyboard-Event Handling***

- Key events occur when keys on the keyboard are pressed and released.
- There are three key events—`KeyPress`, `KeyUp` and `KeyDown`.
- The `KeyPress` event occurs when the user presses a key that represents an ASCII character. The specific key can be determined with property `KeyChar` of the event handler's `KeyPressEventArgs` argument.
- The `KeyPress` event does not indicate whether modifier keys were pressed when a key event occurred. If this information is important, the `KeyUp` or `KeyDown` events can be used.

## **Terminology**

|                                                                     |                                                                         |
|---------------------------------------------------------------------|-------------------------------------------------------------------------|
| active control                                                      | <code>Control</code> class                                              |
| active window                                                       | <code>Controls</code> property of a container                           |
| anchor a control                                                    | <code>DecimalPlaces</code> property of class <code>NumericUpDown</code> |
| bitwise operator                                                    | default event                                                           |
| Button properties and events                                        | delegate                                                                |
| <code>Button</code> property of class <code>MouseEventArgs</code>   | delegate class                                                          |
| <code>ButtonBase</code> class                                       | delegate keyword                                                        |
| checkbox                                                            | deselected state                                                        |
| <code>CheckBox</code> class                                         | <code>DialogResult</code> enumeration                                   |
| <code>Checked</code> property of class <code>CheckBox</code>        | dock a control                                                          |
| <code>Checked</code> property of class <code>RadioButton</code>     | <code>Dock</code> property of class <code>Control</code>                |
| <code>CheckedChanged</code> event of class <code>CheckBox</code>    | <code>Enabled</code> property of class <code>Control</code>             |
| <code>CheckedChanged</code> event of class <code>RadioButton</code> | event                                                                   |
| <code>CheckState</code> property of class <code>CheckBox</code>     | event-driven programming                                                |
| <code>CheckStateChanged</code> event of class <code>CheckBox</code> | event handler                                                           |
| Color structure                                                     | event handling                                                          |
| component                                                           | event multicasting                                                      |
| component tray                                                      | event handler                                                           |
| container                                                           | event sender                                                            |

|                                                                        |                                                                           |
|------------------------------------------------------------------------|---------------------------------------------------------------------------|
| FillEllipse method of class <code>Graphics</code>                      | multicast delegate                                                        |
| <code>FlatStyle</code> property of class <code>Button</code>           | <code>MulticastDelegate</code> class                                      |
| focus                                                                  | multiple document interface (MDI) window                                  |
| Font class                                                             | mutual exclusion                                                          |
| <code>FontStyle</code> enumeration                                     | “not-selected” state                                                      |
| <code>GetObject</code> method of class <code>ResourceManager</code>    | <code>NumericUpDown</code> class                                          |
| <code>Graphics</code> class                                            | <code>Padding</code> property of class <code>Control</code>               |
| <code>GroupBox</code> class                                            | <code>Panel</code> class                                                  |
| Height property of structure <code>Size</code>                         | partial class                                                             |
| <code>IComponent</code> interface                                      | password <code>TextBox</code>                                             |
| Increment property of class <code>NumericUpDown</code>                 | <code>PictureBox</code> class                                             |
| key code                                                               | radio button                                                              |
| key event                                                              | radio button group                                                        |
| <code>KeyChar</code> property of class <code>KeyPressEventArgs</code>  | <code>RadioButton</code> class                                            |
| <code>KeyCode</code> property of class <code>KeyEventEventArgs</code>  | <code>ReadOnly</code> property of class <code>NumericUpDown</code>        |
| <code>KeyData</code> property of class <code>KeyEventEventArgs</code>  | <code>ResourceManager</code> class                                        |
| <code>KeyDown</code> event of class <code>Control</code>               | <code>Resources</code> class                                              |
| <code>KeyEventEventArgs</code> class                                   | <code>Select</code> method of class <code>Control</code>                  |
| <code>KeyPress</code> event of class <code>Control</code>              | selected state                                                            |
| <code>KeyPressEventArgs</code> class                                   | Size property of class <code>Control</code>                               |
| Keys enumeration                                                       | Size structure                                                            |
| <code>KeyUp</code> event of class <code>Control</code>                 | snap line                                                                 |
| <code>KeyValue</code> property of class <code>KeyEventEventArgs</code> | <code>SolidBrush</code> class                                             |
| Maximum property of class <code>NumericUpDown</code>                   | state button                                                              |
| MaximumSize property of class <code>Control</code>                     | Style property of class <code>Font</code>                                 |
| <code>MessageBox</code> class                                          | <code>TabIndex</code> property of class <code>Control</code>              |
| Minimum property of class <code>NumericUpDown</code>                   | <code>TabStop</code> property of class <code>Control</code>               |
| MinimumSize property of class <code>Control</code>                     | <code>ToolTip</code> class                                                |
| modifier key                                                           | <code>ThreeState</code> property of class <code>CheckBox</code>           |
| mouse click                                                            | <code>UseSystemPasswordChar</code> property of class <code>TextBox</code> |
| mouse event                                                            | <code>UpDownAlign</code> property of class <code>NumericUpDown</code>     |
| mouse move                                                             | <code>Value</code> property of class <code>NumericUpDown</code>           |
| mouse press                                                            | <code>Visible</code> property of class <code>Control</code>               |
| <code>MouseDown</code> event of class <code>Control</code>             | widget                                                                    |
| <code>MouseEventArgs</code> class                                      | Width property of structure <code>Size</code>                             |
| <code>MouseEventHandler</code> delegate                                | window gadget                                                             |
| <code>MouseMove</code> event of class <code>Control</code>             | Windows Form                                                              |
| <code>MouseUp</code> event of class <code>Control</code>               |                                                                           |

## Self-Review Exercises

- 14.1** State whether each of the following is *true* or *false*. If *false*, explain why.
- The `KeyData` property includes data about modifier keys.
  - A `Form` is a container.
  - All `Forms`, components and controls are classes.
  - `Checkboxes` are used to represent a set of mutually exclusive options.
  - A `Label` displays text that a user running an app can edit.
  - Button presses generate events.
  - All mouse events use the same event arguments class.
  - Visual Studio can register an event and create an empty event handler.

- i) The `NumericUpDown` control is used to specify a range of input values.
- ii) A control's tool tip text is set with the `ToolTip` property of class `Control`.

**14.2** Fill in the blanks in each of the following statements:

- a) The active control is said to have the \_\_\_\_\_.
- b) The `Form` acts as a(n) \_\_\_\_\_ for the controls that are added.
- c) GUIs are \_\_\_\_\_ driven.
- d) Every method that handles the same event must have the same \_\_\_\_\_.
- e) A(n) \_\_\_\_\_ `TextBox` masks user input with a character used repeatedly.
- f) Class \_\_\_\_\_ and class \_\_\_\_\_ help arrange controls on a GUI and provide logical groups for radio buttons.
- g) Typical mouse events include \_\_\_\_\_ and \_\_\_\_\_.
- h) \_\_\_\_\_ events are generated when a key on the keyboard is pressed or released.
- i) The modifier keys are \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.
- j) A(n) \_\_\_\_\_ event or delegate can be used to call multiple methods.

## Answers To Self-Review Exercises

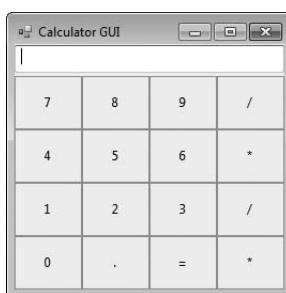
**14.1** a) True. b) True. c) True. d) False. `RadioButtons` are used to represent a set of mutually exclusive options. e) False. A `Label`'s text cannot be edited by the user. f) True. g) False. Some mouse events use `EventArgs`, others use `MouseEventArgs`. h) True. i) True. j) False. A control's tool tip text is set using a `ToolTip` component that must be added to the app.

**14.2** a) focus. b) container. c) event. d) signature. e) password. f) `GroupBox`, `Panel`. g) mouse clicks, mouse moves. h) Key. i) *Shift*, *Ctrl*, *Alt*. j) multicast.

## Exercises

**14.3** Extend the program in Fig. 14.26 to include a `CheckBox` for every font-style option. [Hint: Use logical exclusive OR ( $\wedge$ ) rather than testing for every bit explicitly.]

**14.4** Create the GUI in Fig. 14.41 (you do not have to provide functionality).

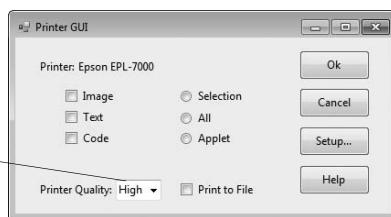


**Fig. 14.41** | Calculator GUI.

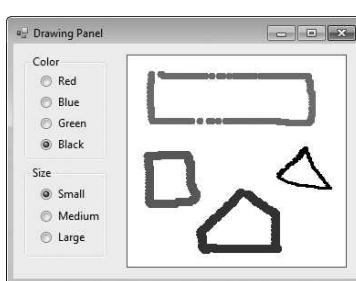
**14.5** Create the GUI in Fig. 14.42 (you do not have to provide functionality).

**14.6** (*Temperature Conversions*) Write a temperature conversion program that converts from Fahrenheit to Celsius. The Fahrenheit temperature should be entered from the keyboard (via a `TextBox`). A `Label` should be used to display the converted temperature. Use the following formula for the conversion:

$$\text{Celsius} = (5 / 9) \times (\text{Fahrenheit} - 32)$$



**Fig. 14.42** | Printer GUI.



**Fig. 14.43** | Drawing Panel GUI.

**14.7 (Enhanced Painter)** Extend the program of Fig. 14.38 to include options for changing the size and color of the lines drawn. Create a GUI similar to Fig. 14.43. The user should be able to draw on the app’s `Panel`. To retrieve a `Graphics` object for drawing, call method `panelName.CreateGraphics()`, substituting in the name of your `Panel`.

**14.8 (Guess the Number Game)** Write a program that plays “guess the number” as follows: Your program chooses the number to be guessed by selecting an `int` at random in the range 1–1000. The program then displays the following text in a label:

```
I have a number between 1 and 1000--can you guess my number?  
Please enter your first guess.
```

A `TextBox` should be used to input the guess. As each guess is input, the background color should change to red or blue. Red indicates that the user is getting “warmer,” blue that the user is getting “colder.” A `Label` should display either “Too High” or “Too Low,” to help the user zero in on the correct answer. When the user guesses the correct answer, display “Correct!” in a message box, change the `Form`’s background color to green and disable the `TextBox`. Recall that a `TextBox` (like other controls) can be disabled by setting the control’s `Enabled` property to `false`. Provide a `Button` that allows the user to play the game again. When the `Button` is clicked, generate a new random number, change the background to the default color and enable the `TextBox`.

**14.9 (Fuzzy Dice Order Form)** Write an app that allows users to process orders for fuzzy dice. The app should calculate the total price of the order, including tax and shipping. `TextBoxes` for inputting the order number, the customer name and the shipping address are provided. Initially, these fields contain text that describes their purpose. Provide `Checkboxes` for selecting the fuzzy-dice color and `TextBoxes` for inputting the quantities of fuzzy dice to order. The app should update the total cost, tax and shipping when the user changes any one of the three quantity fields’ values. The app should also contain a `Button` that when clicked, returns all fields to their original values. Use 5% for the tax rate. Shipping charges are

\$1.50 for up to 20 pairs of dice. If more than 20 pairs of dice are ordered, shipping is free. All fields must be filled out, and an item must be checked for the user to enter a quantity for that item.

## Making a Difference Exercises

**14.10** (*Ecofont*) Ecofont—developed by SPRANQ (a Netherlands-based company)—is a font designed to reduce by as much as 20% the amount of ink used for printing, thus reducing also the number of ink cartridges used and the environmental impact of the manufacturing and shipping processes (using less energy, less fuel for shipping, and so on). The font, based on sans-serif Verdana, has small circular “holes” in the letters that are not visible in smaller sizes—such as the 9- or 10-point type frequently used. Download the free version of Ecofont ([www.ecofont.com/en/products/green/font/download-the-ink-saving-font.html](http://www.ecofont.com/en/products/green/font/download-the-ink-saving-font.html)), then install the font file `ecofont_vera_sans_regular.ttf` using the instructions from the Ecofont website. Next, develop a GUI-based program that allows you to type text in a `TextBox` to be displayed in the Ecofont. Create **Increase Font Size** and **Decrease Font Size** buttons that allow you to scale up or down by one point at a time. Set the `TextBox`’s `Font` property to 9 point Ecofont. Set the `TextBox`’s `MultiLine` property to `true` so the user can enter multiple lines of text. As you scale up the font, you’ll be able to see the holes in the letters more clearly. As you scale down, the holes will be less apparent. To change the `TextBox`’s font programmatically, use a statement of the form:

```
inputTextBox.Font = new Font( inputTextBox.Font.FontFamily,  
    inputTextBox.Font.SizeInPoints + 1 );
```

This changes the `TextBox`’s `Font` property to a new `Font` object that uses the `TextBox`’s current font, but adds 1 to its `SizeInPoints` property to increase the font size. A similar statement can be used to decrease the font size. What is the smallest font size at which you begin to notice the holes?

**14.11** (*Project: Typing Tutor—Tuning a Crucial Skill in the Computer Age*) Typing quickly and correctly is an essential skill for working effectively with computers and the Internet. In this exercise, you’ll build an app that can help users learn to “touch type” (i.e., type correctly without looking at the keyboard). The app should display a *virtual keyboard* that mimics the one on your computer and should allow the user to watch what he or she is typing on the screen without looking at the *actual keyboard*. Use `Buttons` to represent the keys. As the user presses each key, the app highlights the corresponding `Button` and adds the character to a `TextBox` that shows what the user has typed so far. [Hint: To highlight a `Button`, use its `BackColor` property to change its background color. When the key is released, reset its original background color.]

You can test your program by typing a pangram—a phrase that contains every letter of the alphabet at least once—such as “The quick brown fox jumped over a lazy dog.” You can find other pangrams on the web.

To make the program more interesting you could monitor the user’s accuracy. You could have the user type specific phrases that you’ve prestored in your program and that you display on the screen above the virtual keyboard. You could keep track of how many keystrokes the user types correctly and how many are typed incorrectly. You could also keep track of which keys the user is having difficulty with and display a report showing those keys.

# Graphical User Interfaces with Windows Forms: Part 2

# 15



*I claim not to have controlled events, but confess plainly that events have controlled me.*

—Abraham Lincoln

*But, soft! what light through yonder window breaks?  
It is the east, and Juliet is the sun!*

—William Shakespeare

## Objectives

In this chapter you'll learn:

- To create menus, tabbed windows and multiple document interface (MDI) programs.
- To use the `ListView` and `TreeView` controls for displaying information.
- To create hyperlinks using the `LinkLabel` control.
- To display lists of information in `ListBox`, `CheckedListBox` and `ComboBox` controls.
- To input dates with the `MonthCalendar` control.
- To input date and time data with the `DateTimePicker` control.
- To create custom controls.

# Outline

|                             |                                                 |
|-----------------------------|-------------------------------------------------|
| 15.1 Introduction           | 15.9 TreeView Control                           |
| 15.2 Menus                  | 15.10 ListView Control                          |
| 15.3 MonthCalendar Control  | 15.11 TabControl Control                        |
| 15.4 DateTimePicker Control | 15.12 Multiple Document Interface (MDI) Windows |
| 15.5 LinkLabel Control      | 15.13 Visual Inheritance                        |
| 15.6 ListBox Control        | 15.14 User-Defined Controls                     |
| 15.7 CheckedListBox Control | 15.15 Wrap-Up                                   |
| 15.8 ComboBox Control       |                                                 |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 15.1 Introduction

This chapter continues our study of Windows Forms GUIs. We start with menus, which present users with logically organized commands (or options). We show how to develop menus with the tools provided by Visual Studio. Next, we discuss how to input and display dates and times using the MonthCalendar and DateTimePicker controls. We also introduce LinkLabels—powerful GUI components that enable the user to access one of several destinations, such as a file on the current machine or a web page, simply by clicking the mouse.

We demonstrate how to manipulate a list of values via a ListBox and how to combine several checkboxes in a CheckedListBox. We also create drop-down lists using ComboBoxes and display data hierarchically with a TreeView control. You'll learn two other important GUI elements—tab controls and multiple document interface (MDI) windows. These components enable you to create real-world programs with sophisticated GUIs.

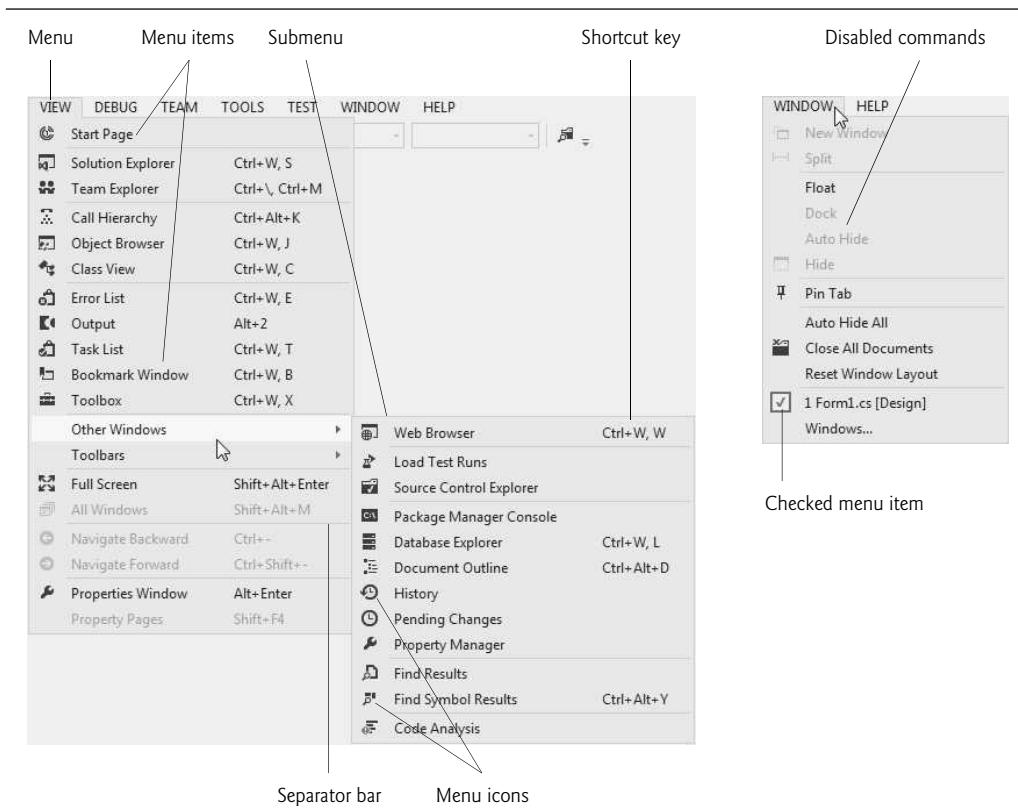
Visual Studio provides many GUI components, several of which are discussed in this (and the previous) chapter. You can also design custom controls and add them to the ToolBox, as we demonstrate in this chapter's last example. The techniques presented here form the groundwork for creating more substantial GUIs and custom controls.

## 15.2 Menus

Menus provide groups of related commands for Windows Forms apps. Although these commands depend on the program, some—such as **Open** and **Save**—are common to many apps. Menus are an integral part of GUIs, because they organize commands without “cluttering” the GUI.

In Fig. 15.1, an expanded menu from the Visual C# IDE lists various commands (called **menu items**), plus **submenus** (menus within a menu). The top-level menus appear in the left portion of the figure, whereas any submenus or menu items are displayed to the right. The menu that contains a menu item is called that menu item's **parent menu**. A menu item that contains a submenu is considered to be the parent of that submenu.

Menus can have *Alt* key shortcuts (also called **access shortcuts**, **keyboard shortcuts** or **hotkeys**), which are accessed by pressing *Alt* and the underlined letter—for example, *Alt* + *F* typically expands the **File** menu. Menu items can have shortcut keys as well (combinations of *Ctrl*, *Shift*, *Alt*, *F1*, *F2*, letter keys, and so on). Some menu items display checkmarks, usually indicating that multiple options on the menu can be selected at once.

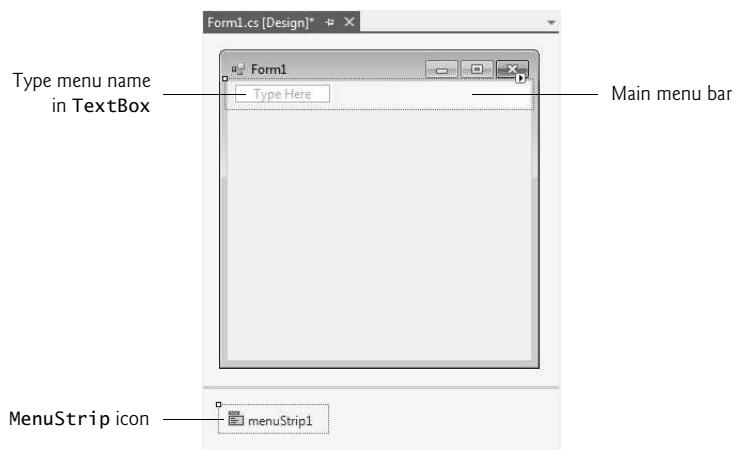
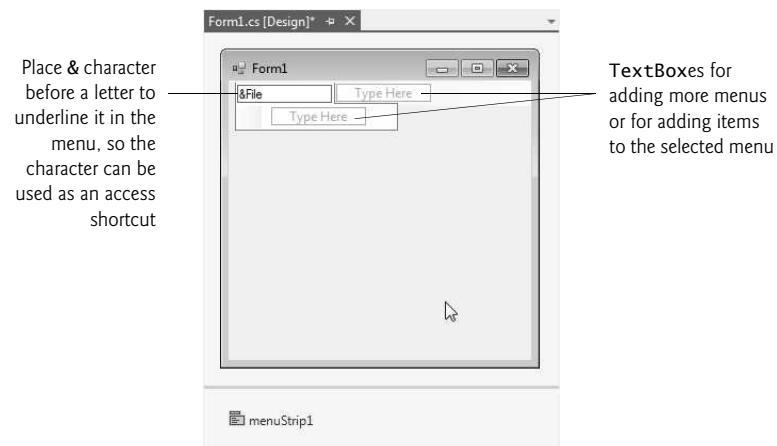
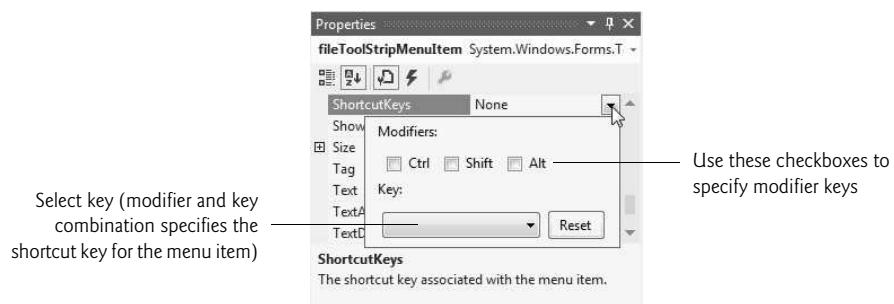


**Fig. 15.1** | Menus, submenus and menu items.

To create a menu, open the **Toolbox** and drag a **MenuStrip** control onto the Form. This creates a menu bar across the top of the Form (below the title bar) and places a **MenuStrip** icon in the component tray. To select the **MenuStrip**, click this icon. You can now use **Design** mode to create and edit menus for your app. Menus, like other controls, have properties and events, which can be accessed through the **Properties** window.

To add menu items to the menu, click the **Type Here TextBox** (Fig. 15.2) and type the menu item's name. This action adds an entry to the menu of type **ToolStripMenuItem**. After you press the *Enter* key, the menu item name is added to the menu. Then more **Type Here TextBoxes** appear, allowing you to add items underneath or to the side of the original menu item (Fig. 15.3).

To create an access shortcut, type an ampersand (&) before the character to be underlined. For example, to create the **File** menu item with the letter **F** underlined, type &File. To display an ampersand, type &&. To add other shortcut keys (e.g., *Ctrl + F9*) for menu items, set the **ShortcutKeys** property of the appropriate **ToolStripMenuItem**s. To do this, select the down arrow to the right of this property in the **Properties** window. In the window that appears (Fig. 15.4), use the **Checkboxes** and drop-down list to select the shortcut keys. When you're finished, click elsewhere on the screen. You can hide the shortcut keys by setting property **ShowShortcutKeys** to **false**, and you can modify how the shortcut keys are displayed in the menu item by modifying property **ShortcutKeyDisplayString**.

**Fig. 15.2** | Editing menus in Visual Studio.**Fig. 15.3** | Adding ToolStripMenuItem s to a MenuStrip.**Fig. 15.4** | Setting a menu item's shortcut keys.

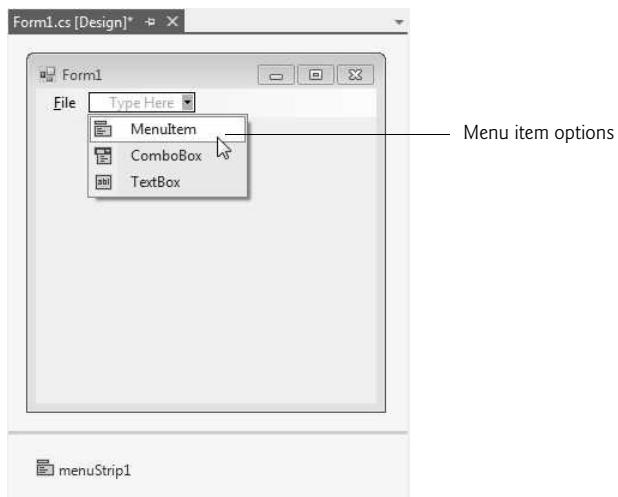


### Look-and-Feel Observation 15.1

Buttons can have access shortcuts. Place the & symbol immediately before the desired character in the Button's text. To press the button by using its access key in the running app, the user presses Alt and the underlined character. If the underline is not visible when the app runs, press the Alt key to display the underlines.

You can remove a menu item by selecting it with the mouse and pressing the *Delete* key. Menu items can be grouped logically by **separator bars**, which are inserted by right clicking the menu and selecting **Insert > Separator** or by typing “\_” for the text of a menu item.

In addition to text, Visual Studio allows you to easily add **TextBoxes** and **ComboBoxes** (drop-down lists) as menu items. When adding an item in **Design** mode, you may have noticed that before you enter text for a new item, you're provided with a drop-down list. Clicking the down arrow (Fig. 15.5) allows you to select the type of item to add—**MenuItem** (of type **ToolStripMenuItem**, the default), **ComboBox** (of type **ToolStripComboBox**) and **TextBox** (of type **ToolStripTextBox**). We focus on **ToolStripMenuItem**s. [Note: If you view this drop-down list for menu items that are not on the top level, a fourth option appears, allowing you to insert a separator bar.]



**Fig. 15.5** | Menu-item options.

**ToolStripMenuItem**s generate a **Click** event when selected. To create an empty **Click** event handler, double click the menu item in **Design** mode. Common actions in response to these events include displaying dialogs and setting properties. Common menu properties and a common event are summarized in Fig. 15.6.



### Look-and-Feel Observation 15.2

It's a convention to place an ellipsis (...) after the name of a menu item (e.g., **Save As...**) that requires the user to provide more information—typically through a dialog. A menu item that produces an immediate action without prompting the user for more information (e.g., **Save**) should not have an ellipsis following its name.

| MenuStrip and ToolStripMenuItem properties and an event | Description                                                                                                                                                                                                                                    |
|---------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>MenuStrip Properties</i>                             |                                                                                                                                                                                                                                                |
| RightToLeft                                             | Causes text to display from right to left. This is useful for languages that are read from right to left.                                                                                                                                      |
| <i>ToolStripMenuItem Properties</i>                     |                                                                                                                                                                                                                                                |
| Checked                                                 | Indicates whether a menu item is checked. The default value is <code>false</code> , meaning that the menu item is unchecked.                                                                                                                   |
| CheckOnClick                                            | Indicates that a menu item should appear checked or unchecked as it is clicked.                                                                                                                                                                |
| ShortcutKey-DisplayString                               | Specifies text that should appear beside a menu item for a shortcut key. If left blank, the key names are displayed. Otherwise, the text in this property is displayed for the shortcut key.                                                   |
| ShortcutKeys                                            | Specifies the shortcut key for the menu item (e.g., <code>&lt;Ctrl&gt;-F9</code> is equivalent to clicking a specific item).                                                                                                                   |
| ShowShortcutKeys                                        | Indicates whether a shortcut key is shown beside menu item text. The default is <code>true</code> , which displays the shortcut key.                                                                                                           |
| Text                                                    | Specifies the menu item's text. To create an <code>Alt</code> access shortcut, precede a character with <code>&amp;</code> (e.g., <code>&amp;File</code> to specify a menu named <code>File</code> with the letter <code>F</code> underlined). |
| <i>Common ToolStripMenuItem Event</i>                   |                                                                                                                                                                                                                                                |
| Click                                                   | Generated when an item is clicked or a shortcut key is used. This is the default event when the menu is double clicked in the designer.                                                                                                        |

**Fig. 15.6** | MenuStrip and ToolStripMenuItem properties and an event.

Class `MenuTestForm` (Fig. 15.7) creates a simple menu on a `Form`. The `Form` has a top-level `File` menu with menu items `About` (which displays a `MessageBox`) and `Exit` (which terminates the program). The program also includes a `Format` menu, which contains menu items that change the format of the text on a `Label`. The `Format` menu has submenus `Color` and `Font`, which change the color and font of the text on a `Label`.

### Create the GUI

To create this GUI, begin by dragging the `MenuStrip` from the `ToolBox` onto the `Form`. Then use `Design` mode to create the menu structure shown in the sample outputs. The `File` menu (`fileToolStripMenuItem`) has menu items `About` (`aboutToolStripMenuItem`) and `Exit` (`exitToolStripMenuItem`); the `Format` menu (`formatToolStripMenuItem`) has two submenus. The first submenu, `Color` (`colorToolStripMenuItem`), contains menu items `Black` (`blackToolStripMenuItem`), `Blue` (`blueToolStripMenuItem`), `Red` (`redToolStripMenuItem`) and `Green` (`greenToolStripMenuItem`). The second submenu, `Font` (`fontToolStripMenuItem`), contains menu items `Times New Roman` (`timesToolStripMenuItem`), `Courier` (`courierToolStripMenuItem`), `Comic Sans` (`comicToolStripMenuItem`), a separator bar (`dashToolStripMenuItem`), `Bold` (`boldToolStripMenuItem`) and `Italic` (`italicToolStripMenuItem`).

```
1 // Fig. 15.7: MenuTestForm.cs
2 // Using Menus to change font colors and styles.
3 using System;
4 using System.Drawing;
5 using System.Windows.Forms;
6
7 namespace MenuTest
8 {
9     // our Form contains a Menu that changes the font color
10    // and style of the text displayed in Label
11    public partial class MenuTestForm : Form
12    {
13        // constructor
14        public MenuTestForm()
15        {
16            InitializeComponent();
17        } // end constructor
18
19        // display MessageBox when About ToolStripMenuItem is selected
20        private void aboutToolStripMenuItem_Click(
21            object sender, EventArgs e )
22        {
23            MessageBox.Show( "This is an example\nof using menus.", "About",
24                MessageBoxButtons.OK, MessageBoxIcon.Information );
25        } // end method aboutToolStripMenuItem_Click
26
27        // exit program when Exit ToolStripMenuItem is selected
28        private void exitToolStripMenuItem_Click(
29            object sender, EventArgs e )
30        {
31            Application.Exit();
32        } // end method exitToolStripMenuItem_Click
33
34        // reset checkmarks for Color ToolStripMenuItems
35        private void ClearColor()
36        {
37            // clear all checkmarks
38            blackToolStripMenuItem.Checked = false;
39            blueToolStripMenuItem.Checked = false;
40            redToolStripMenuItem.Checked = false;
41            greenToolStripMenuItem.Checked = false;
42        } // end method ClearColor
43
44        // update Menu state and color display black
45        private void blackToolStripMenuItem_Click(
46            object sender, EventArgs e )
47        {
48            // reset checkmarks for Color ToolStripMenuItems
49            ClearColor();
50
51            // set color to Black
52            displayLabel.ForeColor = Color.Black;
```

**Fig. 15.7** | Menus for changing text font and color. (Part I of 4.)

```
53         blackToolStripMenuItem.Checked = true;
54     } // end method blackToolStripMenuItem_Click
55
56     // update Menu state and color display blue
57     private void blueToolStripMenuItem_Click(
58         object sender, EventArgs e )
59     {
60         // reset checkmarks for Color ToolStripMenuItems
61         ClearColor();
62
63         // set color to Blue
64         displayLabel.ForeColor = Color.Blue;
65         blueToolStripMenuItem.Checked = true;
66     } // end method blueToolStripMenuItem_Click
67
68     // update Menu state and color display red
69     private void redToolStripMenuItem_Click(
70         object sender, EventArgs e )
71     {
72         // reset checkmarks for Color ToolStripMenuItems
73         ClearColor();
74
75         // set color to Red
76         displayLabel.ForeColor = Color.Red;
77         redToolStripMenuItem.Checked = true;
78     } // end method redToolStripMenuItem_Click
79
80     // update Menu state and color display green
81     private void greenToolStripMenuItem_Click(
82         object sender, EventArgs e )
83     {
84         // reset checkmarks for Color ToolStripMenuItems
85         ClearColor();
86
87         // set color to Green
88         displayLabel.ForeColor = Color.Green;
89         greenToolStripMenuItem.Checked = true;
90     } // end method greenToolStripMenuItem_Click
91
92     // reset checkmarks for Font ToolStripMenuItems
93     private void ClearFont()
94     {
95         // clear all checkmarks
96         timesToolStripMenuItem.Checked = false;
97         courierToolStripMenuItem.Checked = false;
98         comicToolStripMenuItem.Checked = false;
99     } // end method ClearFont
100
101    // update Menu state and set Font to Times New Roman
102    private void timesToolStripMenuItem_Click(
103        object sender, EventArgs e )
104    {
105        // reset checkmarks for Font ToolStripMenuItems
```

---

Fig. 15.7 | Menus for changing text font and color. (Part 2 of 4.)

```
106     ClearFont();
107
108     // set Times New Roman font
109     timesToolStripMenuItem.Checked = true;
110     displayLabel.Font = new Font( "Times New Roman", 14,
111         displayLabel.Font.Style );
112 } // end method timesToolStripMenuItem_Click
113
114 // update Menu state and set Font to Courier
115 private void courierToolStripMenuItem_Click(
116     object sender, EventArgs e )
117 {
118     // reset checkmarks for Font ToolStripMenuItems
119     ClearFont();
120
121     // set Courier font
122     courierToolStripMenuItem.Checked = true;
123     displayLabel.Font = new Font( "Courier", 14,
124         displayLabel.Font.Style );
125 } // end method courierToolStripMenuItem_Click
126
127 // update Menu state and set Font to Comic Sans MS
128 private void comicToolStripMenuItem_Click(
129     object sender, EventArgs e )
130 {
131     // reset checkmarks for Font ToolStripMenuItems
132     ClearFont();
133
134     // set Comic Sans font
135     comicToolStripMenuItem.Checked = true;
136     displayLabel.Font = new Font( "Comic Sans MS", 14,
137         displayLabel.Font.Style );
138 } // end method comicToolStripMenuItem_Click
139
140 // toggle checkmark and toggle bold style
141 private void boldToolStripMenuItem_Click(
142     object sender, EventArgs e )
143 {
144     // toggle checkmark
145     boldToolStripMenuItem.Checked = !boldToolStripMenuItem.Checked;
146
147     // use Xor to toggle bold, keep all other styles
148     displayLabel.Font = new Font( displayLabel.Font,
149         displayLabel.Font.Style ^ FontStyle.Bold );
150 } // end method boldToolStripMenuItem_Click
151
152 // toggle checkmark and toggle italic style
153 private void italicToolStripMenuItem_Click(
154     object sender, EventArgs e )
155 {
156     // toggle checkmark
157     italicToolStripMenuItem.Checked =
158         !italicToolStripMenuItem.Checked;
```

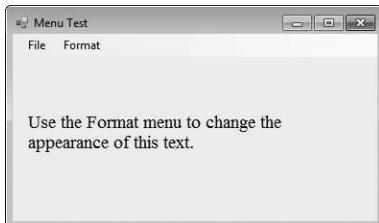
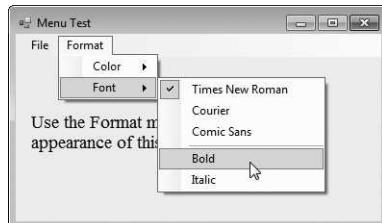
Fig. 15.7 | Menus for changing text font and color. (Part 3 of 4.)

```

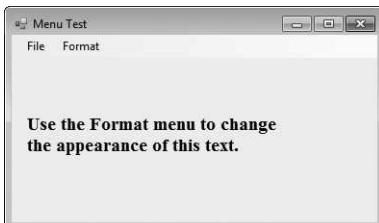
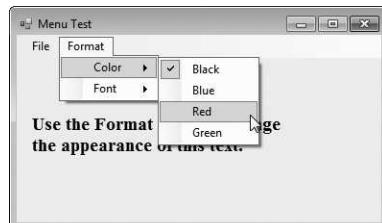
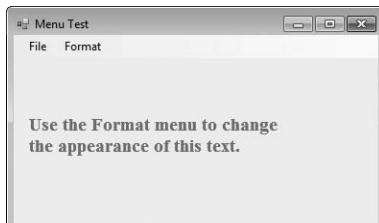
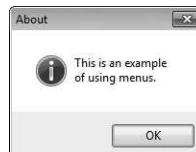
159         // use Xor to toggle italic, keep all other styles
160         displayLabel.Font = new Font( displayLabel.Font,
161             displayLabel.Font.Style ^ FontStyle.Italic );
162     } // end method italicToolStripMenuItem_Click
163 } // end class MenuTestForm
164 } // end namespace MenuTest

```

a) Initial GUI

b) Selecting the **Bold** menu item

c) GUI after text set to bold

d) Selecting the **Red** menu iteme) GUI after text set to **Red**f) Dialog displayed by selecting **File > About****Fig. 15.7** | Menus for changing text font and color. (Part 4 of 4.)

### *Handling the Click Events for the About and Exit Menu Items*

The **About** menu item in the **File** menu displays a **MessageBox** when clicked (lines 20–25). The **Exit** menu item closes the app through **static** method **Exit** of class **Application** (line 31). Class **Application**'s **static** methods control program execution. Method **Exit** causes our app to terminate.

### *Color Submenu Events*

We made the items in the **Color** submenu (**Black**, **Blue**, **Red** and **Green**) mutually exclusive—the user can select *only one* at a time (we explain how we did this shortly). To indicate that a menu item is selected, we will set each **Color** menu item's **Checked** property to **true**. This causes a check to appear to the left of a menu item.

Each **Color** menu item has its own `Click` event handler. The method handler for color **Black** is `blackToolStripMenuItem_Click` (lines 45–54). Similarly, the event handlers for colors **Blue**, **Red** and **Green** are `blueToolStripMenuItem_Click` (lines 57–66), `redToolStripMenuItem_Click` (lines 69–78) and `greenToolStripMenuItem_Click` (lines 81–90), respectively. Each **Color** menu item must be *mutually exclusive*, so each event handler calls method `ClearColor` (lines 35–42) before setting its corresponding `Checked` property to `true`. Method `ClearColor` sets the `Checked` property of each color `ToolStripMenuItem` to `false`, effectively preventing more than one menu item from being selected at a time. In the designer, we initially set the **Black** menu item's `Checked` property to `true`, because at the start of the program, the text on the Form is black.



### Software Engineering Observation 15.1

*The mutual exclusion of menu items is not enforced by the `MenuStrip`, even when the `Checked` property is true. You must program this behavior.*

### Font Submenu Events

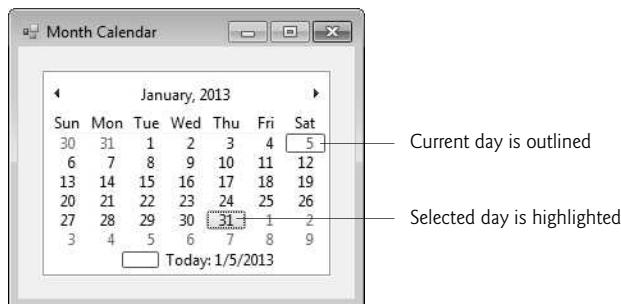
The **Font** menu contains three menu items for fonts (**Courier**, **Times New Roman** and **Comic Sans**) and two menu items for font styles (**Bold** and **Italic**). We added a separator bar between the font and font-style menu items to indicate that these are separate options. A **Font** object can specify only one font at a time but can *set multiple styles at once* (e.g., a font can be both *bold* and *italic*). We set the font menu items to display checks. As with the **Color** menu, we must enforce mutual exclusion of these items in our event handlers.

Event handlers for font menu items **Times New Roman**, **Courier** and **Comic Sans** are `timesToolStripMenuItem_Click` (lines 102–112), `courierToolStripMenuItem_Click` (lines 115–125) and `comicToolStripMenuItem_Click` (lines 128–138), respectively. These event handlers are similar to those of the **Color** menu items. Each clears the `Checked` properties for all font menu items by calling method `ClearFont` (lines 93–99), then sets the `Checked` property of the menu item that raised the event to `true`. This enforces the mutual exclusion of the font menu items. In the designer, we initially set the **Times New Roman** menu item's `Checked` property to `true`, because this is the original font for the text on the Form. The event handlers for the **Bold** and **Italic** menu items (lines 141–163) use the bitwise logical exclusive OR (`^`) operator to combine font styles, as we discussed in Chapter 14.

## 15.3 MonthCalendar Control

Many apps must perform date and time calculations. The .NET Framework provides two controls that allow an app to retrieve date and time information—the **MonthCalendar** and **DateTimePicker** (Section 15.4) controls.

The **MonthCalendar** (Fig. 15.8) control displays a monthly calendar on the Form. The user can select a date from the currently displayed month or can use the provided arrows to navigate to another month. When a date is selected, it is highlighted. Multiple dates can be selected by clicking dates on the calendar while holding down the *Shift* key. The default event for this control is the **DateChanged** event, which is generated when a new date is selected. Properties are provided that allow you to modify the appearance of the calendar, how many dates can be selected at once, and the minimum date and maximum date that may be selected. **MonthCalendar** properties and a common **MonthCalendar** event are summarized in Fig. 15.9.



**Fig. 15.8** | MonthCalendar control.

| MonthCalendar properties and an event | Description                                                                      |
|---------------------------------------|----------------------------------------------------------------------------------|
| <i>MonthCalendar Properties</i>       |                                                                                  |
| FirstDayOfWeek                        | Sets which day of the week is the first displayed for each week in the calendar. |
| MaxDate                               | The last date that can be selected.                                              |
| MaxSelectionCount                     | The maximum number of dates that can be selected at once.                        |
| MinDate                               | The first date that can be selected.                                             |
| MonthlyBoldedDates                    | An array of dates that will be displayed in bold in the calendar.                |
| SelectionEnd                          | The last of the dates selected by the user.                                      |
| SelectionRange                        | The dates selected by the user.                                                  |
| SelectionStart                        | The first of the dates selected by the user.                                     |
| <i>Common MonthCalendar Event</i>     |                                                                                  |
| DateChanged                           | Generated when a date is selected in the calendar.                               |

**Fig. 15.9** | MonthCalendar properties and an event.

## 15.4 DateTimePicker Control

The **DateTimePicker** control (see output of Fig. 15.11) is similar to the **MonthCalendar** control but displays the calendar when a *down arrow* is selected. The **DateTimePicker** can be used to retrieve date and time information from the user. A **DateTimePicker**'s **Value** property stores a **DateTime** object, which always contains both date and time information. You can retrieve the date information from the **DateTime** object by using property **Date**, and you can retrieve only the time information by using the **TimeOfDay** property.

The **DateTimePicker** is also more customizable than a **MonthCalendar** control—more properties are provided to edit the look and feel of the drop-down calendar. Property **Format** specifies the user's selection options using the **DateTimePickerFormat** enumeration. The values in this enumeration are **Long** (displays the date in long format, as in **Thursday, July 10, 2013**), **Short** (displays the date in short format, as in **7/10/2013**), **Time** (displays a time value, as in **5:31:02 PM**) and **Custom** (indicates that a custom format will

be used). If value **Custom** is used, the display in the **DateTimePicker** is specified using property **CustomFormat**. The default event for this control is **ValueChanged**, which occurs when the selected value (whether a date or a time) is changed. **DateTimePicker** properties and a common event are summarized in Fig. 15.10.

| DateTimePicker properties and an event |  | Description                                                                                                                                                                                          |
|----------------------------------------|--|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>DateTimePicker Properties</i>       |  |                                                                                                                                                                                                      |
| CalendarForeColor                      |  | Sets the text color for the calendar.                                                                                                                                                                |
| CalendarMonthBackground                |  | Sets the calendar's background color.                                                                                                                                                                |
| CustomFormat                           |  | Sets the custom format string for the date and/or time displayed in the control.                                                                                                                     |
| Format                                 |  | Sets the format of the date and/or time used for the date and/or time displayed in the control.                                                                                                      |
| MaxDate                                |  | The maximum date and time that can be selected.                                                                                                                                                      |
| MinDate                                |  | The minimum date and time that can be selected.                                                                                                                                                      |
| ShowCheckBox                           |  | Indicates if a CheckBox should be displayed to the left of the selected date and time.                                                                                                               |
| ShowUpDown                             |  | Indicates whether the control displays up and down Buttons. Helpful when the <b>DateTimePicker</b> is used to select a time—the Buttons can be used to increase or decrease hour, minute and second. |
| Value                                  |  | The data selected by the user.                                                                                                                                                                       |
| <i>Common DateTimePicker Event</i>     |  |                                                                                                                                                                                                      |
| ValueChanged                           |  | Generated when the <b>Value</b> property changes, including when the user selects a new date or time.                                                                                                |

**Fig. 15.10** | DateTimePicker properties and an event.

Figure 15.11 demonstrates using a **DateTimePicker** to select an item's drop-off time. Many companies use such functionality—several online DVD rental companies specify the day a movie is sent out and the estimated time that it will arrive at your home. The user selects a drop-off day, then an estimated arrival date is displayed. The date is always two days after drop-off, three days if a Sunday is reached (mail is not delivered on Sunday).

---

```

1 // Fig. 15.11: DateTimePickerForm.cs
2 // Using a DateTimePicker to select a drop-off time.
3 using System;
4 using System.Windows.Forms;
5
6 namespace DateTimePickerTest
7 {

```

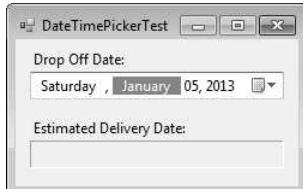
**Fig. 15.11** | Demonstrating DateTimePicker. (Part 1 of 3.)

```

8   // Form lets user select a drop-off date using a DateTimePicker
9   // and displays an estimated delivery date
10  public partial class DateTimePickerForm : Form
11  {
12      // constructor
13  public DateTimePickerForm()
14  {
15      InitializeComponent();
16  } // end constructor
17
18  private void dateTimePickerDropOff_ValueChanged(
19      object sender, EventArgs e )
20  {
21      DateTime dropOffDate = dateTimePickerDropOff.Value;
22
23      // add extra time when items are dropped off around Sunday
24      if ( dropOffDate.DayOfWeek == DayOfWeek.Friday ||
25          dropOffDate.DayOfWeek == DayOfWeek.Saturday ||
26          dropOffDate.DayOfWeek == DayOfWeek.Sunday )
27
28          //estimate three days for delivery
29          outputLabel.Text =
30              dropOffDate.AddDays( 3 ).ToString();
31      else
32          // otherwise estimate only two days for delivery
33          outputLabel.Text =
34              dropOffDate.AddDays( 2 ).ToString();
35  } // end method dateTimePickerDropOff_ValueChanged
36
37  private void DateTimePickerForm_Load( object sender, EventArgs e )
38  {
39      // user cannot select days before today
40      dateTimePickerDropOff.MinDate = DateTime.Today;
41
42      // user can only select days up to one year in the future
43      dateTimePickerDropOff.MaxDate = DateTime.Today.AddYears( 1 );
44  } // end method DateTimePickerForm_Load
45 } // end class DateTimePickerForm
46 } // end namespace DateTimePickerTest

```

a) GUI when app first executes shows current date



b) Selecting a drop-off date

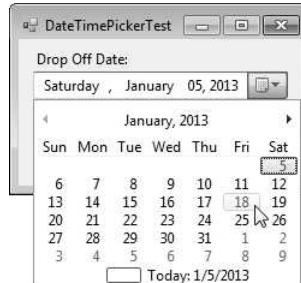
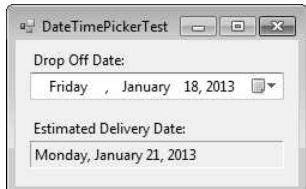
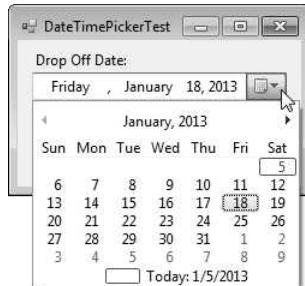


Fig. 15.11 | Demonstrating DateTimePicker. (Part 2 of 3.)

c) GUI after selecting drop-off date



d) GUI showing current and selected dates

**Fig. 15.11** | Demonstrating DateTimePicker. (Part 3 of 3.)

The `DateTimePicker` (`dropOffDateTimePicker`) has its `Format` property set to `Long`, so the user can select just a date in this app. When the user selects a date, the `ValueChanged` event occurs. The event handler for this event (lines 18–35) first retrieves the selected date from the `DateTimePicker`'s `Value` property (line 21). Lines 24–26 use the `DateTime` structure's `DayOfWeek` property to determine the day of the week on which the selected date falls. The day values are represented using the `DayOfWeek` enumeration. Lines 29–30 and 33–34 use `DateTime`'s `AddDays` method to increase the date by three days or two days, respectively. The resulting date is then displayed in `Long` format using method `ToLongDateString`.

In this app, we do not want the user to be able to select a drop-off day before the current day, or one that's more than a year into the future. To enforce this, we set the `DateTimePicker`'s `MinDate` and `MaxDate` properties when the `Form` is loaded (lines 40 and 43). Property `Today` returns the current day, and method `AddYears` (with an argument of 1) is used to specify a date one year in the future.

Let's take a closer look at the output. This app begins by displaying the current date (Fig. 15.11(a)). In Fig. 15.11(b), we selected the 18th of January. In Fig. 15.11(c), the estimated arrival date is displayed as the 21st of January. Figure 15.11(d) shows that the 18th, after it is selected, is highlighted in the calendar.

## 15.5 LinkLabel Control

The `LinkLabel` control displays *links* to other resources, such as files or web pages (Fig. 15.12). A `LinkLabel` appears as underlined text (colored blue by default). When the mouse moves over the link, the pointer changes to a hand; this is similar to the behavior of a hyperlink in a web page. The link can change color to indicate whether it is not yet visited, previously visited or active (the mouse is over the link). When clicked, the `LinkLabel` generates a `LinkClicked` event (see Fig. 15.13). Class `LinkLabel` is derived from class `Label` and therefore inherits all of class `Label`'s functionality.

**Fig. 15.12** | LinkLabel control in running program.



| <b>Look-and-Feel Observation 15.3</b>                                                                                                                                                |                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>A LinkLabel is the preferred control for indicating that the user can click a link to jump to a resource such as a web page, though other controls can perform similar tasks.</i> |                                                                                                                                                            |
| LinkLabel properties and an event                                                                                                                                                    | Description                                                                                                                                                |
| <i>Common Properties</i>                                                                                                                                                             |                                                                                                                                                            |
| ActiveLinkColor                                                                                                                                                                      | Specifies the color of the active link when the user is in the process of clicking the link. The default color (typically red) is set by the system.       |
| LinkArea                                                                                                                                                                             | Specifies which portion of text in the LinkLabel is part of the link.                                                                                      |
| LinkBehavior                                                                                                                                                                         | Specifies the link's behavior, such as how the link appears when the mouse is placed over it.                                                              |
| LinkColor                                                                                                                                                                            | Specifies the original color of the link before it's been visited. The default color (typically blue) is set by the system.                                |
| LinkVisited                                                                                                                                                                          | If true, the link appears as though it has been visited (its color is changed to that specified by property VisitedLinkColor). The default value is false. |
| Text                                                                                                                                                                                 | Specifies the control's text.                                                                                                                              |
| UseMnemonic                                                                                                                                                                          | If true, the & character in the Text property acts as a shortcut (similar to the Alt shortcut in menus).                                                   |
| VisitedLinkColor                                                                                                                                                                     | Specifies the color of a visited link. The default color (typically purple) is set by the system.                                                          |
| <i>Common Event (Event arguments LinkLabelLinkClickedEventArgs)</i>                                                                                                                  |                                                                                                                                                            |
| LinkClicked                                                                                                                                                                          | Generated when the link is clicked. This is the default event when the control is double clicked in Design mode.                                           |

**Fig. 15.13** | LinkLabel properties and an event.

Class LinkLabelTestForm (Fig. 15.14) uses three LinkLabels to link to the C: drive, the Deitel website ([www.deitel.com](http://www.deitel.com)) and the Notepad app, respectively. The Text properties of the LinkLabel's cDriveLinkLabel, deitelLinkLabel and notepadLinkLabel describe each link's purpose.

---

```

1 // Fig. 15.14: LinkLabelTestForm.cs
2 // Using LinkLabels to create hyperlinks.
3 using System;
4 using System.Windows.Forms;
5
6 namespace LinkLabelTest
7 {
8     // Form using LinkLabels to browse the C:\ drive,
9     // load a web page and run Notepad
10    public partial class LinkLabelTestForm : Form
11    {

```

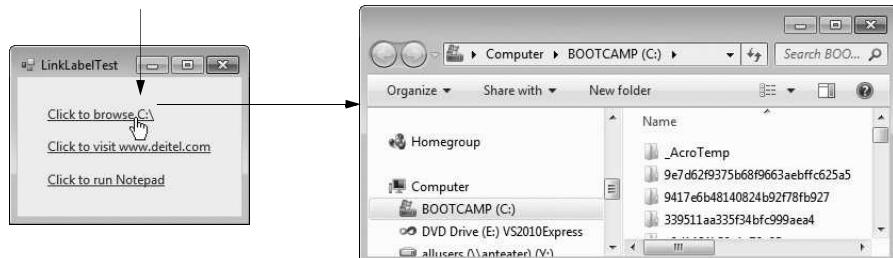
**Fig. 15.14** | LinkLabels used to link to a drive, a web page and an app. (Part 1 of 3.)

```

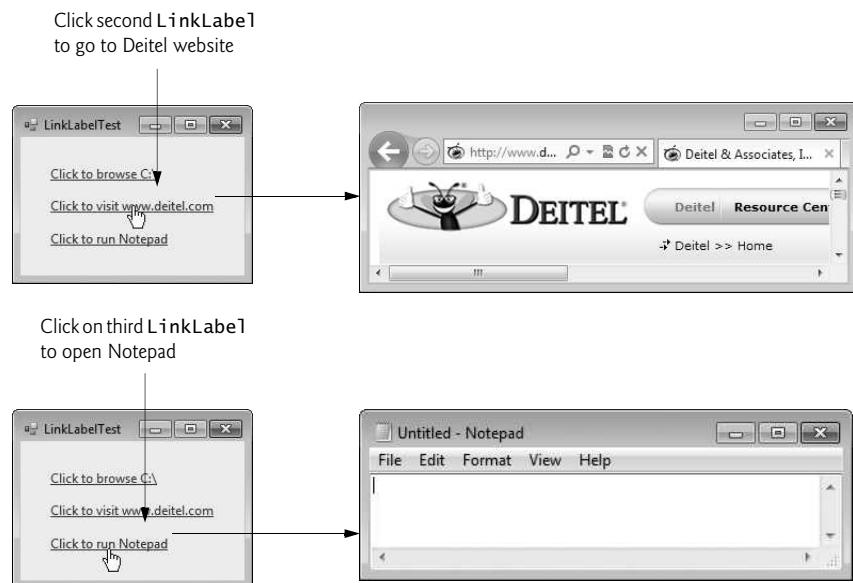
12     // constructor
13     public LinkLabelTestForm()
14     {
15         InitializeComponent();
16     } // end constructor
17
18     // browse C:\ drive
19     private void cDriveLinkLabel_LinkClicked( object sender,
20         LinkLabelLinkClickedEventArgs e )
21     {
22         // change LinkColor after it has been clicked
23         driveLinkLabel.LinkVisited = true;
24
25         System.Diagnostics.Process.Start( @"C:\" );
26     } // end method cDriveLinkLabel_LinkClicked
27
28     // load www.deitel.com in web browser
29     private void deitelLinkLabel_LinkClicked( object sender,
30         LinkLabelLinkClickedEventArgs e )
31     {
32         // change LinkColor after it has been clicked
33         deitelLinkLabel.LinkVisited = true;
34
35         System.Diagnostics.Process.Start( "http://www.deitel.com" );
36     } // end method deitelLinkLabel_LinkClicked
37
38     // run app Notepad
39     private void notepadLinkLabel_LinkClicked( object sender,
40         LinkLabelLinkClickedEventArgs e )
41     {
42         // change LinkColor after it has been clicked
43         notepadLinkLabel.LinkVisited = true;
44
45         // program called as if in run
46         // menu and full path not needed
47         System.Diagnostics.Process.Start( "notepad" );
48     } // end method notepadLinkLabel_LinkClicked
49 } // end class LinkLabelTestForm
50 } // end namespace LinkLabelTest

```

Click first LinkLabel to  
look at contents of C: drive



**Fig. 15.14** | LinkLabels used to link to a drive, a web page and an app. (Part 2 of 3.)



**Fig. 15.14** | LinkLabels used to link to a drive, a web page and an app. (Part 3 of 3.)

The event handlers for the LinkLabels call method **Start** of class **Process** (namespace **System.Diagnostics**), which allows you to execute other programs, or load documents or web sites from an app. Method **Start** can take one argument, the file to open, or two arguments, the app to run and its command-line arguments. Method **Start**'s arguments can be in the same form as if they were provided for input to the Windows **Run** command (**Start > Run...**). For apps that are known to Windows, full path names are not needed, and the file extension often can be omitted. To open a file of a type that Windows recognizes (and knows how to handle), simply use the file's full path name. For example, if you pass the method a .docx file, Windows will open it in Microsoft Word (or whatever program is registered to open .docx files, if any). The Windows operating system must be able to use the app associated with the given file's extension to open the file.

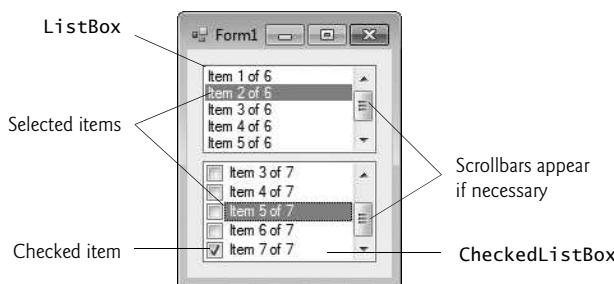
The event handler for **cDriveLinkLabel**'s **LinkClicked** event browses the C: drive (lines 19–26). Line 23 sets the **LinkVisited** property to **true**, which changes the link's color from blue to purple (the **LinkVisited** colors can be configured through the **Properties** window in Visual Studio). The event handler then passes @"C:\\" to method **Start** (line 25), which opens a **Windows Explorer** window. The @ symbol that we placed before "C:\\" indicates that all characters in the string should be interpreted literally—this is known as a **verbatim string**. Thus, the backslash within the string is not considered to be the first character of an escape sequence. This simplifies strings that represent directory paths, since you do not need to use \\ for each \ character in the path.

The event handler for **deitelLinkLabel**'s **LinkClicked** event (lines 29–36) opens the web page [www.deitel.com](http://www.deitel.com) in the user's default web browser. We achieve this by passing the web-page address as a **string** (line 35), which opens the web page in a new web browser window or tab. Line 33 sets the **LinkVisited** property to **true**.

The event handler for `notepadLinkLabel`'s `LinkClicked` event (lines 39–48) opens the Notepad app. Line 43 sets the `LinkVisited` property to `true` so that the link appears as a visited link. Line 47 passes the argument "notepad" to method `Start`, which runs `notepad.exe`. In line 47, neither the full path nor the `.exe` extension is required—Windows automatically recognizes the argument given to method `Start` as an executable file.

## 15.6 ListBox Control

The **ListBox** control allows the user to view and select from multiple items in a list. **List-Boxes** are static GUI entities, which means that users cannot directly edit the list of items. The user can be provided with **TextBoxes** and **Buttons** with which to specify items to be added to the list, but the actual additions must be performed in code. The **CheckedList-Box** control (Section 15.7) extends a **ListBox** by including **Checkboxes** next to each item in the list. This allows users to place checks on multiple items at once, as is possible with **CheckBox** controls. (Users also can select multiple items from a **ListBox** by setting the **ListBox**'s **SelectionMode** property, which is discussed shortly.) Figure 15.15 displays a **ListBox** and a **CheckedListBox**. In both controls, scrollbars appear if the number of items exceeds the **ListBox**'s viewable area.



**Fig. 15.15** | **ListBox** and **CheckedListBox** on a Form.

Figure 15.16 lists common **ListBox** properties and methods and a common event. The **SelectionMode** property determines the number of items that can be selected. This property has the possible values **None**, **One**, **MultiSimple** and **MultiExtended** (from the **SelectionMode** enumeration)—the differences among these settings are explained in Fig. 15.16. The **SelectedIndexChanged** event occurs when the user selects a new item.

| ListBox properties, methods and an event | Description                                                                                                                         |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>                 |                                                                                                                                     |
| <b>Items</b>                             | The collection of items in the <b>ListBox</b> .                                                                                     |
| <b>MultiColumn</b>                       | Indicates whether the <b>ListBox</b> can display multiple columns. Multiple columns eliminate vertical scrollbars from the display. |

**Fig. 15.16** | **ListBox** properties, methods and an event. (Part 1 of 2.)

| ListBox properties, methods and an event |  | Description                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------------------|--|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SelectedIndex</b>                     |  | Returns the index of the selected item. If no items have been selected, the property returns -1. If the user selects multiple items, this property returns only one of the selected indices. If multiple items are selected, use property <b>SelectedIndices</b> .                                                                                            |
| <b>SelectedIndices</b>                   |  | Returns a collection containing the indices for all selected items.                                                                                                                                                                                                                                                                                           |
| <b>SelectedItem</b>                      |  | Returns a reference to the selected item. If multiple items are selected, it can return any of the selected items.                                                                                                                                                                                                                                            |
| <b>SelectedItems</b>                     |  | Returns a collection of the selected item(s).                                                                                                                                                                                                                                                                                                                 |
| <b>SelectionMode</b>                     |  | Determines the number of items that can be selected and the means through which multiple items can be selected. Values <b>None</b> , <b>One</b> (the default), <b>MultiSimple</b> (multiple selection allowed) or <b>Multi-Extended</b> (multiple selection allowed using a combination of arrow keys or mouse clicks and <i>Shift</i> and <i>Ctrl</i> keys). |
| <b>Sorted</b>                            |  | Indicates whether items are sorted <i>alphabetically</i> . Setting this property's value to <b>true</b> sorts the items. The default value is <b>false</b> .                                                                                                                                                                                                  |
| <i>Common Methods</i>                    |  |                                                                                                                                                                                                                                                                                                                                                               |
| <b>ClearSelected</b>                     |  | Deselects every item.                                                                                                                                                                                                                                                                                                                                         |
| <b>GetSelected</b>                       |  | Returns <b>true</b> if the item at the specified index is selected.                                                                                                                                                                                                                                                                                           |
| <i>Common Event</i>                      |  |                                                                                                                                                                                                                                                                                                                                                               |
| <b>SelectedIndexChanged</b>              |  | Generated when the selected index changes. This is the default event when the control is double clicked in the designer.                                                                                                                                                                                                                                      |

**Fig. 15.16** | ListBox properties, methods and an event. (Part 2 of 2.)

Both the `ListBox` and `CheckedListBox` have properties `Items`, `SelectedItem` and `SelectedIndex`. Property `Items` returns a collection of the list items. *Collections* are a common way to manage lists of objects in the .NET framework. Many .NET GUI components (e.g., `ListBoxes`) use collections to expose lists of internal objects (e.g., items in a `ListBox`). We discuss collections further in Chapter 21. The collection returned by property `Items` is represented as an object of type `ListBox.ObjectCollection`. Property `SelectedItem` returns the `ListBox`'s currently selected item. If the user can select multiple items, use collection `SelectedItems` to return all the selected items as a `ListBox.SelectedObjectCollection`. Property `SelectedIndex` returns the index of the selected item—if there could be more than one, use property `SelectedIndices`, which returns a `ListBox.SelectedIndexCollection`. If no items are selected, property `SelectedIndex` returns -1. Method `GetSelected` takes an index and returns **true** if the corresponding item is selected.

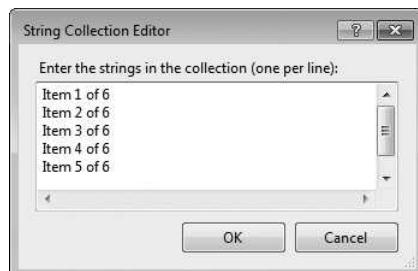
### *Adding Items to ListBoxes and CheckedListBoxes*

To add items to a `ListBox` or to a `CheckedListBox`, we must add objects to its `Items` collection. This can be accomplished by calling method `Add` to add a `string` to the `ListBox`'s or `CheckedListBox`'s `Items` collection. For example, we could write

```
myListBox.Items.Add( myListItem );
```

to add string *myListItem* to *ListBox myListbox*. To add multiple objects, you can either call method *Add* multiple times or call method *AddRange* to add an array of objects. Classes *ListBox* and *CheckedListBox* each call the submitted object's *ToString* method to determine the *Label* for the corresponding object's entry in the list. This allows you to add different objects to a *ListBox* or a *CheckedListBox* that later can be returned through properties *SelectedItem* and *SelectedItems*.

Alternatively, you can add items to *ListBoxes* and *CheckedListBoxes* visually by examining the *Items* property in the **Properties** window. Clicking the ellipsis button opens the **String Collection Editor**, which contains a text area for adding items; each item appears on a separate line (Fig. 15.17). Visual Studio then writes code to add these strings to the *Items* collection inside method *InitializeComponent*.



**Fig. 15.17 |** String Collection Editor.

Figure 15.18 uses class *ListBoxTestForm* to add, remove and clear items from *ListBox displayListBox*. Class *ListBoxTestForm* uses *TextBox inputTextBox* to allow the user to type in a new item. When the user clicks the **Add** **Button**, the new item appears in *displayListBox*. Similarly, if the user selects an item and clicks **Remove**, the item is deleted. When clicked, **Clear** deletes all entries in *displayListBox*. The user terminates the app by clicking **Exit**.

The *addButton\_Click* event handler (lines 20–24) calls method *Add* of the *Items* collection in the *ListBox*. This method takes a *string* as the item to add to *displayListBox*. In this case, the *string* used is the user input from the *inputTextBox* (line 22). After the item is added, *inputTextBox.Text* is cleared (line 23).

```

1 // Fig. 15.18: ListBoxTestForm.cs
2 // Program to add, remove and clear ListBox items
3 using System;
4 using System.Windows.Forms;
5
6 namespace ListBoxTest
7 {
8     // Form uses a TextBox and Buttons to add,
9     // remove, and clear ListBox items
10    public partial class ListBoxTestForm : Form
11    {

```

**Fig. 15.18 |** Program that adds, removes and clears *ListBox* items. (Part I of 3.)

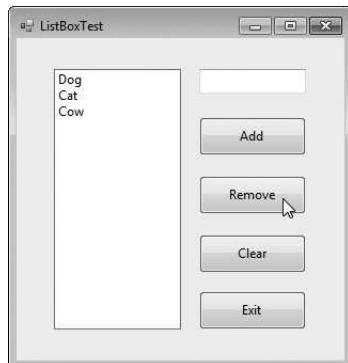
```

12     // constructor
13     public ListBoxTestForm()
14     {
15         InitializeComponent();
16     } // end constructor
17
18     // add new item to ListBox (text from input TextBox)
19     // and clear input TextBox
20     private void addButton_Click( object sender, EventArgs e )
21     {
22         displayListBox.Items.Add( inputTextBox.Text );
23         inputTextBox.Clear();
24     } // end method addButton_Click
25
26     // remove item if one is selected
27     private void removeButton_Click( object sender, EventArgs e )
28     {
29         // check whether item is selected; if so, remove
30         if ( displayListBox.SelectedIndex != -1 )
31             displayListBox.Items.RemoveAt(
32                 displayListBox.SelectedIndex );
33     } // end method removeButton_Click
34
35     // clear all items in ListBox
36     private void clearButton_Click( object sender, EventArgs e )
37     {
38         displayListBox.Items.Clear();
39     } // end method clearButton_Click
40
41     // exit app
42     private void exitButton_Click( object sender, EventArgs e )
43     {
44         Application.Exit();
45     } // end method exitButton_Click
46 } // end class ListBoxTestForm
47 } // end namespace ListBoxTest

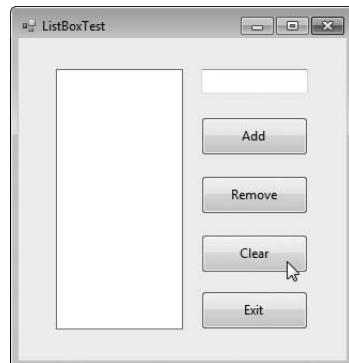
```

a) GUI after adding **Dog**, **Cat** and **Chicken** and before adding **Cow**b) GUI after adding **Cow** and before deleting **Chicken****Fig. 15.18** | Program that adds, removes and clears ListBox items. (Part 2 of 3.)

c) GUI after deleting Chicken



d) GUI after clearing the ListBox

**Fig. 15.18** | Program that adds, removes and clears ListBox items. (Part 3 of 3.)

The `removeButton_Click` event handler (lines 27–33) uses method `RemoveAt` to remove an item from the `ListBox`. Event handler `removeButton_Click` first uses property `SelectedIndex` to determine which index is selected. If `SelectedIndex` is not `-1` (i.e., no item is selected), lines 31–32 remove the item that corresponds to the selected index.

The `clearButton_Click` event handler (lines 36–39) calls method `Clear` of the `Items` collection (line 38). This removes all the entries in `displayListBox`. Finally, event handler `exitButton_Click` (lines 42–45) terminates the app by calling method `Application.Exit` (line 44).

## 15.7 CheckedListBox Control

The `CheckedListBox` control derives from `ListBox` and displays a `CheckBox` with each item. Items can be added via methods `Add` and `AddRange` or through the **String Collection Editor**. `CheckedListBoxes` allow multiple items to be checked, but item selection is more restrictive. The only values for the `SelectionMode` property are `None` and `One`. `One` allows a single selection, whereas `None` allows no selections. Because an item must be selected to be checked, you must set the `SelectionMode` to be `One` if you wish to allow users to check items. Thus, toggling property `SelectionMode` between `One` and `None` effectively switches between enabling and disabling the user's ability to check list items. Common properties, a method and an event of `CheckedListBoxes` appear in Fig. 15.19.



### Common Programming Error 15.1

*The IDE displays an error message if you attempt to set the `SelectionMode` property to `MultiSimple` or `MultiExtended` in the **Properties** window of a `CheckedListBox`. If this value is set programmatically, a runtime error occurs.*

Event `ItemCheck` occurs whenever a user checks or unchecks a `CheckedListBox` item. Event-argument properties `CurrentValue` and `NewValue` return `CheckState` values for the current and new state of the item, respectively. A comparison of these values allows you to determine whether the `CheckedListBox` item was checked or unchecked. The `CheckedListBox` control retains the `SelectedItems` and `SelectedIndices` properties (it inherits

| CheckedListBox properties, a method and an event                      | Description                                                                                                                                                                                                                                                                                  |
|-----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>                                              | (All the <code>ListBox</code> properties, methods and events are inherited by <code>CheckedListBox</code> .)                                                                                                                                                                                 |
| <code>CheckedItems</code>                                             | Accessible only at runtime. Returns the collection of items that are checked as a <code>CheckedListBox.CheckedItemCollection</code> . This is distinct from the selected item, which is highlighted (but not necessarily checked). There can be at most one selected item at any given time. |
| <code>CheckedIndices</code>                                           | Accessible only at runtime. Returns indices for all checked items as a <code>CheckedListBox.CheckedIndexCollection</code> .                                                                                                                                                                  |
| <code>CheckOnClick</code>                                             | When <code>true</code> and the user clicks an item, the item is both selected and checked or unchecked. By default, this property is <code>false</code> , which means that the user must select an item, then click it again to check or uncheck it.                                         |
| <code>SelectionMode</code>                                            | Determines whether items can be selected and checked. The possible values are <code>One</code> (the default; allows multiple checks to be placed) or <code>None</code> (does not allow any checks to be placed).                                                                             |
| <i>Common Method</i>                                                  |                                                                                                                                                                                                                                                                                              |
| <code>GetItemChecked</code>                                           | Takes an index and returns <code>true</code> if the corresponding item is checked.                                                                                                                                                                                                           |
| <i>Common Event (Event arguments <code>ItemCheckEventArgs</code>)</i> |                                                                                                                                                                                                                                                                                              |
| <code>ItemCheck</code>                                                | Generated when an item is checked or unchecked.                                                                                                                                                                                                                                              |
| <i><code>ItemCheckEventArgs</code> Properties</i>                     |                                                                                                                                                                                                                                                                                              |
| <code>CurrentValue</code>                                             | Indicates whether the current item is checked or unchecked. Possible values are <code>Checked</code> , <code>Unchecked</code> and <code>Indeterminate</code> .                                                                                                                               |
| <code>Index</code>                                                    | Returns the zero-based index of the item that changed.                                                                                                                                                                                                                                       |
| <code>NewValue</code>                                                 | Specifies the new state of the item.                                                                                                                                                                                                                                                         |

**Fig. 15.19** | `CheckedListBox` properties, a method and an event.

them from class `ListBox`). However, it also includes properties `CheckedItems` and `CheckedIndices`, which return information about the checked items and indices.

In Fig. 15.20, class `CheckedListBoxTestForm` uses a `CheckedListBox` and a `ListBox` to display a user's selection of books. The `CheckedListBox` allows the user to select multiple titles. In the **String Collection Editor**, items were added for some Deitel books: C, C++, Java™, Internet & WWW, VB 2012, Visual C++ and Visual C# 2012 (the abbreviation HTP stands for "How to Program"). The `ListBox` (named `displayListBox`) displays the user's selection. In the screenshots accompanying this example, the `CheckedListBox` appears to the left, the `ListBox` on the right.

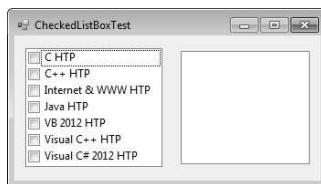
When the user checks or unchecks an item in `itemCheckedListBox`, an `ItemCheck` event occurs and event handler `itemCheckedListBox_ItemCheck` (lines 19–31) executes. An `if...else` statement (lines 27–30) determines whether the user checked or unchecked an item in the `CheckedListBox`. Line 27 uses the `NewValue` property to determine whether

```

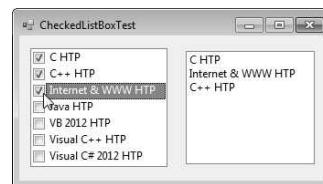
1 // Fig. 15.20: CheckedListBoxTestForm.cs
2 // Using a CheckedListBox to add items to a display ListBox
3 using System;
4 using System.Windows.Forms;
5
6 namespace CheckedListBoxTest
7 {
8     // Form uses a checked ListBox to add items to a display ListBox
9     public partial class CheckedListBoxTestForm : Form
10    {
11        // constructor
12        public CheckedListBoxTestForm()
13        {
14            InitializeComponent();
15        } // end constructor
16
17        // item checked or unchecked
18        // add or remove from display ListBox
19        private void itemCheckedListBox_ItemCheck(
20            object sender, ItemCheckEventArgs e )
21        {
22            // obtain reference of selected item
23            string item = itemCheckedListBox.SelectedItem.ToString();
24
25            // if item checked, add to ListBox
26            // otherwise remove from ListBox
27            if ( e.NewValue == CheckState.Checked )
28                displayListBox.Items.Add( item );
29            else
30                displayListBox.Items.Remove( item );
31        } // end method itemCheckedListBox_ItemCheck
32    } // end class CheckedListBoxTestForm
33 } // end namespace CheckedListBoxTest

```

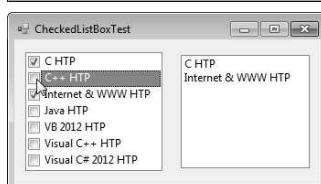
a) Initial GUI displayed when the app executes



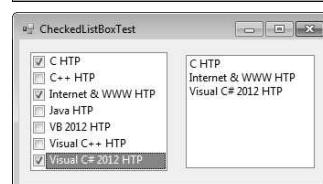
b) GUI after selecting the first three items



c) GUI after deselecting C++HTP



d) GUI after selecting Visual C# 2012 HTP



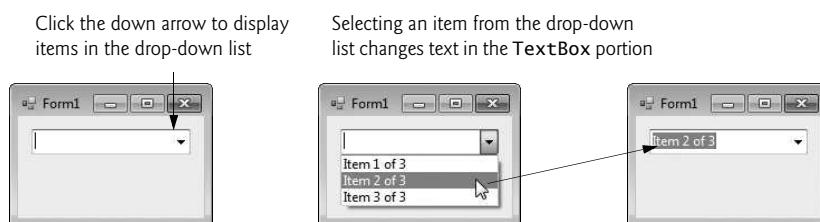
**Fig. 15.20** | CheckedListBox and ListBox used in an app to display a user selection.

the item is being checked (`CheckState.Checked`). If the user checks an item, line 28 adds the checked entry to the `ListBox` `displayListBox`. If the user unchecks an item, line 30 removes the corresponding item from `displayListBox`. This event handler was created by

selecting the **CheckedListBox** in **Design** mode, viewing the control's events in the **Properties** window and double clicking the **ItemCheck** event. The default event for a **CheckedListBox** is a **SelectedIndexChanged** event.

## 15.8 ComboBox Control

The **ComboBox** control combines **TextBox** features with a **drop-down list**—a GUI component that contains a list from which a value can be selected. A **ComboBox** usually appears as a **TextBox** with a down arrow to its right. By default, the user can enter text into the **TextBox** or click the down arrow to display a list of predefined items. If a user chooses an element from this list, that element is displayed in the **TextBox**. If the list contains more elements than can be displayed in the drop-down list, a *scrollbar* appears. The maximum number of items that a drop-down list can display at one time is set by property **MaxDropDownItems**. Figure 15.21 shows a sample **ComboBox** in three different states.



**Fig. 15.21** | **ComboBox** demonstration.

As with the **ListBox** control, you can add objects to collection **Items** programmatically, using methods **Add** and **AddRange**, or visually, with the **String Collection Editor**. Figure 15.22 lists common properties and a common event of class **ComboBox**.



**Look-and-Feel Observation 15.4**

Use a **ComboBox** to save space on a GUI. A disadvantage is that, unlike with a **ListBox**, the user cannot see available items without expanding the drop-down list.

| ComboBox properties and an event | Description                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Common Properties</b>         |                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>DropDownStyle</b>             | Determines the type of <b>ComboBox</b> . Value <b>Simple</b> means that the text portion is editable and the list portion is always visible. Value <b>DropDown</b> (the default) means that the text portion is editable but the user must click an arrow button to see the list portion. Value <b>DropDownList</b> means that the text portion is not editable and the user must click the arrow button to see the list portion. |
| <b>Items</b>                     | The collection of items in the <b>ComboBox</b> control.                                                                                                                                                                                                                                                                                                                                                                           |

**Fig. 15.22** | **ComboBox** properties and an event. (Part 1 of 2.)

| ComboBox properties and an event | Description                                                                                                                                                                                |
|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MaxDropDownItems                 | Specifies the maximum number of items (between 1 and 100) that the drop-down list can display. If the number of items exceeds the maximum number of items to display, a scrollbar appears. |
| SelectedIndex                    | Returns the index of the selected item, or -1 if none are selected.                                                                                                                        |
| SelectedItem                     | Returns a reference to the selected item.                                                                                                                                                  |
| Sorted                           | Indicates whether items are sorted alphabetically. Setting this property's value to true sorts the items. The default is false.                                                            |
| <i>Common Event</i>              |                                                                                                                                                                                            |
| SelectedIndexChanged             | Generated when the selected index changes (such as when a different item is selected). This is the default event when control is double clicked in the designer.                           |

**Fig. 15.22** | ComboBox properties and an event. (Part 2 of 2.)

Property **DropDownStyle** determines the type of ComboBox and is represented as a value of the **ComboBoxStyle** enumeration, which contains values **Simple**, **DropDown** and **DropDownList**. Option **Simple** does not display a drop-down arrow. Instead, a scrollbar appears next to the control, allowing the user to select a choice from the list. The user also can type in a selection. Style **DropDown** (the default) displays a drop-down list when the down arrow is clicked (or the down arrow key is pressed). The user can type a new item in the ComboBox. The last style is **DropDownList**, which displays a drop-down list but does not allow the user to type in the TextBox.

The ComboBox control has properties **Items** (a collection), **SelectedItem** and **SelectedIndex**, which are similar to the corresponding properties in **ListBox**. There can be at most one selected item in a ComboBox. If no items are selected, then **SelectedIndex** is -1. When the selected item changes, a **SelectedIndexChanged** event occurs.

Class **ComboBoxTestForm** (Fig. 15.23) allows users to select a shape to draw—circle, ellipse, square or pie (in both filled and unfilled versions)—by using a ComboBox. The ComboBox in this example is uneditable, so the user cannot type in the TextBox.



### Look-and-Feel Observation 15.5

Make lists (such as ComboBoxes) editable only if the app is designed to accept user-submitted elements. Otherwise, the user might try to enter a custom item that's improper for the purposes of your app.

---

```

1 // Fig. 15.23: ComboBoxTestForm.cs
2 // Using ComboBox to select a shape to draw.
3 using System;
4 using System.Drawing;
5 using System.Windows.Forms;
```

**Fig. 15.23** | ComboBox used to draw a selected shape. (Part 1 of 3.)

```
6  namespace ComboBoxTest
7  {
8      // Form uses a ComboBox to select different shapes to draw
9      public partial class ComboBoxTestForm : Form
10     {
11         // constructor
12         public ComboBoxTestForm()
13         {
14             InitializeComponent();
15         } // end constructor
16
17         // get index of selected shape, draw shape
18         private void imageComboBox_SelectedIndexChanged(
19             object sender, EventArgs e )
20         {
21             // create graphics object, Pen and SolidBrush
22             Graphics myGraphics = base.CreateGraphics();
23
24             // create Pen using color DarkRed
25             Pen myPen = new Pen( Color.DarkRed );
26
27             // create SolidBrush using color DarkRed
28             SolidBrush mySolidBrush = new SolidBrush( Color.DarkRed );
29
30             // clear drawing area, setting it to color white
31             myGraphics.Clear( Color.White );
32
33             // find index, draw proper shape
34             switch ( imageComboBox.SelectedIndex )
35             {
36                 case 0: // case Circle is selected
37                     myGraphics.DrawEllipse( myPen, 50, 50, 150, 150 );
38                     break;
39                 case 1: // case Rectangle is selected
40                     myGraphics.DrawRectangle( myPen, 50, 50, 150, 150 );
41                     break;
42                 case 2: // case Ellipse is selected
43                     myGraphics.DrawEllipse( myPen, 50, 85, 150, 115 );
44                     break;
45                 case 3: // case Pie is selected
46                     myGraphics.DrawPie( myPen, 50, 50, 150, 150, 0, 45 );
47                     break;
48                 case 4: // case Filled Circle is selected
49                     myGraphics.FillEllipse( mySolidBrush, 50, 50, 150, 150 );
50                     break;
51                 case 5: // case Filled Rectangle is selected
52                     myGraphics.FillRectangle( mySolidBrush, 50, 50, 150,
53                                         150 );
54                     break;
55                 case 6: // case Filled Ellipse is selected
56                     myGraphics.FillEllipse( mySolidBrush, 50, 85, 150, 115 );
57                     break;
58             }
59         }
60     }
61 }
```

---

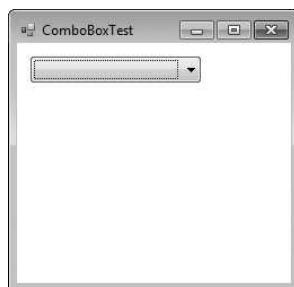
Fig. 15.23 | ComboBox used to draw a selected shape. (Part 2 of 3.)

```

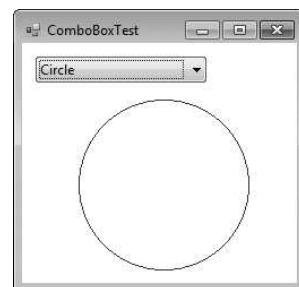
59             case 7: // case Filled Pie is selected
60                 myGraphics.FillPie( mySolidBrush, 50, 50, 150, 150, 0,
61                                         45 );
62             break;
63         } // end switch
64
65         myGraphics.Dispose(); // release the Graphics object
66     } // end method imageComboBox_SelectedIndexChanged
67 } // end class ComboBoxTestForm
68 } // end namespace ComboBoxTest

```

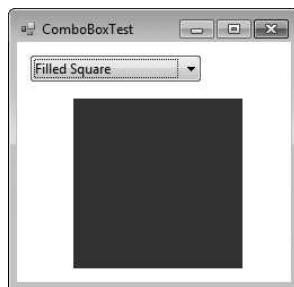
a) Initial GUI displayed when the app executes



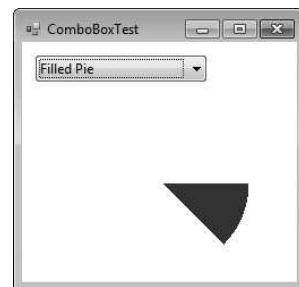
b) GUI after selecting **Circle** from the ComboBox



c) GUI after selecting **Filled Square** from the ComboBox



d) GUI after selecting **Filled Pie** from the ComboBox



**Fig. 15.23** | ComboBox used to draw a selected shape. (Part 3 of 3.)

After creating ComboBox `imageComboBox`, make it uneditable by setting its `DropDownStyle` to `DropDownList` in the **Properties** window. Next, add items **Circle**, **Square**, **Ellipse**, **Pie**, **Filled Circle**, **Filled Square**, **Filled Ellipse** and **Filled Pie** to the `Items` collection using the **String Collection Editor**. Whenever the user selects an item from `imageComboBox`, a `SelectedIndexChanged` event occurs and event handler `imageComboBox_SelectedIndexChanged` (lines 19–66) executes. Lines 23–29 create a `Graphics` object, a `Pen` and a `SolidBrush`, which are used to draw on the Form. The `Graphics` object (line 23) allows a pen or brush to draw on a component, using one of several `Graphics` methods. The `Pen` object (line 26) is used by methods `DrawEllipse`, `DrawRectangle` and `DrawPie` (lines 38, 41, 44 and 47) to draw the outlines of their corresponding shapes. The `SolidBrush` object (line 29) is used by methods `FillEllipse`, `FillRectangle` and `FillPie` (lines 50, 53–54, 57 and 60–61) to fill their corresponding solid shapes. Line 32 colors the entire Form `White`, using `Graphics` method `Clear`.

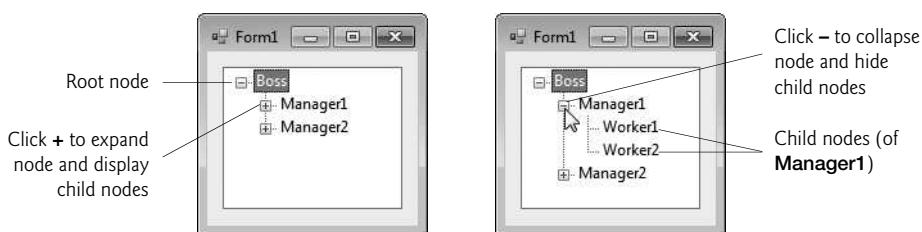
The app draws a shape based on the selected item's index. The `switch` statement (lines 35–63) uses `imageComboBox.SelectedIndex` to determine which item the user selected. `Graphics` method `DrawEllipse` (line 38) takes a `Pen`, and the *x*- and *y*-coordinates of the

upper-left corner, the width and height of the bounding box (i.e., rectangular area) in which the ellipse will be displayed. The origin of the coordinate system is in the upper-left corner of the Form; the *x*-coordinate increases to the right, and the *y*-coordinate increases downward. A circle is a special case of an ellipse (with the width and height equal). Line 38 draws a circle. Line 44 draws an ellipse that has different values for width and height.

Class **Graphics** method **DrawRectangle** (line 41) takes a **Pen**, the *x*- and *y*-coordinates of the upper-left corner and the width and height of the rectangle to draw. Method **DrawPie** (line 47) draws a pie as a portion of an ellipse. The ellipse is bounded by a rectangle. Method **DrawPie** takes a **Pen**, the *x*- and *y*-coordinates of the upper-left corner of the rectangle, its width and height, the start angle (in degrees) and the sweep angle (in degrees) of the pie. Angles increase clockwise. The **FillEllipse** (lines 50 and 57), **FillRectangle** (line 53–54) and **FillPie** (line 60–61) methods are similar to their unfilled counterparts, except that they take a **Brush** (e.g., **SolidBrush**) instead of a **Pen**. Some of the drawn shapes are illustrated in the screenshots of Fig. 15.23.

## 15.9 TreeView Control

The **TreeView** control displays **nodes** hierarchically in a **tree**. Traditionally, nodes are objects that contain values and can refer to other nodes. A **parent node** contains **child nodes**, and the child nodes can be parents to other nodes. Two child nodes that have the same parent node are considered **sibling nodes**. A tree is a collection of nodes, usually organized in a *hierarchical* manner. The first parent node of a tree is the **root node** (a **TreeView** can have multiple roots). For example, the file system of a computer can be represented as a tree. The top-level directory (perhaps C:) would be the root, each subfolder of C: would be a child node and each child folder could have its own children. **TreeView** controls are useful for displaying hierarchical information, such as the file structure that we just mentioned. We cover nodes and trees in greater detail in Chapter 19, Data Structures. Figure 15.24 displays a sample **TreeView** control on a Form.



**Fig. 15.24** | **TreeView** displaying a sample tree.

A parent node can be expanded or collapsed by clicking the plus box or minus box to its left. Nodes without children do not have these boxes.

The nodes in a **TreeView** are instances of class **TreeNode**. Each **TreeNode** has a **Nodes** collection (type **TreeNodeCollection**), which contains a list of other **TreeNodes**—known as its children. The **Parent** property returns a reference to the parent node (or **null** if the node is a root node). Figures 15.25 and 15.26 list the common properties of **TreeViews** and **TreeNodes**, common **TreeNode** methods and a common **TreeView** event.

| TreeView properties and an event                                     | Description                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>                                             |                                                                                                                                                                                                                                                                                                                                              |
| CheckBoxes                                                           | Indicates whether CheckBoxes appear next to nodes. A value of <code>true</code> displays CheckBoxes. The default value is <code>false</code> .                                                                                                                                                                                               |
| ImageList                                                            | Specifies an <code>ImageList</code> object containing the node icons. An <code>ImageList</code> object is a collection that contains <code>Image</code> objects.                                                                                                                                                                             |
| Nodes                                                                | Returns the collection of <code>TreeNodes</code> in the control as a <code>TreeNodeCollection</code> . It contains methods <code>Add</code> (adds a <code>TreeNode</code> object), <code>Clear</code> (deletes the entire collection) and <code>Remove</code> (deletes a specific node). Removing a parent node deletes all of its children. |
| SelectedNode                                                         | The selected node.                                                                                                                                                                                                                                                                                                                           |
| <i>Common Event (Event arguments <code>TreeViewEventArgs</code>)</i> |                                                                                                                                                                                                                                                                                                                                              |
| AfterSelect                                                          | Generated after selected node changes. This is the default event when the control is double clicked in the designer.                                                                                                                                                                                                                         |

**Fig. 15.25** | TreeView properties and an event.

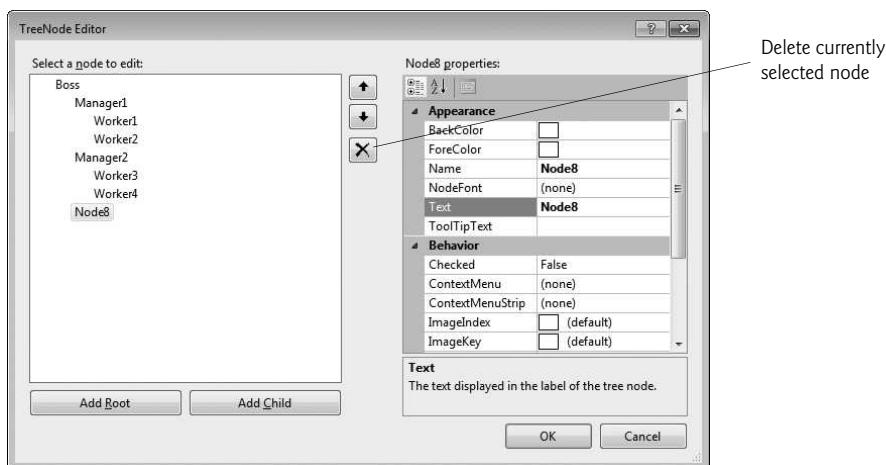
| TreeNode properties and methods | Description                                                                                                                                                                                                                                                                                                                                            |
|---------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>        |                                                                                                                                                                                                                                                                                                                                                        |
| Checked                         | Indicates whether the <code>TreeNode</code> is checked ( <code>CheckBoxes</code> property must be set to <code>true</code> in the parent <code>TreeView</code> ).                                                                                                                                                                                      |
| FirstNode                       | Specifies the first node in the <code>Nodes</code> collection (i.e., the first child in the tree).                                                                                                                                                                                                                                                     |
| FullPath                        | Indicates the path of the node, starting at the root of the tree.                                                                                                                                                                                                                                                                                      |
| ImageIndex                      | Specifies the index in the <code>TreeView</code> 's <code>ImageList</code> of the image shown when the node is deselected.                                                                                                                                                                                                                             |
| LastNode                        | Specifies the last node in the <code>Nodes</code> collection (i.e., the last child in the tree).                                                                                                                                                                                                                                                       |
| NextNode                        | Next sibling node.                                                                                                                                                                                                                                                                                                                                     |
| Nodes                           | Collection of <code>TreeNodes</code> contained in the current node (i.e., all the children of the current node). It contains methods <code>Add</code> (adds a <code>TreeNode</code> object), <code>Clear</code> (deletes the entire collection) and <code>Remove</code> (deletes a specific node). Removing a parent node deletes all of its children. |
| PrevNode                        | Previous sibling node.                                                                                                                                                                                                                                                                                                                                 |
| SelectedImageIndex              | Specifies the index in the <code>TreeView</code> 's <code>ImageList</code> of the image to use when the node is selected.                                                                                                                                                                                                                              |
| Text                            | Specifies the <code>TreeNode</code> 's text.                                                                                                                                                                                                                                                                                                           |
| <i>Common Methods</i>           |                                                                                                                                                                                                                                                                                                                                                        |
| Collapse                        | Collapses a node.                                                                                                                                                                                                                                                                                                                                      |

**Fig. 15.26** | TreeNode properties and methods. (Part I of 2.)

| TreeNode properties and methods | Description                         |
|---------------------------------|-------------------------------------|
| Expand                          | Expands a node.                     |
| ExpandAll                       | Expands all the children of a node. |
| GetNodeCount                    | Returns the number of child nodes.  |

**Fig. 15.26** | TreeNode properties and methods. (Part 2 of 2.)

To add nodes to the TreeView visually, click the ellipsis next to the Nodes property in the **Properties** window. This opens the **TreeNode Editor** (Fig. 15.27), which displays an empty tree representing the TreeView. There are Buttons to create a root and to add or delete a node. To the right are the properties of the current node. Here you can rename the node.

**Fig. 15.27** | TreeNode Editor.

To add nodes programmatically, first create a root node. Create a new **TreeNode** object and pass it a **string** to display. Then call method **Add** to add this new **TreeNode** to the **TreeView**'s **Nodes** collection. Thus, to add a root node to **TreeView myTreeView**, write

```
myTreeView.Nodes.Add( new TreeNode( rootLabel ) );
```

where **myTreeView** is the **TreeView** to which we are adding nodes, and **rootLabel** is the text to display in **myTreeView**. To add children to a root node, add new **TreeNodes** to its **Nodes** collection. We select the appropriate root node from the **TreeView** by writing

```
myTreeView.Nodes[ myIndex ]
```

where **myIndex** is the root node's index in **myTreeView**'s **Nodes** collection. We add nodes to child nodes through the same process by which we added root nodes to **myTreeView**. To add a child to the root node at index **myIndex**, write

```
myTreeView.Nodes[ myIndex ].Nodes.Add( new TreeNode( ChildLabel ) );
```

Class `TreeViewDirectoryStructureForm` (Fig. 15.28) uses a `TreeView` to display the contents of a directory chosen by the user. A `TextBox` and a `Button` are used to specify the directory. First, enter the full path of the directory you want to display. Then click the `Button` to set the specified directory as the root node in the `TreeView`. Each subdirectory of this directory becomes a child node. This layout is similar to that used in **Windows Explorer**. Folders can be expanded or collapsed by clicking the plus or minus boxes that appear to their left.

When the user clicks the `enterButton`, all the nodes in `directoryTreeView` are cleared (line 68). Then, if the directory exists (line 73), the path entered in `inputTextBox` is used to create the root node. Line 76 adds the directory to `directoryTreeView` as the root node, and lines 79–80 call method `PopulateTreeView` (lines 21–62), which takes a directory (a `string`) and a parent node. Method `PopulateTreeView` then creates child nodes corresponding to the subdirectories of the directory it receives as an argument.

---

```

1 // Fig. 15.28: TreeViewDirectoryStructure.cs
2 // Using TreeView to display directory structure.
3 using System;
4 using System.Windows.Forms;
5 using System.IO;
6
7 namespace TreeViewDirectoryStructure
8 {
9     // Form uses TreeView to display directory structure
10    public partial class TreeViewDirectoryStructure : Form
11    {
12        string substringDirectory; // store last part of full path name
13
14        // constructor
15        public TreeViewDirectoryStructure()
16        {
17            InitializeComponent();
18        } // end constructor
19
20        // populate current node with subdirectories
21        public void PopulateTreeView(
22            string directoryValue, TreeNode parentNode )
23        {
24            // array stores all subdirectories in the directory
25            string[] directoryArray =
26                Directory.GetDirectories( directoryValue );
27
28            // populate current node with subdirectories
29            try
30            {
31                // check to see if any subdirectories are present
32                if ( directoryArray.Length != 0 )
33                {
34                    // for every subdirectory, create new TreeNode,
35                    // add as a child of current node and recursively
36                    // populate child nodes with subdirectories

```

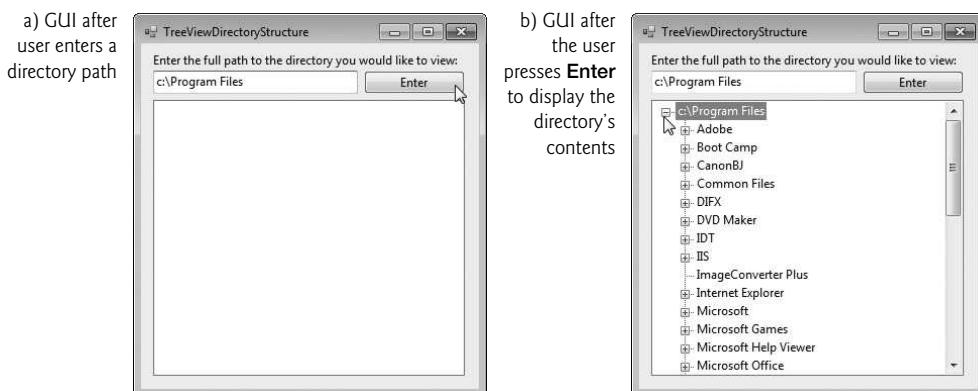
---

**Fig. 15.28** | `TreeView` used to display directories. (Part 1 of 3.)

```
37     foreach ( string directory in directoryArray )
38     {
39         // obtain last part of path name from the full path
40         // name by calling the GetFileNameWithoutExtension
41         // method of class Path
42         substringDirectory =
43             Path.GetFileNameWithoutExtension( directory );
44
45         // create TreeNode for current directory
46         TreeNode myNode = new TreeNode( substringDirectory );
47
48         // add current directory node to parent node
49         parentNode.Nodes.Add( myNode );
50
51         // recursively populate every subdirectory
52         PopulateTreeView( directory, myNode );
53     } // end foreach
54 } // end if
55 } //end try
56
57 // catch exception
58 catch ( UnauthorizedAccessException )
59 {
60     parentNode.Nodes.Add( "Access denied" );
61 } // end catch
62 } // end method PopulateTreeView
63
64 // handles enterButton click event
65 private void enterButton_Click( object sender, EventArgs e )
66 {
67     // clear all nodes
68     directoryTreeView.Nodes.Clear();
69
70     // check if the directory entered by user exists
71     // if it does, then fill in the TreeView,
72     // if not, display error MessageBox
73     if ( Directory.Exists( inputTextBox.Text ) )
74     {
75         // add full path name to directoryTreeView
76         directoryTreeView.Nodes.Add( inputTextBox.Text );
77
78         // insert subfolders
79         PopulateTreeView(
80             inputTextBox.Text, directoryTreeView.Nodes[ 0 ] );
81     }
82     // display error MessageBox if directory not found
83     else
84         MessageBox.Show( inputTextBox.Text + " could not be found.",
85                         "Directory Not Found", MessageBoxButtons.OK,
86                         MessageBoxIcon.Error );
87     } // end method enterButton_Click
88 } // end class TreeViewDirectoryStructureForm
89 } // end namespace TreeViewDirectoryStructure
```

---

**Fig. 15.28** | TreeView used to display directories. (Part 2 of 3.)



**Fig. 15.28** | TreeView used to display directories. (Part 3 of 3.)

Method `PopulateTreeView` (lines 21–62) obtains a list of subdirectories, using method `GetDirectories` of class `Directory` (namespace `System.IO`) in lines 25–26. Method `GetDirectories` takes a `string` (the current directory) and returns an array of `strings` (the subdirectories). If a directory is not accessible for security reasons, an `UnauthorizedAccessException` is thrown. Lines 58–61 catch this exception and add a node containing “Access denied” instead of displaying the subdirectories.

If there are accessible subdirectories, lines 42–43 use method `GetFileNameWithoutExtension` of class `Path` to increase readability by shortening the full path name to just the directory name. The `Path` class provides functionality for working with `strings` that are file or directory paths. Next, each `string` in the `directoryArray` is used to create a new child node (line 46). We use method `Add` (line 49) to add each child node to the parent. Then method `PopulateTreeView` is called recursively on every subdirectory (line 52), which eventually populates the `TreeView` with the entire directory structure. Our recursive algorithm may cause a delay when the program loads large directories. However, once the folder names are added to the appropriate `Nodes` collection, they can be expanded and collapsed without delay. In the next section, we present an alternate algorithm to solve this problem.

## 15.10 ListView Control

The `ListView` control is similar to a `ListBox` in that both display lists from which the user can select one or more items (an example of a `ListView` can be found in Fig. 15.31). `ListView` is more versatile and can display items in different formats. For example, a `ListView` can display icons next to the list items (controlled by its `SmallImageList`, `LargeImageList` or `StateImageList` properties) and show the details of items in columns. Property `MultiSelect` (a `bool`) determines whether multiple items can be selected. `CheckBoxes` can be included by setting property `CheckBoxes` (a `bool`) to `true`, making the `ListView`’s appearance similar to that of a `CheckedListBox`. The `View` property specifies the layout of the `ListView`. Property `Activation` determines the method by which the user selects a list item. The details of these properties and the `ItemActivate` event are explained in Fig. 15.29.

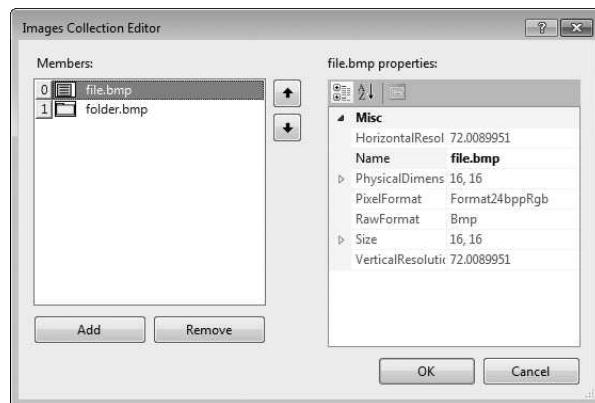
`ListView` allows you to define the images used as icons for `ListView` items. To display images, an `ImageList` component is required. Create one by dragging it to a `Form` from the

| ListView properties and events | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common Properties</i>       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Activation                     | Determines how the user activates an item. This property takes a value in the <code>ItemActivation</code> enumeration. Possible values are <code>OneClick</code> (single-click activation), <code>TwoClick</code> (double-click activation, item changes color when selected) and <code>Standard</code> (the default; double-click activation, item does not change color).                                                                                                                                                              |
| CheckBoxes                     | Indicates whether items appear with <code>CheckBoxes</code> . <code>true</code> displays <code>CheckBoxes</code> . The default is <code>false</code> .                                                                                                                                                                                                                                                                                                                                                                                   |
| LargeImageList                 | Specifies the <code>ImageList</code> containing large icons for display.                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Items                          | Returns the collection of <code>ListViewItems</code> in the control.                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| MultiSelect                    | Determines whether multiple selection is allowed. The default is <code>true</code> , which enables multiple selection.                                                                                                                                                                                                                                                                                                                                                                                                                   |
| SelectedItems                  | Returns the collection of selected items as a <code>ListView.SelectedListViewItemCollection</code> .                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| SmallImageList                 | Specifies the <code>ImageList</code> containing small icons for display.                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| View                           | Determines appearance of <code>ListViewItems</code> . Possible values are <code>LargeIcon</code> (the default; large icon displayed, items can be in multiple columns), <code>SmallIcon</code> (small icon displayed, items can be in multiple columns), <code>List</code> (small icons displayed, items appear in a single column), <code>Details</code> (like <code>List</code> , but multiple columns of information can be displayed per item) and <code>Tile</code> (large icons displayed, information provided to right of icon). |
| <i>Common Events</i>           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Click                          | Generated when an item is clicked. This is the default event.                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| ItemActivate                   | Generated when an item in the <code>ListView</code> is activated (clicked or double clicked). Does not contain the specifics of which item is activated—you can use <code>SelectedItems</code> or <code>SelectedIndices</code> to determine this.                                                                                                                                                                                                                                                                                        |

**Fig. 15.29** | ListView properties and events.

ToolBox. Then, select the `Images` property in the **Properties** window to display the **Image Collection Editor** (Fig. 15.30). Here you can browse for images that you wish to add to the `ImageList`, which contains an array of `Images`. Adding images this way embeds them into the app (like resources), so they do not need to be included separately with the published app. They're not however part of the project. In this example, we added images to the `ImageList` programmatically rather than using the **Image Collection Editor** so that we could use image resources. After creating an empty `ImageList`, add the file and folder icon images (provided with this chapter's examples) to the project as resources. Next, set property `SmallImageList` of the `ListView` to the new `ImageList` object. Property `SmallImageList` specifies the image list for the small icons. Property `LargeImageList` sets the `ImageList` for large icons. The items in a `ListView` are each of type `ListViewItem`. Icons for the `ListView` items are selected by setting the item's `ImageIndex` property to the appropriate index.

Class `ListViewTestForm` (Fig. 15.31) displays files and folders in a `ListView`, along with small icons representing each file or folder. If a file or folder is inaccessible because of



**Fig. 15.30 |** Image Collection Editor window for an `ImageList` component.

permission settings, a `MessageBox` appears. The program scans the contents of the directory as it browses, rather than indexing the entire drive at once.

#### *Method ListViewTestForm\_Load*

Method `ListViewTestForm_Load` (lines 114–123) handles the Form's Load event. When the app loads, the folder and file icon images are added to the `Images` collection of `file-FolderImageList` (lines 117–118). Since the `ListView`'s `SmallImageList` property is set to this `ImageList`, the `ListView` can display these images as icons for each item. Because the folder icon was added first, it has array index 0, and the file icon has array index 1. The app also loads its home directory (obtained at line 14) into the `ListView` when it first loads (line 121) and displays the directory path (line 122).

```

1 // Fig. 15.31: ListViewTestForm.cs
2 // Displaying directories and their contents in ListView.
3 using System;
4 using System.Windows.Forms;
5 using System.IO;
6
7 namespace ListViewTest
8 {
9     // Form contains a ListView which displays
10    // folders and files in a directory
11    public partial class ListViewTestForm : Form
12    {
13        // store current directory
14        string currentDirectory = Directory.GetCurrentDirectory();
15
16        // constructor
17        public ListViewTestForm()
18        {
19            InitializeComponent();
20        } // end constructor

```

**Fig. 15.31 |** ListView displaying files and folders. (Part 1 of 4.)

```
21 // browse directory user clicked or go up one level
22 private void browserListView_Click( object sender, EventArgs e )
23 {
24     // ensure an item is selected
25     if ( browserListView.SelectedItems.Count != 0 )
26     {
27         // if first item selected, go up one level
28         if ( browserListView.Items[ 0 ].Selected )
29         {
30             // create DirectoryInfo object for directory
31             DirectoryInfo directoryObject =
32                 new DirectoryInfo( currentDirectory );
33
34             // if directory has parent, load it
35             if ( directoryObject.Parent != null )
36             {
37                 LoadFilesInDirectory(
38                     directoryObject.Parent.FullName );
39             } // end if
40         } // end if
41     } // end if
42
43     // selected directory or file
44     else
45     {
46         // directory or file chosen
47         string chosen = browserListView.SelectedItems[ 0 ].Text;
48
49         // if item selected is directory, load selected directory
50         if ( Directory.Exists(
51             Path.Combine( currentDirectory, chosen ) ) )
52         {
53             LoadFilesInDirectory(
54                 Path.Combine( currentDirectory, chosen ) );
55         } // end if
56     } // end else
57
58     // update displayLabel
59     displayLabel.Text = currentDirectory;
60     } // end if
61 } // end method browserListView_Click
62
63 // display files/subdirectories of current directory
64 public void LoadFilesInDirectory( string currentDirectoryName )
65 {
66     // load directory information and display
67     try
68     {
69         // clear ListView and set first item
70         browserListView.Items.Clear();
71         browserListView.Items.Add( "Go Up One Level" );
72     }
```

---

Fig. 15.31 | ListView displaying files and folders. (Part 2 of 4.)

```

73         // update current directory
74         currentDirectory = currentDirectoryValue;
75         DirectoryInfo newCurrentDirectory =
76             new DirectoryInfo( currentDirectory );
77
78         // put files and directories into arrays
79         DirectoryInfo[] directoryArray =
80             newCurrentDirectory.GetDirectories();
81         FileInfo[] fileArray = newCurrentDirectory.GetFiles();
82
83         // add directory names to ListView
84         foreach ( DirectoryInfo dir in directoryArray )
85         {
86             // add directory to ListView
87             ListViewItem newDirectoryItem =
88                 browserListView.Items.Add( dir.Name );
89
90             newDirectoryItem.ImageIndex = 0; // set directory image
91         } // end foreach
92
93         // add file names to ListView
94         foreach ( FileInfo file in fileArray )
95         {
96             // add file to ListView
97             ListViewItem newFileItem =
98                 browserListView.Items.Add( file.Name );
99
100            newFileItem.ImageIndex = 1; // set file image
101        } // end foreach
102    } // end try
103
104    // access denied
105    catch ( UnauthorizedAccessException )
106    {
107        MessageBox.Show( "Warning: Some files may not be " +
108            "visible due to permission settings",
109            "Attention", 0, MessageBoxIcon.Warning );
110    } // end catch
111 } // end method LoadFilesInDirectory
112
113 // handle load event when Form displayed for first time
114 private void ListViewTestForm_Load( object sender, EventArgs e )
115 {
116     // add icon images to ImageList
117     fileFolderImageList.Images.Add( Properties.Resources.folder );
118     fileFolderImageList.Images.Add( Properties.Resources.file );
119
120     // load current directory into browserListView
121     LoadFilesInDirectory( currentDirectory );
122     displayLabel.Text = currentDirectory;
123 } // end method ListViewTestForm_Load
124 } // end class ListViewTestForm
125 } // end namespace ListViewTest

```

**Fig. 15.31** | ListView displaying files and folders. (Part 3 of 4.)



**Fig. 15.31** | ListView displaying files and folders. (Part 4 of 4.)

### Method LoadFilesInDirectory

The `LoadFilesInDirectory` method (lines 64–111) populates `browserListView` with the directory passed to it (`currentDirectoryName`). It clears `browserListView` and adds the element "Go Up One Level". When the user clicks this element, the program attempts to move up one level (we see how shortly). The method then creates a `DirectoryInfo` object initialized with the string `currentDirectory` (lines 75–76). If permission is not given to browse the directory, an exception is thrown (and caught in line 105). Method `LoadFilesInDirectory` works differently from method `PopulateTreeView` in the previous program (Fig. 15.28). Instead of loading all the folders on the hard drive, method `LoadFilesInDirectory` loads only the folders in the current directory.

Class  `DirectoryInfo` (namespace `System.IO`) enables us to browse or manipulate the directory structure easily. Method `GetDirectories` (line 80) returns an array of  `DirectoryInfo` objects containing the subdirectories of the current directory. Similarly, method `.GetFiles` (line 81) returns an array of class  `FileInfo` objects containing the files in the current directory. Property `Name` (of both class  `DirectoryInfo` and class  `FileInfo`) contains only the directory or file name, such as `temp` instead of `C:\myfolder\temp`. To access the full name, use property `FullName`.

Lines 84–91 and lines 94–101 iterate through the subdirectories and files of the current directory and add them to `browserListView`. Lines 90 and 100 set the `ImageIndex` properties of the newly created items. If an item is a directory, we set its icon to a directory icon (index 0); if an item is a file, we set its icon to a file icon (index 1).

#### **Method `browserListView_Click`**

Method `browserListView_Click` (lines 23–61) responds when the user clicks control `browserListView`. Line 26 checks whether anything is selected. If a selection has been made, line 29 determines whether the user chose the first item in `browserListView`. The first item in `browserListView` is always **Go Up One Level**; if it's selected, the program attempts to go up a level. Lines 32–33 create a `DirectoryInfo` object for the current directory. Line 36 tests property `Parent` to ensure that the user is not at the root of the directory tree. Property `Parent` indicates the parent directory as a `DirectoryInfo` object; if no parent directory exists, `Parent` returns the value `null`. If a parent directory does exist, lines 38–39 pass the parent directory's full name to `LoadFilesInDirectory`.

If the user did not select the first item in `browserListView`, lines 44–56 allow the user to continue navigating through the directory structure. Line 47 creates string `chosen` and assigns it the text of the selected item (the first item in collection `SelectedItems`). Lines 50–51 determine whether the user selected a valid directory (rather than a file). Using the `Combine` method of class `Path`, the program combines strings `currentDirectory` and `chosen` to form the new directory path. The `Combine` method automatically adds a back-slash (\), if necessary, between the two pieces. This value is passed to the `Exists` method of class `Directory`. Method `Exists` returns `true` if its `string` parameter is a valid directory. If so, the program passes the `string` to method `LoadFilesInDirectory` (lines 53–54). Finally, `displayLabel` is updated with the new directory (line 59).

This program loads quickly, because it indexes only the files in the current directory. A small delay may occur when a new directory is loaded. In addition, changes in the directory structure can be shown by reloading a directory. The previous program (Fig. 15.28) may have a large initial delay, as it loads an entire directory structure. This type of trade-off is typical in the software world.



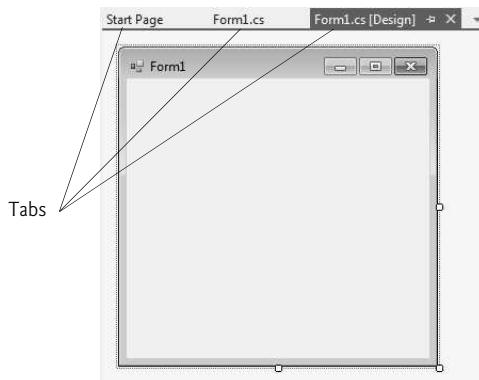
#### **Software Engineering Observation 15.2**

*When designing apps that run for long periods of time, you might choose a large initial delay to improve performance throughout the rest of the program. However, in apps that run for only short periods, developers often prefer fast initial loading times and small delays after each action.*

## **15.11 TabControl Control**

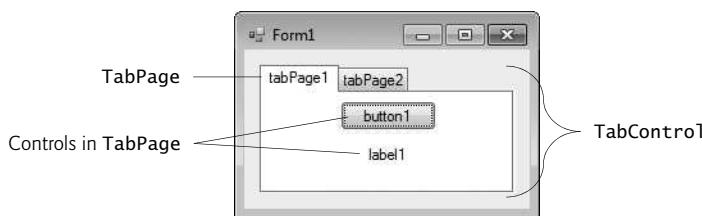
The `TabControl` creates tabbed windows, such as those in Visual Studio (Fig. 15.32). This enables you to specify more information in the same space on a `Form` and group displayed data logically. `TabControl`s contain `TabPage` objects, which are similar to `Panels` and `GroupBoxes` in that `TabPage`s also can contain controls. You first add controls to the `TabPage` objects, then add the `TabPage`s to the `TabControl`. Only one `TabPage` is displayed at a time. To add objects to the `TabPage` and the `TabControl`, write

```
myTabPage.Controls.Add( myControl );
myTabControl.TabPages.Add( myTabPage );
```



**Fig. 15.32** | Tabbed windows in Visual Studio.

The preceding statements call method `Add` of the `Controls` collection and method `Add` of the `TabPages` collection. The example adds `TabControl myControl` to `TabPage myTabPage`, then adds `myTabPage` to `myTabControl`. Alternatively, we can use method `AddRange` to add an array of `TabPage`s or controls to a `TabControl` or `TabPage`, respectively. Figure 15.33 depicts a sample `TabControl`.

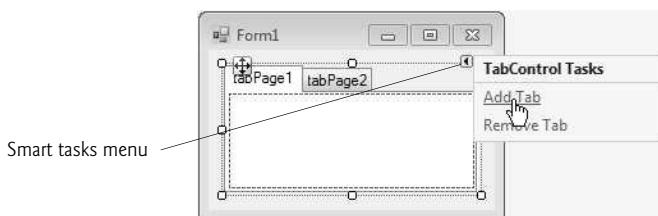


**Fig. 15.33** | `TabControl` with `TabPage`s example.

You can add `TabControl`s visually by dragging and dropping them onto a `Form` in **Design mode**. To add `TabPage`s in **Design mode**, click the top of the `TabControl`, open its *smart tasks menu* and select **Add Tab** (Fig. 15.34). Alternatively, click the **TabPage**s property in the **Properties** window and add tabs in the dialog that appears. To change a tab label, set the **Text** property of the `TabPage`. Clicking the tabs selects the `TabControl`—to select the `TabPage`, click the control area underneath the tabs. You can add controls to the `TabPage` by dragging and dropping items from the **ToolBox**. To view different `TabPage`s, click the appropriate tab (in either design or run mode). Common properties and a common event of `TabControl`s are described in Fig. 15.35.

Each `TabPage` generates a `Click` event when its tab is clicked. Event handlers for this event can be created by double clicking the body of the `TabPage`.

Class `UsingTabsForm` (Fig. 15.36) uses a `TabControl` to display various options relating to the text on a label (**Color**, **Size** and **Message**). The last `TabPage` displays an **About** message, which describes the use of `TabControl`s.



**Fig. 15.34** | TabPages added to a TabControl.

| TabControl properties and an event | Description                                                                                 |
|------------------------------------|---------------------------------------------------------------------------------------------|
| <i>Common Properties</i>           |                                                                                             |
| ImageList                          | Specifies images to be displayed on tabs.                                                   |
| ItemSize                           | Specifies the tab size.                                                                     |
| Multiline                          | Indicates whether multiple rows of tabs can be displayed.                                   |
| SelectedIndex                      | Index of the selected TabPage.                                                              |
| SelectedTab                        | The selected TabPage.                                                                       |
| TabCount                           | Returns the number of tab pages.                                                            |
| TabPages                           | Returns the collection of TabPages within the TabControl as a TabControl.TabPageCollection. |
| <i>Common Event</i>                |                                                                                             |
| SelectedIndexChanged               | Generated when SelectedIndex changes (i.e., another TabPage is selected).                   |

**Fig. 15.35** | TabControl properties and an event.

```

1 // Fig. 15.36: UsingTabsForm.cs
2 // Using TabControl to display various font settings.
3 using System;
4 using System.Drawing;
5 using System.Windows.Forms;
6
7 namespace UsingTabs
8 {
9     // Form uses Tabs and RadioButtons to display various font settings
10    public partial class UsingTabsForm : Form
11    {
12        // constructor
13        public UsingTabsForm()
14        {
15            InitializeComponent();
16        } // end constructor

```

**Fig. 15.36** | TabControl used to display various font settings. (Part 1 of 3.)

```
17 // event handler for Black RadioButton
18 private void blackRadioButton_CheckedChanged(
19     object sender, EventArgs e )
20 {
21     displayLabel.ForeColor = Color.Black; // change color to black
22 } // end method blackRadioButton_CheckedChanged
23
24 // event handler for Red RadioButton
25 private void redRadioButton_CheckedChanged(
26     object sender, EventArgs e )
27 {
28     displayLabel.ForeColor = Color.Red; // change color to red
29 } // end method redRadioButton_CheckedChanged
30
31 // event handler for Green RadioButton
32 private void greenRadioButton_CheckedChanged(
33     object sender, EventArgs e )
34 {
35     displayLabel.ForeColor = Color.Green; // change color to green
36 } // end method greenRadioButton_CheckedChanged
37
38 // event handler for 12 point RadioButton
39 private void size12RadioButton_CheckedChanged(
40     object sender, EventArgs e )
41 {
42     // change font size to 12
43     displayLabel.Font = new Font( displayLabel.Font.Name, 12 );
44 } // end method size12RadioButton_CheckedChanged
45
46 // event handler for 16 point RadioButton
47 private void size16RadioButton_CheckedChanged(
48     object sender, EventArgs e )
49 {
50     // change font size to 16
51     displayLabel.Font = new Font( displayLabel.Font.Name, 16 );
52 } // end method size16RadioButton_CheckedChanged
53
54 // event handler for 20 point RadioButton
55 private void size20RadioButton_CheckedChanged(
56     object sender, EventArgs e )
57 {
58     // change font size to 20
59     displayLabel.Font = new Font( displayLabel.Font.Name, 20 );
60 } // end method size20RadioButton_CheckedChanged
61
62 // event handler for Hello! RadioButton
63 private void helloRadioButton_CheckedChanged(
64     object sender, EventArgs e )
65 {
66     displayLabel.Text = "Hello!"; // change text to Hello!
67 } // end method helloRadioButton_CheckedChanged
68
69
```

---

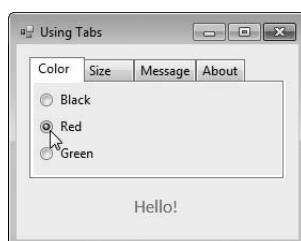
**Fig. 15.36** | TabControl used to display various font settings. (Part 2 of 3.)

```

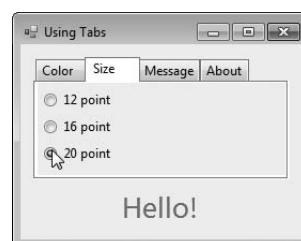
70      // event handler for Goodbye! RadioButton
71  private void goodbyeRadioButton_CheckedChanged(
72      object sender, EventArgs e )
73  {
74      displayLabel.Text = "Goodbye!"; // change text to Goodbye!
75  } // end method goodbyeRadioButton_CheckedChanged
76 } // end class UsingTabsForm
77 } // end namespace UsingTabs

```

a) Selecting the Red RadioButton from the Color tab



b) Selecting the 20 Point RadioButton from the Size tab



c) Selecting the Goodbye! RadioButton from the Message tab



d) Selecting the About tab



**Fig. 15.36** | TabControl used to display various font settings. (Part 3 of 3.)

The `textOptionsTabControl` and the `colorTabPage`, `sizeTabPage`, `messageTabPage` and `aboutTabPage` are created in the designer (as described previously). The `colorTabPage` contains three RadioButtons for the colors black (`blackRadioButton`), red (`redRadioButton`) and green (`greenRadioButton`). This TabPage is displayed in Fig. 15.36(a). The `CheckedChanged` event handler for each RadioButton updates the color of the text in `displayLabel` (lines 22, 29 and 36). The `sizeTabPage` (Fig. 15.36(b)) has three RadioButtons, corresponding to font sizes 12 (`size12RadioButton`), 16 (`size16RadioButton`) and 20 (`size20RadioButton`), which change the font size of `displayLabel`—lines 44, 52 and 60, respectively. The `messageTabPage` (Fig. 15.36(c)) contains two RadioButtons for the messages `Hello!` (`helloRadioButton`) and `Goodbye!` (`goodbyeRadioButton`). The two RadioButtons determine the text on `displayLabel` (lines 67 and 74, respectively). The `aboutTabPage` (Fig. 15.36(d)) contains a Label (`messageLabel`) describing the purpose of TabControls.



### Software Engineering Observation 15.3

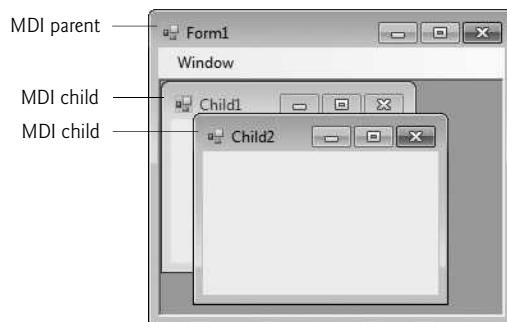
A TabPage can act as a container for a single logical group of RadioButtons, enforcing their mutual exclusivity. To place multiple RadioButton groups inside a single TabPage, you should group RadioButtons within Panels or GroupBoxes contained within the TabPage.

## 15.12 Multiple Document Interface (MDI) Windows

In previous chapters, we have built only **single document interface (SDI)** apps. Such programs (including Microsoft's Notepad and Paint) can support only one open window or document at a time. SDI apps usually have limited abilities—Paint and Notepad, for example, have limited image- and text-editing features. To edit *multiple* documents, the user must execute another instance of the SDI app.

Many complex apps are **multiple document interface (MDI)** programs, which allow users to edit multiple documents at once (e.g., Microsoft Office products). MDI programs also tend to be more complex—Paint Shop Pro and Photoshop have a greater number of image-editing features than does Paint.

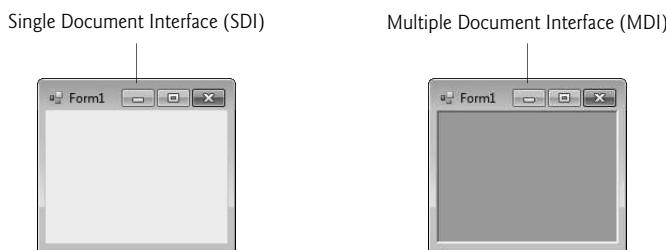
An MDI program's main window is called the **parent window**, and each window inside the app is referred to as a **child window**. Although an MDI app can have many child windows, each has only one parent window. Furthermore, a maximum of one child window can be active at once. Child windows cannot be parents themselves and cannot be moved outside their parent. Otherwise, a child window behaves like any other window (with regard to closing, minimizing, resizing, and so on). A child window's functionality can differ from that of other child windows of the parent. For example, one child window might allow the user to edit images, another might allow the user to edit text and a third might display network traffic graphically, but all could belong to the same MDI parent. Figure 15.37 depicts a sample MDI app with two child windows.



**Fig. 15.37** | MDI parent window and MDI child windows.

To create an MDI Form, create a new Form and set its **IsMdiContainer** property to true. The Form changes appearance, as in Fig. 15.38. Next, create a child Form class to be added to the Form. To do this, right click the project in the **Solution Explorer**, select **Project > Add Windows Form...** and name the file. Edit the Form as you like. To add the child Form to the parent, we must create a new child Form object, set its **MdiParent** property to the parent Form and call the child Form's Show method. In general, to add a child Form to a parent, write

```
ChildFormClass childForm = New ChildFormClass();
childForm.MdiParent = parentForm;
childForm.Show();
```



**Fig. 15.38** | SDI and MDI forms.

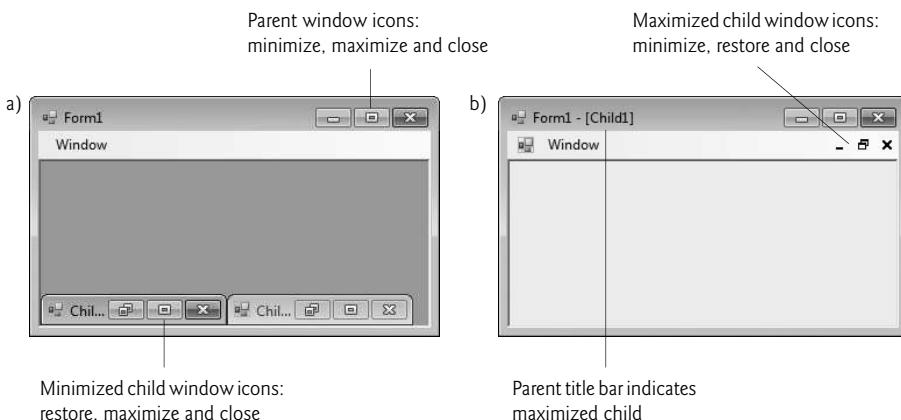
In most cases, the parent `Form` creates the child, so the `parentForm` reference is `this`. The code to create a child usually lies inside an event handler, which creates a new window in response to a user action. Menu selections (such as `File`, followed by a submenu option of `New`, followed by a submenu option of `Window`) are common techniques for creating new child windows.

Class `Form` property `MdiChildren` returns an array of child `Form` references. This is useful if the parent window wants to check the status of all its children (for example, ensuring that all are saved before the parent closes). Property `ActiveMdiChild` returns a reference to the active child window; it returns `null` if there are no active child windows. Other features of MDI windows are described in Fig. 15.39.

| MDI Form properties,<br>a method and an<br>event | Description                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Common MDI Child Properties</i>               |                                                                                                                                                                                                                                                                                                                     |
| <code>IsMdiChild</code>                          | Indicates whether the <code>Form</code> is an MDI child. If <code>true</code> , <code>Form</code> is an MDI child (read-only property).                                                                                                                                                                             |
| <code>MdiParent</code>                           | Specifies the MDI parent <code>Form</code> of the child.                                                                                                                                                                                                                                                            |
| <i>Common MDI Parent Properties</i>              |                                                                                                                                                                                                                                                                                                                     |
| <code>ActiveMdiChild</code>                      | Returns the <code>Form</code> that's the currently active MDI child (returns <code>null</code> if no children are active).                                                                                                                                                                                          |
| <code>IsMdiContainer</code>                      | Indicates whether a <code>Form</code> can be an MDI parent. If <code>true</code> , the <code>Form</code> can be an MDI parent. The default value is <code>false</code> .                                                                                                                                            |
| <code>MdiChildren</code>                         | Returns the MDI children as an array of <code>Forms</code> .                                                                                                                                                                                                                                                        |
| <i>Common Method</i>                             |                                                                                                                                                                                                                                                                                                                     |
| <code>LayoutMdi</code>                           | Determines the display of child forms on an MDI parent. The method takes as a parameter an <code>MdiLayout</code> enumeration with possible values <code>ArrangeIcons</code> , <code>Cascade</code> , <code>TileHorizontal</code> and <code>TileVertical</code> . Figure 15.42 depicts the effects of these values. |
| <i>Common Event</i>                              |                                                                                                                                                                                                                                                                                                                     |
| <code>MdiChildActivate</code>                    | Generated when an MDI child is closed or activated.                                                                                                                                                                                                                                                                 |

**Fig. 15.39** | MDI parent and MDI child properties, a method and an event.

Child windows can be minimized, maximized and closed independently of the parent window. Figure 15.40 shows two images: one containing two minimized child windows and a second containing a maximized child window. When the parent is minimized or closed, the child windows are minimized or closed as well. Notice that the title bar in Fig. 15.40(b) is **Form1 - [Child1]**. When a child window is maximized, its title-bar text is inserted into the parent window's title bar. When a child window is minimized or maximized, its title bar displays a restore icon, which can be used to return the child window to its previous size (its size before it was minimized or maximized).



**Fig. 15.40** | Minimized and maximized child windows.

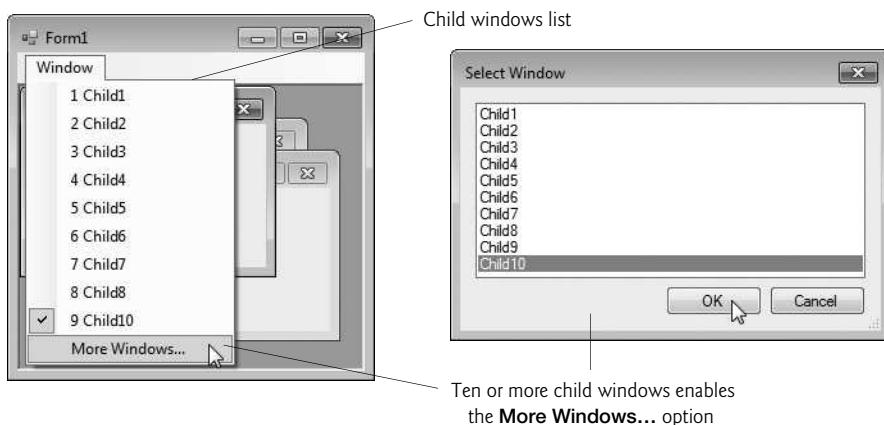
C# provides a property that helps track which child windows are open in an MDI container. Property **MdiWindowListItem** of class **MenuStrip** specifies which menu, if any, displays a list of open child windows that the user can select to bring the corresponding window to the foreground. When a new child window is opened, an entry is added to the end of the list (Fig. 15.41). If ten or more child windows are open, the list includes the option **More Windows...**, which allows the user to select a window from a list in a dialog.



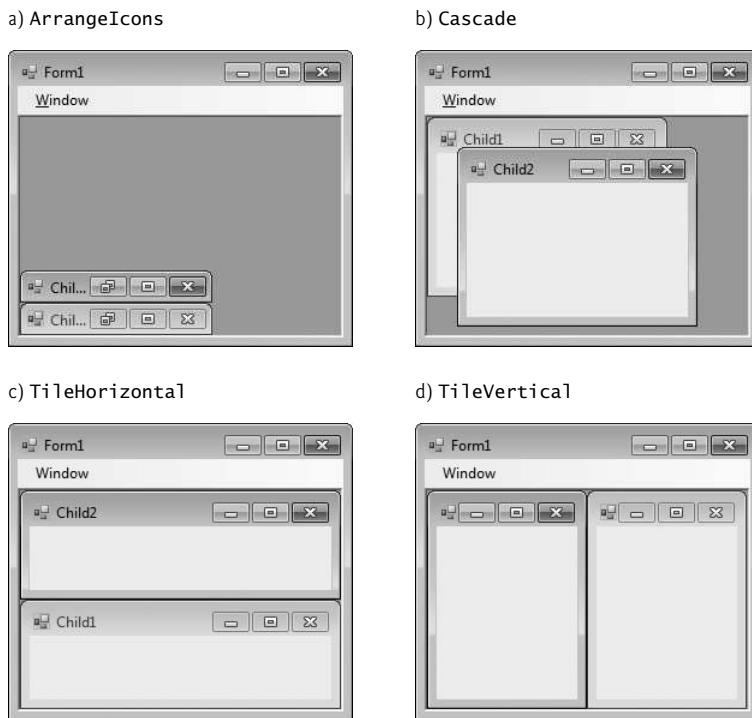
### Good Programming Practice 15.1

*When creating MDI apps, include a menu that displays a list of the open child windows. This helps the user select a child window quickly, rather than having to search for it in the parent window.*

MDI containers allow you to organize the placement of its child windows. The child windows in an MDI app can be arranged by calling method **LayoutMdi** of the parent Form. Method **LayoutMdi** takes an **MdiLayout** enumeration, which can have values **ArrangeIcons**, **Cascade**, **TileHorizontal** and **TileVertical**. **Tiled windows** completely fill the parent and do *not* overlap; such windows can be arranged horizontally (value **TileHorizontal**) or vertically (value **TileVertical**). **Cascaded windows** (value **Cascade**) overlap—each is the same size and displays a visible title bar, if possible. Value **ArrangeIcons** arranges the icons for any minimized child windows. If minimized windows are scattered around the parent window, value **ArrangeIcons** orders them neatly at the bottom-left corner of the parent window. Figure 15.42 illustrates the values of the **MdiLayout** enumeration.



**Fig. 15.41** | `MenuStrip` property `MdiWindowListItem` example.



**Fig. 15.42** | `MdiLayout` enumeration values.

Class `UsingMDIForm` (Fig. 15.43) demonstrates MDI windows. Class `UsingMDIForm` uses three instances of child Form `ChildForm` (Fig. 15.44), each containing a `PictureBox` that displays an image. The parent MDI Form contains a menu enabling users to create and arrange child Forms.

***MDI Parent Form***

Figure 15.43 presents class `UsingMDIForm`—the app’s MDI parent Form. This Form, which is created first, contains two top-level menus. The first of these menus, `File` (`fileToolStripMenuItem`), contains both an `Exit` item (`exitToolStripMenuItem`) and a `New` submenu (`newToolStripMenuItem`) consisting of items for each type of child window. The second menu, `Window` (`windowToolStripMenuItem`), provides options for laying out the MDI children, plus a list of the active MDI children.

```

1 // Fig. 15.43: UsingMDIForm.cs
2 // Demonstrating use of MDI parent and child windows.
3 using System;
4 using System.Windows.Forms;
5
6 namespace UsingMDI
7 {
8     // Form demonstrates the use of MDI parent and child windows
9     public partial class UsingMDIForm : Form
10    {
11        // constructor
12        public UsingMDIForm()
13        {
14            InitializeComponent();
15        } // end constructor
16
17        // create Lavender Flowers image window
18        private void lavenderToolStripMenuItem_Click(
19            object sender, EventArgs e )
20        {
21            // create new child
22            ChildForm child = new ChildForm(
23                "Lavender Flowers", "lavenderflowers" );
24            child.MdiParent = this; // set parent
25            child.Show(); // display child
26        } // end method lavenderToolStripMenuItem_Click
27
28        // create Purple Flowers image window
29        private void purpleToolStripMenuItem_Click(
30            object sender, EventArgs e )
31        {
32            // create new child
33            ChildForm child = new ChildForm(
34                "Purple Flowers", "purpleflowers" );
35            child.MdiParent = this; // set parent
36            child.Show(); // display child
37        } // end method purpleToolStripMenuItem_Click
38
39        // create Yellow Flowers image window
40        private void yellowToolStripMenuItem_Click(
41            object sender, EventArgs e )
42        {

```

**Fig. 15.43** | MDI parent-window class. (Part I of 3.)

```
43         // create new child
44         Child child = new ChildForm(
45             "Yellow Flowers", "yellowflowers" );
46         child.MdiParent = this; // set parent
47         child.Show(); // display child
48     } // end method yellowToolStripMenuItem_Click
49
50     // exit app
51     private void exitToolStripMenuItem_Click(
52         object sender, EventArgs e )
53     {
54         Application.Exit();
55     } // end method exitToolStripMenuItem_Click
56
57     // set Cascade layout
58     private void cascadeToolStripMenuItem_Click(
59         object sender, EventArgs e )
60     {
61         this.LayoutMdi( MdiLayout.Cascade );
62     } // end method cascadeToolStripMenuItem_Click
63
64     // set TileHorizontal layout
65     private void tileHorizontalToolStripMenuItem_Click(
66         object sender, EventArgs e )
67     {
68         this.LayoutMdi( MdiLayout.TileHorizontal );
69     } // end method tileHorizontalToolStripMenuItem_Click
70
71     // set TileVertical layout
72     private void tileVerticalToolStripMenuItem_Click(
73         object sender, EventArgs e )
74     {
75         this.LayoutMdi( MdiLayout.TileVertical );
76     } // end method tileVerticalToolStripMenuItem_Click
77 } // end class UsingMDIForm
78 } // end namespace UsingMDI
```

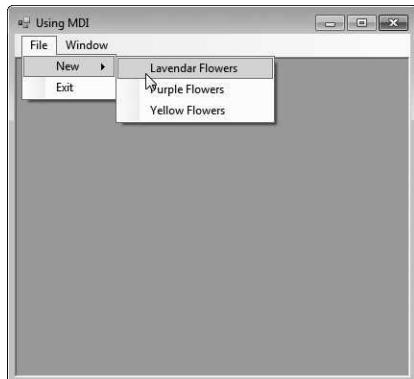
a) Selecting the **Lavender Flowers** menu itemb) **Lavender Flowers** ChildForm window displayed

Fig. 15.43 | MDI parent-window class. (Part 2 of 3.)

c) Selecting the **Cascade** menu item

d) Cascaded child windows in an MDI window

**Fig. 15.43** | MDI parent-window class. (Part 3 of 3.)

In the **Properties** window, we set the Form's `IsMdiContainer` property to `true`, making the Form an MDI parent. In addition, we set the `MenuStrip`'s `MdiWindowListItem` property to `windowToolStripMenuItem`. This enables the **Window** menu to contain the list of child MDI windows.

The **Cascade** menu item (`cascadeToolStripMenuItem`) has an event handler (`cascadeToolStripMenuItem_Click`, lines 58–62) that arranges the child windows in a cascading manner. The event handler calls method `LayoutMdi` with the argument `Cascade` from the `MdiLayout` enumeration (line 61).

The **Tile Horizontal** menu item (`tileHorizontalToolStripMenuItem`) has an event handler (`tileHorizontalToolStripMenuItem_Click`, lines 65–69) that arranges the child windows in a horizontal manner. The event handler calls method `LayoutMdi` with the argument `TileHorizontal` from the `MdiLayout` enumeration (line 68).

Finally, the **Tile Vertical** menu item (`tileVerticalToolStripMenuItem`) has an event handler (`tileVerticalToolStripMenuItem_Click`, lines 72–76) that arranges the child windows in a vertical manner. The event handler calls method `LayoutMdi` with the argument `TileVertical` from the `MdiLayout` enumeration (line 75).

### **MDI Child Form**

At this point, the app is still incomplete—we must define the MDI child class. To do this, right click the project in the **Solution Explorer** and select **Add > Windows Form....** Then name the new class in the dialog as `ChildForm` (Fig. 15.44). Next, we add a `PictureBox` (`displayPictureBox`) to `ChildForm`. In `ChildForm`'s constructor, line 16 sets the title-bar text. Lines 19–21 retrieve the appropriate image resource, cast it to an `Image` and set `displayPictureBox`'s `Image` property. The images that are used can be found in the `Images` subfolder of this chapter's examples directory.

After the MDI child class is defined, the parent MDI Form (Fig. 15.43) can create new child windows. The event handlers in lines 18–48 create a new child Form corresponding to the menu item clicked. Lines 22–23, 33–34 and 44–45 create new instances of `ChildForm`. Lines 24, 35 and 46 set each Child's `MdiParent` property to the parent Form. Lines 25, 36 and 47 call method `Show` to display each child Form.

---

```

1 // Fig. 15.44: ChildForm.cs
2 // Child window of MDI parent.
3 using System;
4 using System.Drawing;
5 using System.Windows.Forms;
6
7 namespace UsingMDI
8 {
9     public partial class ChildForm : Form
10    {
11        public ChildForm( string title, string resourceName )
12        {
13            // Required for Windows Form Designer support
14            InitializeComponent();
15
16            Text = title; // set title text
17
18            // set image to display in PictureBox
19            displayPictureBox.Image =
20                ( Image )( Properties.Resources.ResourceManager.GetObject(
21                    resourceName ) );
22        } // end constructor
23    } // end class ChildForm
24 } // end namespace UsingMDI

```

---

**Fig. 15.44** | MDI child ChildForm.

## 15.13 Visual Inheritance

Chapter 11 discussed how to create classes by inheriting from other classes. We have also used inheritance to create `Forms` that display a GUI, by deriving our new `Form` classes from class `System.Windows.Forms.Form`. This is an example of **visual inheritance**. The derived `Form` class contains the functionality of its `Form` base class, including any base-class properties, methods, variables and controls. The derived class also inherits all visual aspects—such as sizing, component layout, spacing between GUI components, colors and fonts—from its base class.

Visual inheritance enables you to achieve visual consistency across apps. For example, you could define a base `Form` that contains a product’s logo, a specific background color, a predefined menu bar and other elements. You then could use the base `Form` throughout an app for uniformity and branding. You can also create controls that inherit from other controls. For example, you might create a custom `UserControl` (discussed in Section 15.14) that’s derived from an existing control.

### *Creating a Base Form*

Class `VisualInheritanceBaseForm` (Fig. 15.45) derives from `Form`. The output depicts the workings of the program. The GUI contains two `Labels` with text **Bugs**, **Bugs**, **Bugs** and **Copyright 2014, by Deitel & Associates, Inc.**, as well as one `Button` displaying the text **Learn More**. When a user presses the **Learn More** `Button`, method `learnMoreButton_Click` (lines 18–24) is invoked. This method displays a `MessageBox` that provides some informative text.

```

1 // Fig. 15.45: VisualInheritanceBaseForm.cs
2 // Base Form for use with visual inheritance.
3 using System;
4 using System.Windows.Forms;
5
6 namespace VisualInheritanceBase
7 {
8     // base Form used to demonstrate visual inheritance
9     public partial class VisualInheritanceForm : Form
10    {
11        // constructor
12        public VisualInheritanceForm()
13        {
14            InitializeComponent();
15        } // end constructor
16
17        // display MessageBox when Button is clicked
18        private void learnMoreButton_Click( object sender, EventArgs e )
19        {
20            MessageBox.Show(
21                "Bugs, Bugs, Bugs is a product of deitel.com",
22                "Learn More", MessageBoxButtons.OK,
23                MessageBoxIcon.Information );
24        } // end method learnMoreButton_Click
25    } // end class VisualInheritanceBaseForm
26 } // end namespace VisualInheritanceBase

```



**Fig. 15.45** | Class `VisualInheritanceBaseForm`, which inherits from class `Form`, contains a Button (`Learn More`).

### Steps for Declaring and Using a Reusable Class

Before a `Form` (or any class) can be used in multiple apps, it must be placed in a class library to make it reusable. The steps for creating a reusable class are:

1. Declare a `public` class. If the class is not `public`, it can be used only by other classes in the same assembly—that is, compiled into the same DLL or EXE file.
2. Choose a namespace name and add a `namespace` declaration to the source-code file for the reusable class declaration.
3. Compile the class into a class library.
4. Add a reference to the class library in an app.

### 5. Use the class.

Let's take a look at these steps in the context of this example:

#### ***Step 1: Creating a public Class***

For *Step 1* in this discussion, we use the `public` class `VisualInheritanceBaseForm` declared in Fig. 15.45. By default, every new `Form` class you create is declared as a `public` class.

#### ***Step 2: Adding the namespace Declaration***

For *Step 2*, we use the `namespace` declaration that was created for us by the IDE. By default, every new class you define is placed in a `namespace` with the same name as the project. In almost every example in the text, we've seen that classes from preexisting libraries, such as the .NET Framework Class Library, can be imported into a C# app. Each class belongs to a `namespace` that contains a group of related classes. As apps become more complex, `namespaces` help you manage the complexity of app components. `Class libraries` and `namespaces` also facilitate software reuse by enabling apps to add classes from other `namespaces` (as we've done in most examples). We removed the `namespace` declarations in earlier chapters because they were not necessary.

Placing a class inside a `namespace` declaration indicates that the class is part of the specified `namespace`. The `namespace` name is part of the fully qualified class name, so the name of class `VisualInheritanceTestForm` is actually `VisualInheritanceBase.VisualInheritanceBaseForm`. You can use this fully qualified name in your apps, or you can write a `using` directive and use the class's simple name (the unqualified class name—`VisualInheritanceBaseForm`) in the app. If another `namespace` also contains a class with the same name, the fully qualified class names can be used to distinguish between the classes in the app and prevent a name conflict (also called a name collision).

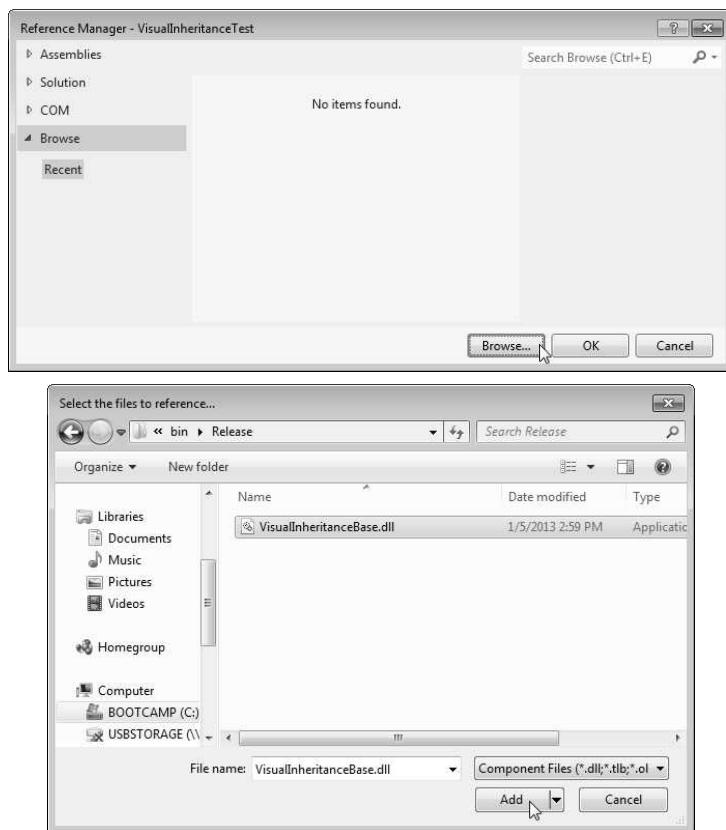
#### ***Step 3: Compiling the Class Library***

To allow other `Forms` to inherit from `VisualInheritanceForm`, we must package `VisualInheritanceForm` as a class library and compile it into a **.dll file**. Such a file is known as a **dynamically linked library**—a way to package classes that you can reference from other apps. Right-click the project name in the **Solution Explorer** and select **Properties**, then choose the **Application** tab. In the **Output type** drop-down list, change **Windows Application** to **Class Library**. Building the project produces the `.dll`. You can configure a project to be a class library when you first create it by selecting the **Class Library** template in the **New Project** dialog. [Note: A class library cannot execute as a stand-alone app. The screen captures in Fig. 15.45 were taken before changing the project to a class library.]

#### ***Step 4: Adding a Reference to the Class Library***

Once the class is compiled and stored in the class library file, the library can be referenced from any app by indicating to the Visual C# Express IDE where to find the class library file. To visually inherit from `VisualInheritanceBaseForm`, first create a new Windows app. Right-click the project name in the **Solution Explorer** window and select **Add Reference...** from the pop-up menu that appears. The dialog box that appears will contain a list of class libraries from the .NET Framework. Some class libraries, like the one containing the `System` `namespace`, are so common that they're added to your app by the IDE. The ones in this list are not.

In the **Reference Manager** dialog box, click **Browse** then click the **Browse...** button. When you build a class library, Visual C# places the .dll file in the project's bin\Debug or bin\Release folder, depending on whether the **Solution Configurations** drop-down list in the IDE's toolbar is set to **Debug** or **Release**. In the **Browse** tab, you can navigate to the directory containing the class library file you created in *Step 3*, as shown in Fig. 15.46. Select the .dll file and click **OK**.



**Fig. 15.46** | Using the **Reference Manager** dialog to browse for a DLL.

#### Step 5: Using the Class—Deriving From a Base Form

Open the file that defines the new app's GUI and modify the line that defines the class to indicate that the app's Form should inherit from class `VisualInheritanceBaseForm`. The class-declaration line should now appear as follows:

```
public partial class VisualInheritanceTestForm :  
    VisualInheritanceBase.VisualInheritanceBaseForm
```

Unless you specify namespace `VisualInheritanceBase` in a `using` directive, you must use the fully qualified name `VisualInheritanceBase.VisualInheritanceBaseForm`. In **Design** view, the new app's Form should now display the controls inherited from the base Form (Fig. 15.47). We can now add more components to the Form.



**Fig. 15.47** | Form demonstrating visual inheritance.

#### *Class VisualInheritanceTestForm*

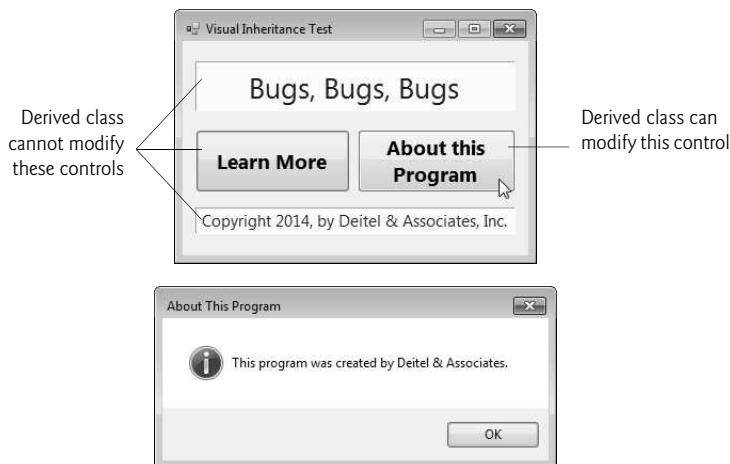
Class *VisualInheritanceTestForm* (Fig. 15.48) is a derived class of *VisualInheritanceBaseForm*. The output illustrates the functionality of the program. The components, their layouts and the functionality of base class *VisualInheritanceBaseForm* (Fig. 15.45) are inherited by *VisualInheritanceTestForm*. We added an additional Button with text **About this Program**. When a user presses this Button, method *aboutButton\_Click* (lines 19–25) is invoked. This method displays another *MessageBox* providing different informative text (lines 21–24).

```

1 // Fig. 15.48: VisualInheritanceTestForm.cs
2 // Derived Form using visual inheritance.
3 using System;
4 using System.Windows.Forms;
5
6 namespace VisualInheritanceTest
7 {
8     // derived form using visual inheritance
9     public partial class VisualInheritanceTestForm :
10         VisualInheritanceBase.VisualInheritanceBaseForm
11     {
12         // constructor
13         public VisualInheritanceTestForm()
14         {
15             InitializeComponent();
16         } // end constructor
17
18         // display MessageBox when Button is clicked
19         private void aboutButton_Click(object sender, EventArgs e)
20         {
21             MessageBox.Show(
22                 "This program was created by Deitel & Associates.",
23                 "About This Program", MessageBoxButtons.OK,
24                 MessageBoxIcon.Information);
25         } // end method aboutButton_Click
26     } // end class VisualInheritanceTestForm
27 } // end namespace VisualInheritanceTest

```

**Fig. 15.48** | Class *VisualInheritanceTestForm*, which inherits from class *VisualInheritanceBaseForm*, contains an additional Button. (Part I of 2.)



**Fig. 15.48** | Class `VisualInheritanceTestForm`, which inherits from class `VisualInheritanceBaseForm`, contains an additional `Button`. (Part 2 of 2.)

If a user clicks the `Learn More` button, the event is handled by the base-class event handler `LearnMoreButton_Click`. Because `VisualInheritanceBaseForm` uses a `private` access modifier to declare its controls, `VisualInheritanceTestForm` cannot modify the controls inherited from class `VisualInheritanceBaseForm` visually or programmatically. The IDE displays a small icon at the top left of the visually inherited controls to indicate that they're inherited and cannot be altered.

## 15.14 User-Defined Controls

The .NET Framework allows you to create **custom controls**. These custom controls appear in the user's **Toolbox** and can be added to **Forms**, **Panels** or **GroupBoxes** in the same way that we add **Buttons**, **Labels** and other predefined controls. The simplest way to create a custom control is to derive a class from an existing control, such as a `Label`. This is useful if you want to add functionality to an existing control, rather than replacing it with one that provides the desired functionality. For example, you can create a new type of `Label` that behaves like a normal `Label` but has a different appearance. You accomplish this by inheriting from class `Label` and overriding method `OnPaint`.

### **Method `OnPaint`**

All controls have an `OnPaint` method, which the system calls when a component must be redrawn (such as when the component is resized). The method receives a `PaintEventArgs` object, which contains graphics information—property `Graphics` is the graphics object used to draw, and property `ClipRectangle` defines the rectangular boundary of the control. Whenever the system raises a `Paint` event to draw the control on the screen, the control catches the event and calls its `OnPaint` method. The base class's `OnPaint` should be called explicitly from an overridden `OnPaint` implementation before executing custom-

paint code. In most cases, you want to do this to ensure that the original painting code executes in addition to the code you define in the custom control's class.

### *Creating New Controls*

To create a new control composed of existing controls, use class **UserControl1**. Controls added to a custom control are called **constituent controls**. For example, a programmer could create a **UserControl** composed of a **Button**, a **Label** and a **TextBox**, each associated with some functionality (for example, the **Button** setting the **Label**'s text to that contained in the **TextBox**). The **UserControl** acts as a container for the controls added to it. The **UserControl** contains constituent controls, but it does not determine how these constituent controls are displayed. To control the appearance of each constituent control, you can handle each control's **Paint** event or override **OnPaint**. Both the **Paint** event handler and **OnPaint** are passed a **PaintEventArgs** object, which can be used to draw graphics (lines, rectangles, and so on) on the constituent controls.

Using another technique, a programmer can create a brand-new control by inheriting from class **Control1**. This class does not define any specific behavior; that's left to you. Instead, class **Control** handles the items associated with all controls, such as events and sizing handles. Method **OnPaint** should contain a call to the base class's **OnPaint** method, which calls the **Paint** event handlers. You add code that draws custom graphics inside the overridden **OnPaint** method. This technique allows for the greatest flexibility but also requires the most planning. All three approaches are summarized in Fig. 15.49.

| Custom-control techniques<br>and <b>PaintEventArgs</b><br>properties | Description                                                                                                                                                                                                                 |
|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Custom-Control Techniques</i>                                     |                                                                                                                                                                                                                             |
| Inherit from Windows<br>Forms control                                | You can do this to add functionality to a preexisting control. If you override method <b>OnPaint</b> , call the base class's <b>OnPaint</b> method. You only can add to the original control's appearance, not redesign it. |
| Create a <b>UserControl1</b>                                         | You can create a <b>UserControl</b> composed of multiple preexisting controls (e.g., to combine their functionality). You place drawing code in a <b>Paint</b> event handler or overridden <b>OnPaint</b> method.           |
| Inherit from class <b>Control1</b>                                   | Define a brand new control. Override method <b>OnPaint</b> , then call base-class method <b>OnPaint</b> and include methods to draw the control. With this method you can customize control appearance and functionality.   |
| <i>PaintEventArgs Properties</i>                                     |                                                                                                                                                                                                                             |
| <b>Graphics</b>                                                      | The control's <b>graphics</b> object, which is used to draw on the control.                                                                                                                                                 |
| <b>ClipRectangle</b>                                                 | Specifies the rectangle indicating the boundary of the control.                                                                                                                                                             |

**Fig. 15.49** | Custom-control creation.

### Clock Control

We create a “clock” control in Fig. 15.50. This is a `UserControl` composed of a `Label` and a `Timer`—whenever the `Timer` raises an event (once per second in this example), the `Label` is updated to reflect the current time.

---

```

1 // Fig. 15.50: ClockUserControl.cs
2 // User-defined control with a timer and a Label.
3 using System;
4 using System.Windows.Forms;
5
6 namespace ClockExample
7 {
8     // UserControl that displays the time on a Label
9     public partial class ClockUserControl : UserControl
10    {
11        // constructor
12        public ClockUserControl()
13        {
14            InitializeComponent();
15        } // end constructor
16
17        // update Label at every tick
18        private void clockTimer_Tick(object sender, EventArgs e)
19        {
20            // get current time (Now), convert to string
21            displayLabel.Text = DateTime.Now.ToString("T");
22        } // end method clockTimer_Tick
23    } // end class ClockUserControl
24 } // end namespace ClockExample

```



**Fig. 15.50** | `UserControl`-defined clock.

### Timers

**Timers** (`System.Windows.Forms` namespace) are non-visual components that generate **Tick** events at a set interval. This interval is set by the `Timer`'s **Interval** property, which defines the number of milliseconds (thousandths of a second) between events. By default, timers are disabled and do not generate events.

### Adding a User Control

This app contains a user control (`ClockUserControl`) and a `Form` that displays the user control. Create a Windows app, then create a `UserControl` class by selecting **Project > Add User Control....** This displays a dialog from which we can select the type of item to add—user controls are already selected. We then name the file (and the class) `ClockUserControl`. Our empty `ClockUserControl` is displayed as a grey rectangle.

### *Designing the User Control*

You can treat this control like a Windows Form, meaning that you can add controls using the **ToolBox** and set properties using the **Properties** window. However, instead of creating an app, you're simply creating a new control composed of other controls. Add a **Label** (`displayLabel`) and a **Timer** (`clockTimer`) to the **UserControl1**. Set the **Timer** interval to 1000 milliseconds and set `displayLabel`'s text with each **Tick** event (lines 18–22). To generate events, `clockTimer` must be enabled by setting property **Enabled** to **true** in the **Properties** window.

Structure **DateTime** (namespace `System`) contains property **Now**, which returns the current time. Method **ToLongTimeString** converts `Now` to a **string** containing the current hour, minute and second (along with AM or PM, depending on your locale). We use this to set the time in `displayLabel` in line 21.

Once created, our clock control appears as an item in the **ToolBox** in the section titled *ProjectName Components*, where *ProjectName* is your project's name. *You may need to switch to the app's Form before the item appears in the ToolBox*. To use the control, simply drag it to the **Form** and run the Windows app. We gave the `ClockUserControl` object a white background to make it stand out in the **Form**. Figure 15.50 shows the output of `Clock`, which contains our `ClockUserControl`. There are no event handlers in `Clock`, so we show only the code for `ClockUserControl`.

### *Sharing Custom Controls with Other Developers*

Visual Studio allows you to share custom controls with other developers. To create a **UserControl** that can be exported to other solutions, do the following:

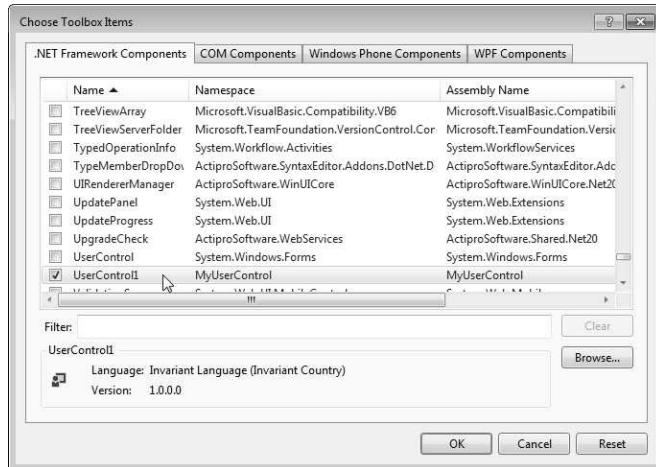
1. Create a new **Class Library** project.
2. Delete `Class1.cs`, initially provided with the app.
3. Right click the project in the **Solution Explorer** and select **Add > User Control....** In the dialog that appears, name the user-control file and click **Add**.
4. Inside the project, add controls and functionality to the **UserControl1** (Fig. 15.51).



**Fig. 15.51** | Custom-control creation.

5. Build the project. Visual Studio creates a `.dll` file for the `UserControl` in the output directory (`bin\Release` or `bin\Debug`). The file is not executable; class libraries are used to define classes that are reused in other executable apps.
6. Create a new Windows app.
7. In the new Windows app, right click the **ToolBox** and select **Choose Items....** In the **Choose Toolbox Items** dialog that appears, click **Browse....** Browse for the `.dll` file from the class library created in *Steps 1–5*. The item will then appear in

the **Choose Toolbox Items** dialog (Fig. 15.52). If it's not already checked, check this item. Click **OK** to add the item to the **Toolbox**. This control can now be added to the **Form** as if it were any other control.



**Fig. 15.52** | Custom control added to the **ToolBox**.

## 15.15 Wrap-Up

Many of today's commercial apps provide GUIs that are easy to use and manipulate. Because of this demand for user-friendly GUIs, the ability to design sophisticated GUIs is an essential programming skill. Visual Studio's IDE makes GUI development quick and easy. In Chapters 14 and 15, we presented basic Windows Forms GUI development techniques. In Chapter 15, we demonstrated how to create menus, which provide users easy access to an app's functionality. You learned the `DateTimePicker` and `MonthCalendar` controls, which allow users to input date and time values. We demonstrated `LinkLabels`, which are used to link the user to an app or a web page. You used several controls that provide lists of data to the user—`ListBoxes`, `CheckedListBoxes` and `ListView`s. We used the `ComboBox` control to create drop-down lists, and the `TreeView` control to display data in hierarchical form. We then introduced complex GUIs that use tabbed windows and multiple document interfaces. The chapter concluded with demonstrations of visual inheritance and creating custom controls. In Chapter 16, we introduce string and character processing.

## Summary

### Section 15.2 Menus

- Menus provide groups of related commands for Windows Forms apps.
- An expanded menu lists menu items and submenus.
- A menu that contains a menu item is called that menu item's parent menu. A menu item that contains a submenu is considered to be the parent of that submenu.

- All menus and menu items can have shortcut keys.
- Some menu items display checkmarks, indicating that multiple options on the menu can be selected at once.
- The `MenuStrip` control is used to create menus in a GUI.
- Top-level menus and their menu items are represented using type `ToolStripMenuItem`.
- To create an access shortcut, type an ampersand (&) before the character to be underlined.
- To add other shortcut keys, set the `ShortcutKeys` property of the `ToolStripMenuItem`.
- You can hide shortcut keys by setting property `ShowShortcutKeys` to `false`. You can modify how shortcut keys are displayed in the menu item by modifying property `ShortcutKeyDisplayString`.
- A menu item's `Checked` property is used to display a check to the left of the menu item.

### ***Section 15.3 MonthCalendar Control***

- The `MonthCalendar` control displays a monthly calendar.
- The user can select a date from the currently displayed month or navigate to another month.
- A `MonthCalendar`'s `DateChanged` event occurs when a new date is selected.

### ***Section 15.4 DateTimePicker Control***

- The `DateTimePicker` control can be used to retrieve date and/or time information from the user.
- Property `Format` of class `DateTimePicker` specifies the user's selection options.
- The `DateTimePicker`'s `ValueChanged` event is raised when the selected value is changed.

### ***Section 15.5 LinkLabel Control***

- The `LinkLabel` control displays links to other resources, such as files or web pages.
- A `LinkLabel` appears as underlined text (colored blue by default). When the mouse moves over the link, the pointer changes to a hand; this is similar to a hyperlink in a web page.
- The link can change color to indicate whether the link is new, previously visited or active.
- When clicked, the `LinkLabel` generates a `LinkClicked` event.

### ***Section 15.6 ListBox Control***

- The `ListBox` control allows the user to view and select items in a list.
- `ListBox` property `SelectionMode` determines the number of items that can be selected.
- The `SelectedIndexChanged` event of class `ListBox` occurs when the user selects a new item.
- Property `Items` returns all the list items as a collection.
- Property `SelectedItem` returns the currently selected item.
- Use method `Add` to add an item to the `ListBox`'s `Items` collection.
- You can add items to `ListBoxes` and `CheckedListBoxes` visually by using the `Items` property in the `Properties` window.

### ***Section 15.7 CheckedListBox Control***

- The `CheckedListBox` control extends a `ListBox` by including a checkbox next to each item.
- Items can be added via methods `Add` and `AddRange` or through the `String Collection Editor`.
- `CheckedListBoxes` imply that multiple items can be checked.
- `CheckedListBox` event `ItemCheck` occurs when a user checks or unchecks a `CheckedListBox` item.

***Section 15.8 ComboBox Control***

- The `ComboBox` control combines `TextBox` features with a drop-down list.
- Property `MaxDropDownItems` specifies the maximum number of items that can display at one time.
- You can add objects to collection `Items` programmatically, using methods `Add` and `AddRange`, or visually, with the **String Collection Editor**.
- Property `DropDownStyle` determines the type of `ComboBox` and is represented as a value of the `ComboBoxStyle` enumeration, which contains values `Simple`, `DropDown` and `DropDownList`.
- There can be at most one selected item in a `ComboBox` (if none, then `SelectedIndex` is -1).
- When the selected item changes in a `ComboBox`, a `SelectedIndexChanged` event occurs.

***Section 15.9 TreeView Control***

- The `TreeView` control displays nodes hierarchically in a tree.
- Traditionally, nodes are objects that contain values and can refer to other nodes.
- A parent node contains child nodes, and the child nodes can be parents to other nodes.
- Two child nodes that have the same parent node are considered sibling nodes.
- A tree is a collection of nodes, usually organized in a hierarchical manner. The first parent node of a tree is a root node—there can be multiple root nodes.
- `TreeView` controls are useful for displaying hierarchical information.
- In a `TreeView`, a parent node can be expanded or collapsed by clicking the plus box or minus box to its left. Nodes without children do not have these boxes.
- The nodes displayed in a `TreeView` are instances of class `TreeNode`.
- Each `TreeNode` has a `Nodes` collection (type `TreeNodeCollection`), containing a list of `TreeNodes`.
- To add nodes to a `TreeView` visually, click the ellipsis next to property `Nodes` in the **Properties** window. This opens the **TreeNode Editor**, which displays an empty tree representing the `TreeView`.
- To add nodes programmatically, you must create a root `TreeNode` object and pass it a string to display. Then call method `Add` to add this new `TreeNode` to the `TreeView`'s `Nodes` collection.

***Section 15.10 ListView Control***

- The `ListView` control is similar to a `ListBox` in that both display lists from which the user can select one or more items. `ListView` is more flexible and can display items in different formats.
- Property `MultiSelect` (a `bool`) determines whether multiple items can be selected.
- To display images, an `ImageList` component is required.
- Property `SmallImageList` of class `ListView` sets the `ImageList` for the small icons.
- Property `LargeImageList` of class `ListView` sets the `ImageList` for large icons.
- The items in a `ListView` are each of type `ListViewItem`.

***Section 15.11 TabControl Control***

- The `TabControl` control creates tabbed windows.
- `TabControl`s contain `TabPage` objects. Only one `TabPage` is displayed at a time.
- You can add `TabControl`s visually by dragging and dropping them on a `Form` in **Design** mode.
- To add `TabPage`s in **Design** mode, open the `TabControl`'s smart tasks menu and click **Add Tab**, or click the `TabPage`s property in the **Properties** window, and add tabs in the dialog that appears.
- Each `TabPage` raises a `Click` event when its tab is clicked.

***Section 15.12 Multiple Document Interface (MDI) Windows***

- The app window of a multiple document interface (MDI) program is called the parent window, and each window inside the app is referred to as a child window.
- Child windows cannot be parents themselves and cannot be moved outside their parent.
- To create an MDI Form, create a new Form and set its IsMdiContainer property to true.
- To add a child Form to the parent, create a new child Form object, set its MdiParent property to the parent Form and call the child Form's Show method.
- Property MdiWindowListItem of class ToolStrip specifies which menu, if any, displays a list of open child windows.
- MDI containers allow you to organize the placement of child windows. The child windows in an MDI app can be arranged by calling method LayoutMdi of the parent Form.

***Section 15.13 Visual Inheritance***

- Visual inheritance allows you to create a new Form by inheriting from an existing Form. The derived Form class contains the functionality of its base class.
- Visual inheritance can also be applied with other controls as well.
- Visual inheritance enables you to achieve visual consistency across apps by reusing code.
- A reusable class is typically placed in a class library.
- When you compile a class library, the compiler will create a .dll file, known as a dynamically linked library—a way to package classes that you can reference from other apps.

***Section 15.14 User-Defined Controls***

- The .NET Framework allows you to create custom controls.
- Custom controls can appear in the user's Toolbox and can be added to Forms, Panels or Group-Boxes in the same way that Buttons, Labels and other predefined controls are added.
- The simplest way to create a custom control is to derive a class from an existing control, such as a Label. This is useful if you want to add functionality to an existing control, rather than replacing it with one that provides the desired functionality.
- To create a new control composed of existing controls, use class UserControl.
- Controls added to a custom control are called constituent controls.
- A programmer can create a brand-new control by inheriting from class Control. This class does not define any specific behavior; that task is left to you.
- Timers are non-visual components that generate Tick events at a set interval. This interval is set by the Timer's Interval property, which defines the number of milliseconds (thousandths of a second) between events. Timers are disabled by default.

**Terminology**

|                                             |                                        |
|---------------------------------------------|----------------------------------------|
| access shortcut                             | CheckedListBox class                   |
| Activation property of class ListView       | child node                             |
| ActiveMdiChild property of class Form       | child window                           |
| AddDays method of struct DateTime           | Clear method of class Graphics         |
| AddYears method of struct DateTime          | Click event of class ToolStripMenuItem |
| Application class                           | ClipRectangle property of class        |
| cascaded window                             | PaintEventArgs                         |
| CheckBoxes property of class ListView       | ComboBox class                         |
| Checked property of class ToolStripMenuItem | ComboBoxStyle enumeration              |

constituent controls  
 CustomFormat property of class DateTimePicker  
 Date property of struct DateTime  
 DateChanged event of class MonthCalendar  
 DateTime struct  
 DateTimePicker class  
 DateTimePickerFormat enumeration  
 DayOfWeek enumeration  
 DayOfWeek property of struct DateTime  
 DirectoryInfo class  
 .dll file  
 DrawEllipse method of class Graphics  
 DrawPie method of class Graphics  
 DrawRectangle method of class Graphics  
 DropDownStyle property of class ComboBox  
 dynamically linked library  
 Exists method of class Directory  
 Exit method of class Application  
 FileInfo class  
 FillEllipse method of class Graphics  
 FillPie method of class Graphics  
 FillRectangle method of class Graphics  
 Format property of class DateTimePicker  
 FullName property of class DirectoryInfo  
 FullName property of class FileInfo  
 GetDirectories method of class DirectoryInfo  
 GetFiles method of class DirectoryInfo  
 GetSelected method of class ListView  
 Graphics property of class PaintEventArgs  
 hotkey  
 ImageIndex property of class ListViewItem  
 ImageList class  
 Images property of class ImageList  
 Interval property of class Timer  
 IsMdiContainer property of class Form  
 ItemCheck event of class CheckedListBox  
 Items property of class ComboBox  
 Items property of class ListView  
 keyboard shortcut  
 LargeImageList property of class ListView  
 LinkLabel class  
 ListView class  
 ListViewItem class  
 MaxDate property of class DateTimePicker  
 MaxDropDownItems property of class ComboBox  
 MdiChildren property of class Form  
 MdiParent property of class Form  
 MdiWindowListItem property of class ToolStrip  
 MenuStrip class  
 MinDate property of class DateTimePicker  
 MonthCalendar class  
 multiple document interface (MDI)  
 MultiSelect property of class ListView  
 Name property of class DirectoryInfo  
 Name property of class FileInfo  
 node  
 Nodes collection  
 Now property of struct DateTime  
 ObjectCollection class  
 OnPaint method of class Control  
 PaintEventArgs class  
 parent node  
 Parent property of class DirectoryInfo  
 parent window  
 Path class  
 Process class  
 root node  
 SelectedIndex property of class ComboBox  
 SelectedIndex property of class ListView  
 SelectedIndexChanged event of class ComboBox  
 SelectedIndexChanged event of class ListView  
 SelectedIndices property of class ListView  
 SelectedItem property of class ComboBox  
 SelectedItem property of class ListView  
 SelectedItems property of class ListView  
 SelectionMode enumeration  
 SelectionMode property of class ListView  
 separator bar  
 ShortcutKeyDisplayString property of class ToolStripMenuItem  
 ShortcutKeys property of class ToolStripMenuItem  
 ShowShortcutKeys property of class ToolStripMenuItem  
 sibling node  
 Single document interface (SDI)  
 SmallImageList property of class ListView  
 Start method of class Process  
 System.Diagnostics namespace  
 TabControl class  
 TabPage class  
 TabPages property of class TabControl  
 Text property of class tabPage  
 Tick event of class Timer  
 tiled window  
 TimeOfDay property of struct DateTime  
 Timer class  
 ToLongDateString method of struct DateTime  
 ToLongTimeString method of struct DateTime

|                         |                                            |
|-------------------------|--------------------------------------------|
| ToolStripMenuItem class | UserControl class                          |
| tree                    | Value property of class DateTimePicker     |
| TreeNode class          | ValueChanged event of class DateTimePicker |
| TreeNodeCollection type | verbatim string                            |
| TreeView class          | View property of class ListView            |
| TreeViewEventArgs class | visual inheritance                         |

## Self-Review Exercises

- 15.1** State whether each of the following is *true* or *false*. If *false*, explain why.
- Menus provide groups of related classes.
  - Menu items can display ComboBoxes, checkmarks and access shortcuts.
  - The ListBox control allows only single selection (like a RadioButton).
  - A ComboBox control typically has a drop-down list.
  - Deleting a parent node in a TreeView control deletes its child nodes.
  - The user can select only one item in a ListView control.
  - A TabPage can act as a container for RadioButtons.
  - An MDI child window can have MDI children.
  - MDI child windows can be moved outside the boundaries of their parent window.
  - There are two basic ways to create a customized control.
- 15.2** Fill in the blanks in each of the following statements:
- Method \_\_\_\_\_ of class Process can open files and web pages, similar to the Run... command in Windows.
  - If more elements appear in a ComboBox than can fit, a(n) \_\_\_\_\_ appears.
  - The top-level node in a TreeView is the \_\_\_\_\_ node.
  - A(n) \_\_\_\_\_ and a(n) \_\_\_\_\_ can display icons contained in an ImageList control.
  - The \_\_\_\_\_ property allows a menu to display a list of active child windows.
  - Class \_\_\_\_\_ allows you to combine several controls into a single, custom control.
  - The \_\_\_\_\_ saves space by layering TabPages on top of each other.
  - The \_\_\_\_\_ window layout option makes all MDI windows the same size and layers them so every title bar is visible (if possible).
  - \_\_\_\_\_ are typically used to display hyperlinks to other resources, files or web pages.

## Answers to Self-Review Exercises

**15.1** a) False. Menus provide groups of related commands. b) True. c) False. It can have single or multiple selection. d) True. e) True. f) False. The user can select one or more items. g) True. h) False. Only an MDI parent window can have MDI children. An MDI parent window cannot be an MDI child. i) False. MDI child windows cannot be moved outside their parent window. j) False. There are three ways: 1) Derive from an existing control, 2) use a UserControl or 3) derive from Control and create a control from scratch.

**15.2** a) Start. b) scrollbar. c) root. d) ListView, TreeView. e) MdiWindowListItem. f) UserControl. g) TabControl. h) Cascade. i) LinkLabels.

## Exercises

**15.3** (*Using ComboBoxes*) Write an app that displays the names of 15 states in a ComboBox. When an item is selected from the ComboBox, remove it.

**15.4** (*Using ComboBoxes and ListBoxes*) Modify your solution to the previous exercise to add a ListBox. When the user selects an item from the ComboBox, remove the item from the ComboBox and

add it to the `ListBox`. Your program should check to ensure that the `ComboBox` contains at least one item. If it does not, display a message, using a message box, then terminate program execution when the user dismisses the message box.

**15.5 (Sorting Strings)** Write an app that allows the user to enter strings in a `TextBox`. Each string input is added to a `ListBox`. As each string is added to the `ListBox`, ensure that the strings are in sorted order. [Note: Use property `Sorted`.]

**15.6 (File Browser)** Create a file browser (similar to Windows Explorer) based on the programs in Figs. 15.14, 15.28 and 15.31. The file browser should have a `TreeView`, which allows the user to browse directories. There should also be a `ListView`, which displays the contents (all subdirectories and files) of the directory being browsed. Double clicking a file in the `ListView` should open it, and double clicking a directory in either the `ListView` or the `TreeView` should browse it. If a file or directory cannot be accessed because of its permission settings, notify the user.

**15.7 (MDI Text Editor)** Create an MDI text editor. Each child window should contain a multi-line `RichTextBox`. The MDI parent should have a `Format` menu, with submenus to control the size, font and color of the text in the active child window. Each submenu should have at least three options. In addition, the parent should have a `File` menu, with menu items `New` (create a new child), `Close` (close the active child) and `Exit` (exit the app). The parent should have a `Window` menu to display a list of the open child windows and their layout options.

**15.8 (Login User Control)** Create a `UserControl` called `LoginPasswordUserControl` that contains a `Label` (`loginLabel`) that displays string "Login:", a `TextBox` (`loginTextBox`), where the user inputs a login name, a `Label` (`passwordLabel`) that displays the string "Password:" and, finally, a `TextBox` (`passwordTextBox`) where a user inputs a password (set property `PasswordChar` to "\*" in the `TextBox`'s `Properties` window). `LoginPasswordUserControl` must provide public read-only properties `Login` and `Password` that allow an app to retrieve the user input from `loginTextBox` and `passwordTextBox`. The `UserControl` must be exported to an app that displays the values input by the user in `LoginPasswordUserControl`.

**15.9 (Restaurant Bill Calculator)** A restaurant wants an app that calculates a table's bill. The app should display all the menu items from Fig. 15.53 in four `ComboBoxes`. Each `ComboBox` should contain a category of food offered by the restaurant (Beverage, Appetizer, Main Course and Dessert). The user can choose from one of these `ComboBoxes` to add an item to a table's bill. As each item is selected in the `ComboBoxes`, add the price of that item to the bill. The user can click the `Clear Bill` button to restore the `Subtotal:`, `Tax:` and `Total:` fields to \$0.00.

| Name            | Category  | Price  | Name            | Category    | Price   |
|-----------------|-----------|--------|-----------------|-------------|---------|
| Soda            | Beverage  | \$1.95 | Chicken Alfredo | Main Course | \$13.95 |
| Tea             | Beverage  | \$1.50 | Chicken Picatta | Main Course | \$13.95 |
| Coffee          | Beverage  | \$1.25 | Turkey Club     | Main Course | \$11.95 |
| Mineral Water   | Beverage  | \$2.95 | Lobster Pie     | Main Course | \$19.95 |
| Juice           | Beverage  | \$2.50 | Prime Rib       | Main Course | \$20.95 |
| Milk            | Beverage  | \$1.50 | Shrimp Scampi   | Main Course | \$18.95 |
| Buffalo Wings   | Appetizer | \$5.95 | Turkey Dinner   | Main Course | \$13.95 |
| Buffalo Fingers | Appetizer | \$6.95 | Stuffed Chicken | Main Course | \$14.95 |
| Potato Skins    | Appetizer | \$8.95 | Apple Pie       | Dessert     | \$5.95  |

**Fig. 15.53** | Food items and prices. (Part 1 of 2.)

| Name            | Category    | Price   | Name        | Category | Price  |
|-----------------|-------------|---------|-------------|----------|--------|
| Nachos          | Appetizer   | \$8.95  | Sundae      | Dessert  | \$3.95 |
| Mushroom Caps   | Appetizer   | \$10.95 | Carrot Cake | Dessert  | \$5.95 |
| Shrimp Cocktail | Appetizer   | \$12.95 | Mud Pie     | Dessert  | \$4.95 |
| Chips and Salsa | Appetizer   | \$6.95  | Apple Crisp | Dessert  | \$5.95 |
| Seafood Alfredo | Main Course | \$15.95 |             |          |        |

**Fig. 15.53** | Food items and prices. (Part 2 of 2.)

**15.10 (Using TabPages)** Create an app that contains three TabPages. On the first TabPage, place a CheckedListBox with six items. On the second TabPage, place six TextBoxes. On the last TabPage, place six LinkLabels. The user's selections on the first TabPage should specify which of the six LinkLabels will be displayed. To hide or display a LinkLabel's value, use its Visible property. Use the second TabPage to modify the web page that's opened by the LinkLabels.

**15.11 (MDI Drawing Programs)** Create an MDI app with child windows that each have a Panel for drawing. Add menus to the MDI app that allow the user to modify the size and color of the paintbrush. When running this app, be aware that if one of the windows overlaps another, the Panel will be cleared.

# 16

## Strings and Characters: A Deeper Look

*The chief defect of Henry King  
Was chewing little bits of string.*  
—Hilaire Belloc

*The difference between the  
almost-right word and the right  
word is really a large matter—  
it's the difference between the  
lightning bug and the lightning.*  
—Mark Twain

### Objectives

In this chapter you'll:

- Create and manipulate immutable character-string objects of class `string` and mutable character-string objects of class `StringBuilder`.
- Use various methods of classes `string` and `StringBuilder`.
- To manipulate character objects of struct `Char`.
- To use regular-expression classes `Regex` and `Match`.



# Outline

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>16.1</b> Introduction<br><b>16.2</b> Fundamentals of Characters and Strings<br><b>16.3</b> <code>string</code> Constructors<br><b>16.4</b> <code>string</code> Indexer, Length Property and <code>CopyTo</code> Method<br><b>16.5</b> Comparing strings<br><b>16.6</b> Locating Characters and Substrings in <code>strings</code><br><b>16.7</b> Extracting Substrings from <code>strings</code><br><b>16.8</b> Concatenating <code>strings</code><br><b>16.9</b> Miscellaneous <code>string</code> Methods | <b>16.10</b> Class <code>StringBuilder</code><br><b>16.11</b> Length and Capacity Properties, <code>EnsureCapacity</code> Method and Indexer of Class <code>StringBuilder</code><br><b>16.12</b> Append and <code>AppendFormat</code> Methods of Class <code>StringBuilder</code><br><b>16.13</b> Insert, Remove and Replace Methods of Class <code>StringBuilder</code><br><b>16.14</b> Char Methods<br><b>16.15</b> (Online) Introduction to Regular Expressions<br><b>16.16</b> Wrap-Up |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercises](#)

## 16.1 Introduction

This chapter introduces the .NET Framework Class Library's string- and character-processing capabilities and demonstrates how to use regular expressions to search for patterns in text. The techniques it presents can be employed in text editors, word processors, page-layout software, computerized typesetting systems and other kinds of text-processing software. Previous chapters presented some basic string-processing capabilities. Now we discuss in detail the text-processing capabilities of class `string` and type `char` from the `System` namespace and class `StringBuilder` from the `System.Text` namespace.

We begin with an overview of the fundamentals of characters and strings in which we discuss *character constants* and *string literals*. We then provide examples of class `string`'s many constructors and methods. The examples demonstrate how to determine the *length* of strings, *copy* strings, *access individual characters* in strings, *search* strings, obtain *substrings* from larger strings, *compare* strings, *concatenate* strings, *replace characters* in strings and convert strings to uppercase or lowercase letters.

Next, we introduce class `StringBuilder`, which is used to build strings dynamically. We demonstrate `StringBuilder` capabilities for determining and specifying the *size* of a `StringBuilder`, as well as *appending*, *inserting*, *removing* and *replacing* characters in a `StringBuilder` object. We then introduce the character-testing methods of struct `Char` that enable a program to determine whether a character is a digit, a letter, a lowercase letter, an uppercase letter, a punctuation mark or a symbol other than a punctuation mark. Such methods are useful for validating individual characters in user input. In addition, type `Char` provides methods for *converting* a character to *uppercase or lowercase*.

We provide an online section that discusses *regular expressions*. We present classes `Regex` and `Match` from the `System.Text.RegularExpressions` namespace as well as the symbols that are used to form regular expressions. We then demonstrate how to *find patterns* in a string, *match entire strings to patterns*, *replace characters* in a string that match a pattern and *split strings* at delimiters specified as a pattern in a regular expression.

## 16.2 Fundamentals of Characters and Strings

Characters are the fundamental building blocks of C# source code. Every program is composed of characters that, when grouped together meaningfully, create a sequence that the compiler interprets as instructions describing how to accomplish a task. A program also can contain **character constants**. A character constant is a character that's represented as an integer value, called a *character code*. For example, the integer value 122 corresponds to the character constant 'z'. The integer value 10 corresponds to the newline character '\n'. Character constants are established according to the **Unicode character set**, an international character set that contains many more symbols and letters than does the ASCII character set (listed in Appendix C). To learn more about Unicode, see Appendix F.

A string is a series of characters treated as a unit. These characters can be uppercase letters, lowercase letters, digits and various **special characters**: +, -, \*, /, \$ and others. A string is an object of class `string` in the `System` namespace.<sup>1</sup> We write **string literals**, also called **string constants**, as sequences of characters in double quotation marks, as follows:

```
"John Q. Doe"
"9999 Main Street"
"Waltham, Massachusetts"
"(201) 555-1212"
```

A declaration can assign a `string` literal to a `string` reference. The declaration

```
string color = "blue";
```

initializes the `string` `color` to refer to the `string` literal object "blue".



### Performance Tip 16.1

If there are multiple occurrences of the same `string` literal object in an app, a single copy of it will be referenced from each location in the program that uses that `string` literal. It's possible to share the object in this manner, because `string` literal objects are implicitly constant. Such sharing conserves memory.

### Verbatim Strings

On occasion, a `string` will contain multiple *backslash characters* (this often occurs in the name of a file). To avoid excessive backslash characters, it's possible to exclude escape sequences and interpret all the characters in a `string` literally, using the @ character to create what's known as a **verbatim string**. Backslashes within the double quotation marks following the @ character are not considered escape sequences. Often this simplifies programming and makes the code easier to read. For example, consider the string "C:\MyFolder\MySubFolder\MyFile.txt" with the following assignment:

```
string file = "C:\\MyFolder\\\\MySubFolder\\\\MyFile.txt";
```

Using the *verbatim string syntax*, the assignment can be altered to

```
string file = @"/C:\\MyFolder\\MySubFolder\\MyFile.txt";
```

This approach also has the advantage of allowing `string` literals to span multiple lines by preserving all newlines, spaces and tabs.

---

1. C# provides the `string` keyword as an alias for class `String`. In this book, we use the term `string`.

## 16.3 string Constructors

Class `string` provides eight constructors for initializing strings in various ways. Figure 16.1 demonstrates three of the constructors.

```

1 // Fig. 16.1: StringConstructor.cs
2 // Demonstrating string class constructors.
3 using System;
4
5 class StringConstructor
6 {
7     public static void Main( string[] args )
8     {
9         // string initialization
10        char[] characterArray =
11            { 'b', 'i', 'r', 't', 'h', ' ', 'd', 'a', 'y' };
12        string originalString = "Welcome to C# programming!";
13        string string1 = originalString;
14        string string2 = new string( characterArray );
15        string string3 = new string( characterArray, 6, 3 );
16        string string4 = new string( 'C', 5 );
17
18        Console.WriteLine( "string1 = " + "\"" + string1 + "\"\n" +
19                          "string2 = " + "\"" + string2 + "\"\n" +
20                          "string3 = " + "\"" + string3 + "\"\n" +
21                          "string4 = " + "\"" + string4 + "\"\n" );
22    } // end Main
23 } // end class StringConstructor

string1 = "Welcome to C# programming!"
string2 = "birth day"
string3 = "day"
string4 = "CCCCC"
```

**Fig. 16.1** | string constructors.

Lines 10–11 allocate the `char` array `characterArray`, which contains nine characters. Lines 12–16 declare the `strings` `originalString`, `string1`, `string2`, `string3` and `string4`. Line 12 assigns `string` literal "Welcome to C# programming!" to `string` reference `originalString`. Line 13 sets `string1` to reference the same `string` literal.

Line 14 assigns to `string2` a new `string`, using the `string` constructor with a `char`acter array argument. The new `string` contains a copy of the array's characters.

Line 15 assigns to `string3` a new `string`, using the `string` constructor that takes a `char` array and two `int` arguments. The second argument specifies the starting index position (the *offset*) from which characters in the array are to be copied. The third argument specifies the number of characters (the *count*) to be copied from the specified starting position in the array. The new `string` contains a copy of the specified characters in the array. If the specified offset or count indicates that the program should access an element outside the bounds of the character array, an `ArgumentOutOfRangeException` is thrown.

Line 16 assigns to `string4` a new `string`, using the `string` constructor that takes as arguments a character and an `int` specifying the number of times to repeat that character in the `string`.



### Software Engineering Observation 16.1

*In most cases, it's not necessary to make a copy of an existing string. All strings are immutable—their character contents cannot be changed after they're created. Also, if there are one or more references to a string (or any object for that matter), the object cannot be reclaimed by the garbage collector.*

## 16.4 string Indexer, Length Property and CopyTo Method

The app in Fig. 16.2 presents the **string indexer**, which facilitates the retrieval of any character in the **string**, and the **string** property **Length**, which returns the length of the **string**. The **string** method **CopyTo** copies a specified number of characters from a **string** into a **char** array.

```

1 // Fig. 16.2: StringMethods.cs
2 // Using the indexer, property Length and method CopyTo
3 // of class string.
4 using System;
5
6 class StringMethods
7 {
8     public static void Main( string[] args )
9     {
10         string string1 = "hello there";
11         char[] characterArray = new char[ 5 ];
12
13         // output string
14         Console.WriteLine( "string1: \"\" + string1 + "\"\"");
15
16         // test Length property
17         Console.WriteLine( "Length of string1: " + string1.Length );
18
19         // loop through characters in string1 and display reversed
20         Console.Write( "The string reversed is: " );
21
22         for ( int i = string1.Length - 1; i >= 0; --i )
23             Console.Write( string1[ i ] );
24
25         // copy characters from string1 into characterArray
26         string1.CopyTo( 0, characterArray, 0, characterArray.Length );
27         Console.Write( "\nThe character array is: " );
28
29         for ( int i = 0; i < characterArray.Length; ++i )
30             Console.Write( characterArray[ i ] );
31
32         Console.WriteLine( "\n" );
33     } // end Main
34 } // end class StringMethods

```

**Fig. 16.2 |** **string** indexer, **Length** property and **CopyTo** method. (Part I of 2.)

```

string1: "hello there"
Length of string1: 11
The string reversed is: ereht olleh
The character array is: hello

```

**Fig. 16.2 |** string indexer, Length property and CopyTo method. (Part 2 of 2.)

This app determines the length of a `string`, displays its characters in reverse order and copies a series of characters from the `string` to a character array. Line 17 uses `string` property `Length` to determine the number of characters in `string1`. Like arrays, `strings` always know their own size.

Lines 22–23 write the characters of `string1` in reverse order using the `string` indexer. The `string` indexer treats a `string` as an array of `chars` and returns each character at a specific position in the `string`. The indexer receives an integer argument as the *position number* and returns the character at that position. As with arrays, the first element of a `string` is considered to be at position 0.



### Common Programming Error 16.1

*Attempting to access a character that's outside a string's bounds results in an IndexOutOfRangeException.*

Line 26 uses `string` method `CopyTo` to copy the characters of `string1` into a character array (`characterArray`). The first argument given to method `CopyTo` is the index from which the method begins copying characters in the `string`. The second argument is the character array into which the characters are copied. The third argument is the index specifying the starting location at which the method begins placing the copied characters into the character array. The last argument is the number of characters that the method will copy from the `string`. Lines 29–30 output the `char` array contents one character at a time.

## 16.5 Comparing strings

The next two examples demonstrate various methods for *comparing strings*. To understand how one `string` can be “greater than” or “less than” another, consider the process of alphabetizing a series of last names. The reader would, no doubt, place “Jones” before “Smith”, because the first letter of “Jones” comes before the first letter of “Smith” in the alphabet. The alphabet is more than just a set of 26 letters—it’s an ordered list of characters in which each letter occurs in a specific position. For example, Z is more than just a letter of the alphabet; it’s specifically the twenty-sixth letter of the alphabet. Computers can order characters alphabetically because they’re represented internally as numeric codes and those codes are ordered according to the alphabet so, for example, ‘a’ is less than ‘b’—see Appendix C.

### *Comparing Strings with Equals, CompareTo and the Equality Operator (==)*

Class `string` provides several ways to compare `strings`. The app in Fig. 16.3 demonstrates the use of method `Equals`, method `CompareTo` and the equality operator (`==`).

The condition in line 21 uses `string` method `Equals` to compare `string1` and literal `string` “hello” to determine whether they’re equal. Method `Equals` (inherited from `object` and overridden in `string`) tests two `strings` for equality (i.e., checks whether the `strings` have *identical contents*). The method returns `true` if the objects are equal and `false`

otherwise. In this case, the condition returns `true`, because `string1` references `string` literal object "hello". Method `Equals` uses word sorting rules that depend on your system's currently selected culture. Comparing "hello" with "HELLO" would return `false`, because the lowercase letters are different from the those of corresponding uppercase letters.

```
1 // Fig. 16.3: StringCompare.cs
2 // Comparing strings
3 using System;
4
5 class StringCompare
6 {
7     public static void Main( string[] args )
8     {
9         string string1 = "hello";
10        string string2 = "good bye";
11        string string3 = "Happy Birthday";
12        string string4 = "happy birthday";
13
14        // output values of four strings
15        Console.WriteLine( "string1 = \\" + string1 + "\"" +
16                           "\nstring2 = \\" + string2 + "\"" +
17                           "\nstring3 = \\" + string3 + "\"" +
18                           "\nstring4 = \\" + string4 + "\"\n" );
19
20        // test for equality using Equals method
21        if ( string1.Equals( "hello" ) )
22            Console.WriteLine( "string1 equals \"hello\"" );
23        else
24            Console.WriteLine( "string1 does not equal \"hello\"" );
25
26        // test for equality with ==
27        if ( string1 == "hello" )
28            Console.WriteLine( "string1 equals \"hello\"" );
29        else
30            Console.WriteLine( "string1 does not equal \"hello\"" );
31
32        // test for equality comparing case
33        if ( string.Equals( string3, string4 ) ) // static method
34            Console.WriteLine( "string3 equals string4" );
35        else
36            Console.WriteLine( "string3 does not equal string4" );
37
38        // test CompareTo
39        Console.WriteLine( "\nstring1.CompareTo( string2 ) is " +
40                           string1.CompareTo( string2 ) + "\n" +
41                           "string2.CompareTo( string1 ) is " +
42                           string2.CompareTo( string1 ) + "\n" +
43                           "string1.CompareTo( string1 ) is " +
44                           string1.CompareTo( string1 ) + "\n" +
45                           "string3.CompareTo( string4 ) is " +
46                           string3.CompareTo( string4 ) + "\n" +
```

Fig. 16.3 | `string` test to determine equality. (Part 1 of 2.)

```

47         "string4.CompareTo( string3 ) is " +
48         string4.CompareTo( string3 ) + "\n\n" );
49     } // end Main
50 } // end class StringCompare

```

```

string1 = "hello"
string2 = "good bye"
string3 = "Happy Birthday"
string4 = "happy birthday"

string1 equals "hello"
string1 equals "hello"
string3 does not equal string4

string1.CompareTo( string2 ) is 1
string2.CompareTo( string1 ) is -1
string1.CompareTo( string1 ) is 0
string3.CompareTo( string4 ) is 1
string4.CompareTo( string3 ) is -1

```

**Fig. 16.3 |** string test to determine equality. (Part 2 of 2.)

The condition in line 27 uses the *overloaded equality operator* (`==`) to compare `string string1` with the literal `string "hello"` for equality. In C#, the equality operator also compares the contents of two `strings`. Thus, the condition in the `if` statement evaluates to `true`, because the values of `string1` and `"hello"` are equal.

Line 33 tests whether `string3` and `string4` are equal to illustrate that comparisons are indeed case sensitive. Here, `static` method `Equals` is used to compare the values of two `strings`. `"Happy Birthday"` does not equal `"happy birthday"`, so the condition of the `if` statement fails, and the message `"string3 does not equal string4"` is output (line 36).

Lines 40–48 use `string` method `CompareTo` to compare `strings`. Method `CompareTo` returns 0 if the `strings` are equal, a negative value if the `string` that invokes `CompareTo` is less than the `string` that's passed as an argument and a positive value if the `string` that invokes `CompareTo` is greater than the `string` that's passed as an argument.

Notice that `CompareTo` considers `string3` to be greater than `string4`. The only difference between these two `strings` is that `string3` contains two uppercase letters in positions where `string4` contains lowercase letters—the uppercase version of a letter has a lower numeric code than the corresponding lowercase letter (e.g., 'A' is 65 and 'a' is 97).

### Determining Whether a String Begins or Ends with a Specified String

Figure 16.4 shows how to test whether a `string` instance begins or ends with a given `string`. Method `StartsWith` determines whether a `string` instance starts with the `string` text passed to it as an argument. Method `EndsWith` determines whether a `string` instance ends with the `string` text passed to it as an argument. Class `StringStartEnd`'s `Main` method defines an array of `strings` (called `strings`), which contains `"started"`, `"starting"`, `"ended"` and `"ending"`. The remainder of method `Main` tests the elements of the array to determine whether they start or end with a particular set of characters.

Line 13 uses method `StartsWith`, which takes a `string` argument. The condition in the `if` statement determines whether the `string` at index `i` of the array starts with the characters `"st"`. If so, the method returns `true`, and `strings[i]` is output along with a message.

Line 21 uses method `EndsWith` to determine whether the `string` at index `i` of the array ends with the characters "ed". If so, the method returns true, and `strings[i]` is displayed along with a message.

```

1 // Fig. 16.4: StringStartEnd.cs
2 // Demonstrating StartsWith and EndsWith methods.
3 using System;
4
5 class StringStartEnd
6 {
7     public static void Main( string[] args )
8     {
9         string[] strings = { "started", "starting", "ended", "ending" };
10
11         // test every string to see if it starts with "st"
12         for ( int i = 0; i < strings.Length; i++ )
13             if ( strings[ i ].StartsWith( "st" ) )
14                 Console.WriteLine( "\\" + strings[ i ] + "\\" +
15                     " starts with \"st\"");
16
17         Console.WriteLine();
18
19         // test every string to see if it ends with "ed"
20         for ( int i = 0; i < strings.Length; i++ )
21             if ( strings[ i ].EndsWith( "ed" ) )
22                 Console.WriteLine( "\\" + strings[ i ] + "\\" +
23                     " ends with \"ed\"");
24
25         Console.WriteLine();
26     } // end Main
27 } // end class StringStartEnd

```

"started" starts with "st"  
 "starting" starts with "st"

"started" ends with "ed"  
 "ended" ends with "ed"

**Fig. 16.4** | StartsWith and EndsWith methods.

## 16.6 Locating Characters and Substrings in strings

In many apps, it's necessary to search for a character or set of characters in a `string`. For example, a programmer creating a word processor would want to provide capabilities for searching through documents. The app in Fig. 16.5 demonstrates some of the many versions of `string` methods `IndexOf`, `IndexOfAny`, `LastIndexOf` and `LastIndexOfAny`, which search for a specified character or substring in a `string`. We perform all searches in this example on the `string` `letters` (initialized with "abcdefghijklmabcdefghijklm") located in method `Main` of class `StringIndexMethods`.

Lines 14, 16 and 18 use method `IndexOf` to locate the first occurrence of a character or substring in a `string`. If it finds a character, `IndexOf` returns the index of the specified

```

1 // Fig. 16.5: StringIndexMethods.cs
2 // Using string-searching methods.
3 using System;
4
5 class StringIndexMethods
6 {
7     public static void Main( string[] args )
8     {
9         string letters = "abcdefghijklmnopqrstuvwxyz";
10        char[] searchLetters = { 'c', 'a', '$' };
11
12        // test IndexOf to locate a character in a string
13        Console.WriteLine( "First 'c' is located at index " +
14            letters.IndexOf( 'c' ) );
15        Console.WriteLine( "First 'a' starting at 1 is located at index " +
16            letters.IndexOf( 'a', 1 ) );
17        Console.WriteLine( "First '$' in the 5 positions starting at 3 " +
18            "is located at index " + letters.IndexOf( '$', 3, 5 ) );
19
20        // test LastIndexOf to find a character in a string
21        Console.WriteLine( "\nLast 'c' is located at index " +
22            letters.LastIndexOf( 'c' ) );
23        Console.WriteLine( "Last 'a' up to position 25 is located at " +
24            "index " + letters.LastIndexOf( 'a', 25 ) );
25        Console.WriteLine( "Last '$' in the 5 positions ending at 15 " +
26            "is located at index " + letters.LastIndexOf( '$', 15, 5 ) );
27
28        // test IndexOf to locate a substring in a string
29        Console.WriteLine( "\nFirst \"def\" is located at index " +
30            letters.IndexOf( "def" ) );
31        Console.WriteLine( "First \"def\" starting at 7 is located at " +
32            "index " + letters.IndexOf( "def", 7 ) );
33        Console.WriteLine( "First \"hello\" in the 15 positions " +
34            "starting at 5 is located at index " +
35            letters.IndexOf( "hello", 5, 15 ) );
36
37        // test LastIndexOf to find a substring in a string
38        Console.WriteLine( "\nLast \"def\" is located at index " +
39            letters.LastIndexOf( "def" ) );
40        Console.WriteLine( "Last \"def\" up to position 25 is located " +
41            "at index " + letters.LastIndexOf( "def", 25 ) );
42        Console.WriteLine( "Last \"hello\" in the 15 positions " +
43            "ending at 20 is located at index " +
44            letters.LastIndexOf( "hello", 20, 15 ) );
45
46        // test IndexOfAny to find first occurrence of character in array
47        Console.WriteLine( "\nFirst 'c', 'a' or '$' is " +
48            "located at index " + letters.IndexOfAny( searchLetters ) );
49        Console.WriteLine("First 'c', 'a' or '$' starting at 7 is " +
50            "located at index " + letters.IndexOfAny( searchLetters, 7 ) );
51        Console.WriteLine( "First 'c', 'a' or '$' in the 5 positions " +
52            "starting at 7 is located at index " +
53            letters.IndexOfAny( searchLetters, 7, 5 ) );

```

**Fig. 16.5** | Searching for characters and substrings in strings. (Part I of 2.)

```

54      // test LastIndexOfAny to find last occurrence of character
55      // in array
56      Console.WriteLine( "\nLast 'c', 'a' or '$' is " +
57          "located at index " + letters.LastIndexOfAny( searchLetters ) );
58      Console.WriteLine( "Last 'c', 'a' or '$' up to position 1 is " +
59          "located at index " +
60              letters.LastIndexOfAny( searchLetters, 1 ) );
61      Console.WriteLine( "Last 'c', 'a' or '$' in the 5 positions " +
62          "ending at 25 is located at index " +
63              letters.LastIndexOfAny( searchLetters, 25, 5 ) );
64  } // end Main
65 } // end class StringIndexMethods

```

```

First 'c' is located at index 2
First 'a' starting at 1 is located at index 13
First '$' in the 5 positions starting at 3 is located at index -1

Last 'c' is located at index 15
Last 'a' up to position 25 is located at index 13
Last '$' in the 5 positions ending at 15 is located at index -1

First "def" is located at index 3
First "def" starting at 7 is located at index 16
First "hello" in the 15 positions starting at 5 is located at index -1

Last "def" is located at index 16
Last "def" up to position 25 is located at index 16
Last "hello" in the 15 positions ending at 20 is located at index -1

First 'c', 'a' or '$' is located at index 0
First 'c', 'a' or '$' starting at 7 is located at index 13
First 'c', 'a' or '$' in the 5 positions starting at 7 is located at index -1

Last 'c', 'a' or '$' is located at index 15
Last 'c', 'a' or '$' up to position 1 is located at index 0
Last 'c', 'a' or '$' in the 5 positions ending at 25 is located at index -1

```

**Fig. 16.5** | Searching for characters and substrings in strings. (Part 2 of 2.)

character in the string; otherwise, `IndexOf` returns -1. The expression in line 16 uses a version of method `IndexOf` that takes two arguments—the character to search for and the starting index at which the search of the string should begin. The method does not examine any characters that occur prior to the starting index (in this case, 1). The expression in line 18 uses another version of method `IndexOf` that takes three arguments—the character to search for, the index at which to start searching and the number of characters to search.

Lines 22, 24 and 26 use method `LastIndexOf` to locate the last occurrence of a character in a string. Method `LastIndexOf` performs the search from the end of the string to the beginning of the string. If it finds the character, `LastIndexOf` returns the index of the specified character in the string; otherwise, `LastIndexOf` returns -1. There are three versions of method `LastIndexOf`. The expression in line 22 uses the version that takes as an argument the character for which to search. The expression in line 24 uses the version that takes two arguments—the character for which to search and the highest index from

which to begin searching backward for the character. The expression in line 26 uses a third version of method `LastIndexOf` that takes three arguments—the character for which to search, the starting index from which to start searching backward and the number of characters (the portion of the `string`) to search.

Lines 29–44 use versions of `IndexOf` and `LastIndexOf` that take a `string` instead of a character as the first argument. These versions of the methods perform identically to those described above except that they search for sequences of characters (or substrings) that are specified by their `string` arguments.

Lines 47–64 use methods `IndexOfAny` and `LastIndexOfAny`, which take an array of characters as the first argument. These versions of the methods also perform identically to those described above, except that they return the index of the first occurrence of any of the characters in the character-array argument.



### Common Programming Error 16.2

*In the overloaded methods `LastIndexOf` and `LastIndexOfAny` that take three parameters, the second argument must be greater than or equal to the third. This might seem counterintuitive, but remember that the search moves from the end of the string toward the start of the string.*

## 16.7 Extracting Substrings from strings

Class `string` provides two `Substring` methods, which create a new `string` by copying part of an existing `string`. Each method returns a new `string`. The app in Fig. 16.6 demonstrates the use of both methods.

---

```

1 // Fig. 16.6: SubString.cs
2 // Demonstrating the string Substring method.
3 using System;
4
5 class SubString
6 {
7     public static void Main( string[] args )
8     {
9         string letters = "abcdefghijklmabcdefghijklm";
10
11         // invoke Substring method and pass it one parameter
12         Console.WriteLine( "Substring from index 20 to end is \\" + 
13             letters.Substring( 20 ) + "\"" );
14
15         // invoke Substring method and pass it two parameters
16         Console.WriteLine( "Substring from index 0 of length 6 is \\" + 
17             letters.Substring( 0, 6 ) + "\"" );
18     } // end method Main
19 } // end class SubString

```

```

Substring from index 20 to end is "hijklm"
Substring from index 0 of length 6 is "abcdef"

```

**Fig. 16.6** | Substrings generated from `strings`.

The statement in line 13 uses the `Substring` method that takes one `int` argument. The argument specifies the starting index from which the method copies characters in the original `string`. The substring returned contains a copy of the characters from the starting index to the end of the `string`. If the index specified in the argument is outside the bounds of the `string`, the program throws an `ArgumentOutOfRangeException`.

The second version of method `Substring` (line 17) takes two `int` arguments. The first argument specifies the starting index from which the method copies characters from the original `string`. The second argument specifies the length of the substring to copy. The substring returned contains a copy of the specified characters from the original `string`. If the supplied length of the substring is too large (i.e., the substring tries to retrieve characters past the end of the original `string`), an `ArgumentOutOfRangeException` is thrown.

## 16.8 Concatenating strings

The `+` operator is not the only way to perform `string` concatenation. The `static` method `Concat` of class `string` (Fig. 16.7) concatenates two `strings` and returns a new `string` containing the combined characters from both original `strings`. Line 16 appends the characters from `string2` to the end of a copy of `string1`, using method `Concat`. The statement in line 16 does not modify the original `strings`.

---

```

1 // Fig. 16.7: SubConcatenation.cs
2 // Demonstrating string class Concat method.
3 using System;
4
5 class StringConcatenation
6 {
7     public static void Main( string[] args )
8     {
9         string string1 = "Happy ";
10        string string2 = "Birthday";
11
12        Console.WriteLine( "string1 = \\" + string1 + "\"\n" +
13                           "string2 = \\" + string2 + "\"" );
14        Console.WriteLine(
15            "\nResult of string.Concat( string1, string2 ) = " +
16            string.Concat( string1, string2 ) );
17        Console.WriteLine( "string1 after concatenation = " + string1 );
18    } // end Main
19 } // end class StringConcatenation

```

```

string1 = "Happy "
string2 = "Birthday"

Result of string.Concat( string1, string2 ) = Happy Birthday
string1 after concatenation = Happy

```

**Fig. 16.7** | `Concat` static method.

## 16.9 Miscellaneous string Methods

Class `string` provides several methods that return modified copies of `strings`. The app in Fig. 16.8 demonstrates the use of these methods, which include `string` methods `Replace`, `ToLower`, `ToUpper` and `Trim`.

```

1 // Fig. 16.8: StringMethods2.cs
2 // Demonstrating string methods Replace, ToLower, ToUpper, Trim,
3 // and ToString.
4 using System;
5
6 class StringMethods2
7 {
8     public static void Main( string[] args )
9     {
10        string string1 = "cheers!";
11        string string2 = "GOOD BYE ";
12        string string3 = "    spaces    ";
13
14        Console.WriteLine( "string1 = \\" + string1 + "\"\n" +
15            "string2 = \\" + string2 + "\"\n" +
16            "string3 = \\" + string3 + "\"" );
17
18        // call method Replace
19        Console.WriteLine(
20            "\nReplacing \"e\" with \"E\" in string1: \\" + 
21            string1.Replace( 'e', 'E' ) + "\"");
22
23        // call ToLower and ToUpper
24        Console.WriteLine( "\nstring1.ToUpper() = \\" + 
25            string1.ToUpper() + "\"\nstring2.ToLower() = \\" + 
26            string2.ToLower() + "\"" );
27
28        // call Trim method
29        Console.WriteLine( "\nstring3 after trim = \\" + 
30            string3.Trim() + "\"");
31
32        Console.WriteLine( "\nstring1 = \\" + string1 + "\"");
33    } // end Main
34 } // end class StringMethods2

```

```

string1 = "cheers!"
string2 = "GOOD BYE "
string3 = "    spaces    "

Replacing "e" with "E" in string1: "chEErs!"

string1.ToUpper() = "CHEERS!"
string2.ToLower() = "good bye "

string3 after trim = "spaces"

string1 = "cheers!"

```

**Fig. 16.8** | `string` methods `Replace`, `ToLower`, `ToUpper` and `Trim`.

Line 21 uses `string` method `Replace` to return a new `string`, replacing every occurrence in `string1` of character 'e' with 'E'. Method `Replace` takes two arguments—a `char` for which to search and another `char` with which to replace all matching occurrences of the first argument. The original `string` remains unchanged. If there are no occurrences of the first argument in the `string`, the method returns the original `string`. An overloaded version of this method allows you to provide two `strings` as arguments.

The `string` method `ToUpper` generates a new `string` (line 25) that replaces any *lowercase* letters in `string1` with their *uppercase* equivalents. The method returns a new `string` containing the converted `string`; the original `string` remains *unchanged*. If there are no characters to convert, the original `string` is returned. Line 26 uses `string` method `ToLower` to return a new `string` in which any *uppercase* letters in `string2` are replaced by their *lowercase* equivalents. The original `string` is *unchanged*. As with `ToUpper`, if there are *no* characters to convert to lowercase, method `ToLower` returns the *original string*.

Line 30 uses `string` method `Trim` to remove all *whitespace characters* that appear at the beginning and end of a `string`. Without otherwise altering the original `string`, the method returns a new `string` that contains the `string`, but *omits* leading and trailing *whitespace characters*. This method is particularly useful for retrieving user input (i.e., via a `TextBox`). Another version of method `Trim` takes a character array and returns a copy of the `string` that does not begin or end with any of the characters in the array argument.

## 16.10 Class `StringBuilder`

The `string` class provides many capabilities for processing `strings`. However a `string`'s contents can *never* change. Operations that seem to concatenate `strings` are in fact creating new `strings`—the `+=` operator creates a new `string` and assigns its reference to the variable on the left of the `+=` operator.

The next several sections discuss the features of class `StringBuilder` (namespace `System.Text`), used to create and manipulate dynamic `string` information—i.e., *mutable* `strings`. Every `StringBuilder` can store a certain number of characters that's specified by its capacity. Exceeding the capacity of a `StringBuilder` causes the capacity to expand to accommodate the additional characters. As we'll see, members of class `StringBuilder`, such as methods `Append` and `AppendFormat`, can be used for *concatenation* like the operators `+` and `+=` for class `string`. `StringBuilder` is particularly useful for manipulating in place a large number of `strings`, as it's much more efficient than creating individual immutable `strings`.



### Performance Tip 16.2

*Objects of class `string` are immutable (i.e., constant `strings`), whereas objects of class `StringBuilder` are mutable. C# can perform certain optimizations involving `strings` (such as the sharing of one `string` among multiple references), because it knows these objects will not change.*

Class `StringBuilder` provides six overloaded constructors. Class `StringBuilderConstructor` (Fig. 16.9) demonstrates three of these overloaded constructors.

Line 10 employs the no-parameter `StringBuilder` constructor to create a `StringBuilder` that contains no characters and has an implementation-specific *default initial capacity*. Line 11 uses the `StringBuilder` constructor that takes an `int` argument to create a `StringBuilder` that contains no characters and has the *initial capacity* specified in the `int` argument (i.e., 10). Line 12 uses the `StringBuilder` constructor that takes a `string` argu-

ment to create a `StringBuilder` containing the characters of the `string` argument—the initial capacity might differ from the `string`'s size. Lines 14–16 implicitly use `StringBuilder` method `Tostring` to obtain `string` representations of the `StringBuilders`' contents.

```

1 // Fig. 16.9: StringBuilderConstructor.cs
2 // Demonstrating StringBuilder class constructors.
3 using System;
4 using System.Text;
5
6 class StringBuilderConstructor
7 {
8     public static void Main( string[] args )
9     {
10         StringBuilder buffer1 = new StringBuilder();
11         StringBuilder buffer2 = new StringBuilder( 10 );
12         StringBuilder buffer3 = new StringBuilder( "hello" );
13
14         Console.WriteLine( "buffer1 = \\" + buffer1 + "\\" );
15         Console.WriteLine( "buffer2 = \\" + buffer2 + "\\" );
16         Console.WriteLine( "buffer3 = \\" + buffer3 + "\\" );
17     } // end Main
18 } // end class StringBuilderConstructor
```

```
buffer1 = ""
buffer2 = ""
buffer3 = "hello"
```

**Fig. 16.9** | `StringBuilder` class constructors.

## 16.11 Length and Capacity Properties, EnsureCapacity Method and Indexer of Class `StringBuilder`

Class `StringBuilder` provides the `Length` and `Capacity` properties to return the number of characters currently in a `StringBuilder` and the number of characters that a `StringBuilder` can store without allocating more memory, respectively. These properties also can increase or decrease the length or the capacity of the `StringBuilder`. Method `EnsureCapacity` allows you to reduce the number of times that a `StringBuilder`'s capacity must be increased. The method ensures that the `StringBuilder`'s capacity is at least the specified value. The program in Fig. 16.10 demonstrates these methods and properties.

```

1 // Fig. 16.10: StringBuilderFeatures.cs
2 // Demonstrating some features of class StringBuilder.
3 using System;
4 using System.Text;
5
6 class StringBuilderFeatures
7 {
```

**Fig. 16.10** | `StringBuilder` size manipulation. (Part 1 of 2.)

```

8  public static void Main( string[] args )
9  {
10     StringBuilder buffer =
11         new StringBuilder( "Hello, how are you?" );
12
13     // use Length and Capacity properties
14     Console.WriteLine( "buffer = " + buffer +
15         "\nLength = " + buffer.Length +
16         "\nCapacity = " + buffer.Capacity );
17
18     buffer.EnsureCapacity( 75 ); // ensure a capacity of at least 75
19     Console.WriteLine( "\nNew capacity = " +
20         buffer.Capacity );
21
22     // truncate StringBuilder by setting Length property
23     buffer.Length = 10;
24     Console.WriteLine( "\nNew length = " +
25         buffer.Length + "\nbuffer = " );
26
27     // use StringBuilder indexer
28     for ( int i = 0; i < buffer.Length; ++i )
29         Console.Write( buffer[ i ] );
30
31     Console.WriteLine( "\n" );
32 } // end Main
33 } // end class StringBuilderFeatures

```

```

buffer = Hello, how are you?
Length = 19
Capacity = 19
New capacity = 75
New length = 10
buffer = Hello, how

```

**Fig. 16.10 |** *StringBuilder* size manipulation. (Part 2 of 2.)

The program contains one *StringBuilder*, called *buffer*. Lines 10–11 of the program use the *StringBuilder* constructor that takes a *string* argument to instantiate the *StringBuilder* and initialize its value to "Hello, how are you?". Lines 14–16 output the content, length and capacity of the *StringBuilder*.

Line 18 expands the capacity of the *StringBuilder* to a minimum of 75 characters. If new characters are added to a *StringBuilder* so that its length exceeds its capacity, the capacity *grows* to accommodate the additional characters in the same manner as if method *EnsureCapacity* had been called.

Line 23 uses property *Length* to set the length of the *StringBuilder* to 10—this does *not* change the *Capacity*. If the specified length is less than the current number of characters in the *StringBuilder*, the contents of the *StringBuilder* are *truncated* to the specified length. If the specified length is greater than the number of characters currently in the *StringBuilder*, null characters (that is, '\0' characters) are appended to the *StringBuilder* until the total number of characters in the *StringBuilder* is equal to the specified length.

## 16.12 Append and AppendFormat Methods of Class `StringBuilder`

Class `StringBuilder` provides 19 overloaded `Append` methods that allow various types of values to be added to the end of a `StringBuilder`. The Framework Class Library provides versions for each of the simple types and for character arrays, strings and objects. (Remember that method `ToString` produces a string representation of any object.) Each method takes an argument, converts it to a string and appends it to the `StringBuilder`. Figure 16.11 demonstrates the use of several `Append` methods.

```

1 // Fig. 16.11: StringBuilderAppend.cs
2 // Demonstrating StringBuilder Append methods.
3 using System;
4 using System.Text;
5
6 class StringBuilderAppend
7 {
8     public static void Main( string[] args )
9     {
10         object objectValue = "hello";
11         string stringValue = "good bye";
12         char[] characterArray = { 'a', 'b', 'c', 'd', 'e', 'f' };
13         bool booleanValue = true;
14         char characterValue = 'Z';
15         int integerValue = 7;
16         long longValue = 1000000;
17         float floatValue = 2.5F; // F suffix indicates that 2.5 is a float
18         double doubleValue = 33.333;
19         StringBuilder buffer = new StringBuilder();
20
21         // use method Append to append values to buffer
22         buffer.Append( objectValue );
23         buffer.Append( " " );
24         buffer.Append( stringValue );
25         buffer.Append( " " );
26         buffer.Append( characterArray );
27         buffer.Append( " " );
28         buffer.Append( characterArray, 0, 3 );
29         buffer.Append( " " );
30         buffer.Append( booleanValue );
31         buffer.Append( " " );
32         buffer.Append( characterValue );
33         buffer.Append( " " );
34         buffer.Append( integerValue );
35         buffer.Append( " " );
36         buffer.Append( longValue );
37         buffer.Append( " " );
38         buffer.Append( floatValue );
39         buffer.Append( " " );
40         buffer.Append( doubleValue );
41

```

**Fig. 16.11** | Append methods of `StringBuilder`. (Part 1 of 2.)

---

```

42     Console.WriteLine( "buffer = " + buffer.ToString() + "\n" );
43 } // end Main
44 } // end class StringBuilderAppend

```

```
buffer = hello  good bye  abcdef  abc  True  Z  7  1000000  2.5  33.333
```

**Fig. 16.11** | Append methods of `StringBuilder`. (Part 2 of 2.)

Lines 22–40 use 10 different overloaded `Append` methods to attach the string representations of objects created in lines 10–18 to the end of the `StringBuilder`.

Class `StringBuilder` also provides method `AppendFormat`, which converts a `string` to a specified format, then appends it to the `StringBuilder`. The example in Fig. 16.12 demonstrates the use of this method.

---

```

1 // Fig. 16.12: StringBuilderAppendFormat.cs
2 // Demonstrating method AppendFormat.
3 using System;
4 using System.Text;
5
6 class StringBuilderAppendFormat
7 {
8     public static void Main( string[] args )
9     {
10         StringBuilder buffer = new StringBuilder();
11
12         // formatted string
13         string string1 = "This {0} costs: {1:C}.\n";
14
15         // string1 argument array
16         object[] objectArray = new object[ 2 ];
17
18         objectArray[ 0 ] = "car";
19         objectArray[ 1 ] = 1234.56;
20
21         // append to buffer formatted string with argument
22         buffer.AppendFormat( string1, objectArray );
23
24         // formatted string
25         string string2 = "Number:{0:d3}.\n" +
26             "Number right aligned with spaces:{0, 4}.\n" +
27             "Number left aligned with spaces:{0, -4}." ;
28
29         // append to buffer formatted string with argument
30         buffer.AppendFormat( string2, 5 );
31
32         // display formatted strings
33         Console.WriteLine( buffer.ToString() );
34     } // end Main
35 } // end class StringBuilderAppendFormat

```

**Fig. 16.12** | `StringBuilder`'s `AppendFormat` method. (Part 1 of 2.)

```
This car costs: $1,234.56.
Number:005.
Number right aligned with spaces:   5.
Number left aligned with spaces:5  .
```

**Fig. 16.12** | `StringBuilder`'s `AppendFormat` method. (Part 2 of 2.)

Line 13 creates a `string` that contains formatting information. The information enclosed in braces specifies how to format a specific piece of data. Format items have the form `{X[,Y][:FormatString]}`, where `X` is the number of the argument to be formatted, counting from zero. `Y` is an optional argument, which can be positive or negative, indicating how many characters should be in the result. If the resulting `string` is less than the number `Y`, it will be padded with spaces to make up for the difference. A positive integer aligns the `string` to the right; a negative integer aligns it to the left. The optional `FormatString` applies a particular format to the argument—currency, decimal or scientific, among others. In this case, “`{0}`” means the first argument will be displayed. “`{1:C}`” specifies that the second argument will be formatted as a *currency* value.

Line 22 shows a version of `AppendFormat` that takes two parameters—a `string` specifying the format and an array of objects to serve as the arguments to the format `string`. The argument referred to by “`{0}`” is in the object array at index 0.

Lines 25–27 define another `string` used for formatting. The first format “`{0:d3}`”, specifies that the first argument will be formatted as a three-digit decimal, meaning that any number having fewer than three digits will have leading zeros placed in front to make up the difference. The next format, “`{0, 4}`”, specifies that the formatted `string` should have four characters and be right aligned. The third format, “`{0, -4}`”, specifies that the formatted `string` should be aligned to the left.

Line 30 uses a version of `AppendFormat` that takes two parameters—a `string` containing a format and an object to which the format is applied. In this case, the object is the number 5. The output of Fig. 16.12 displays the result of applying these two versions of `AppendFormat` with their respective arguments.

## 16.13 Insert, Remove and Replace Methods of Class `StringBuilder`

Class `StringBuilder` provides 18 overloaded `Insert` methods to allow various types of data to be inserted at any position in a `StringBuilder`. The class provides versions for each of the simple types and for character arrays, `strings` and `objects`. Each method takes its second argument, converts it to a `string` and inserts the `string` into the `StringBuilder` in front of the character in the position specified by the first argument. The index specified by the first argument must be greater than or equal to 0 and less than the length of the `StringBuilder`; otherwise, the program throws an `ArgumentOutOfRangeException`.

Class `StringBuilder` also provides method `Remove` for deleting any portion of a `StringBuilder`. Method `Remove` takes two arguments—the index at which to begin deletion and the number of characters to delete. The sum of the starting index and the number of characters to be deleted must always be less than the length of the `StringBuilder`; otherwise, the program throws an `ArgumentOutOfRangeException`. The `Insert` and `Remove` methods are demonstrated in Fig. 16.13.

```

1 // Fig. 16.13: StringBuilderInsertRemove.cs
2 // Demonstrating methods Insert and Remove of the
3 // StringBuilder class.
4 using System;
5 using System.Text;
6
7 class StringBuilderInsertRemove
8 {
9     public static void Main( string[] args )
10    {
11        object objectValue = "hello";
12        string stringValue = "good bye";
13        char[] characterArray = { 'a', 'b', 'c', 'd', 'e', 'f' };
14        bool booleanValue = true;
15        char characterValue = 'K';
16        int integerValue = 7;
17        long longValue = 10000000;
18        float floatValue = 2.5F; // F suffix indicates that 2.5 is a float
19        double doubleValue = 33.333;
20        StringBuilder buffer = new StringBuilder();
21
22        // insert values into buffer
23        buffer.Insert( 0, objectValue );
24        buffer.Insert( 0, " " );
25        buffer.Insert( 0, stringValue );
26        buffer.Insert( 0, " " );
27        buffer.Insert( 0, characterArray );
28        buffer.Insert( 0, " " );
29        buffer.Insert( 0, booleanValue );
30        buffer.Insert( 0, " " );
31        buffer.Insert( 0, characterValue );
32        buffer.Insert( 0, " " );
33        buffer.Insert( 0, integerValue );
34        buffer.Insert( 0, " " );
35        buffer.Insert( 0, longValue );
36        buffer.Insert( 0, " " );
37        buffer.Insert( 0, floatValue );
38        buffer.Insert( 0, " " );
39        buffer.Insert( 0, doubleValue );
40        buffer.Insert( 0, " " );
41
42        Console.WriteLine( "buffer after Inserts: \n" + buffer + "\n" );
43
44        buffer.Remove( 10, 1 ); // delete 2 in 2.5
45        buffer.Remove( 4, 4 ); // delete .333 in 33.333
46
47        Console.WriteLine( "buffer after Removes:\n" + buffer );
48    } // end Main
49 } // end class StringBuilderInsertRemove

```

```

buffer after Inserts:
33.333 2.5 10000000 7 K True abcdef good bye hello

```

**Fig. 16.13** | StringBuilder text insertion and removal. (Part I of 2.)

```
buffer after Removes:
33 .5 10000000 7 K True abcdef good bye hello
```

**Fig. 16.13** | *StringBuilder* text insertion and removal. (Part 2 of 2.)

Another useful method included with *StringBuilder* is *Replace*. *Replace* searches for a specified string or character and *substitutes* another string or character in its place. Figure 16.14 demonstrates this method.

```

1 // Fig. 16.14: StringBuilderReplace.cs
2 // Demonstrating method Replace.
3 using System;
4 using System.Text;
5
6 class StringBuilderReplace
7 {
8     public static void Main( string[] args )
9     {
10        StringBuilder builder1 =
11            new StringBuilder( "Happy Birthday Jane" );
12        StringBuilder builder2 =
13            new StringBuilder( "goodbye greg" );
14
15        Console.WriteLine( "Before replacements:\n" +
16            builder1.ToString() + "\n" + builder2.ToString() );
17
18        builder1.Replace( "Jane", "Greg" );
19        builder2.Replace( 'g', 'G', 0, 5 );
20
21        Console.WriteLine( "\nAfter replacements:\n" +
22            builder1.ToString() + "\n" + builder2.ToString() );
23    } // end Main
24 } // end class StringBuilderReplace
```

```
Before Replacements:
Happy Birthday Jane
good bye greg
```

```
After replacements:
Happy Birthday Greg
Goodbye greg
```

**Fig. 16.14** | *StringBuilder* text replacement.

Line 18 uses method *Replace* to replace all instances of "Jane" with the "Greg" in *builder1*. Another overload of this method takes two characters as parameters and *replaces* each occurrence of the first character with the second. Line 19 uses an overload of *Replace* that takes four parameters, of which the first two can both be characters or both be strings and the second two are *ints*. The method replaces all instances of the first character with the second character (or the first *string* with the second), beginning at the index specified by the first *int* and continuing for a count specified by the second *int*. Thus, in this case,

Replace looks through only five characters, starting with the character at index 0. As the output illustrates, this version of Replace replaces g with G in the word "good", but not in "greg". This is because the gs in "greg" are not in the range indicated by the int arguments (i.e., between indexes 0 and 4).

## 16.14 Char Methods

C# provides a concept called a **struct** (short for “structure”) that’s similar to a class. Although structs and classes are comparable, structs represent value types. Like classes, structs can have methods and properties, and can use the access modifiers **public** and **private**. Also, struct members are accessed via the *member access operator* (**.**).

The simple types are actually aliases for struct types. For instance, an **int** is defined by **struct System.Int32**, a **long** by **System.Int64** and so on. All struct types derive from class **ValueType**, which derives from **object**. Also, all struct types are implicitly **sealed**, so they do not support **virtual** or **abstract** methods, and their members cannot be declared **protected** or **protected internal**.

In the struct **System.Char**,<sup>2</sup> which is the struct for characters, most methods are **static**, take at least one character argument and perform either a test or a manipulation on the character. We present several of these methods in the next example. Figure 16.15 demonstrates **static** methods that test characters to determine whether they’re of a specific character type and **static** methods that perform case conversions on characters.

---

```

1 // Fig. 16.15: StaticCharMethods.cs
2 // Demonstrates static character-testing and case-conversion methods
3 // from Char struct
4 using System;
5
6 class StaticCharMethods
7 {
8     static void Main( string[] args )
9     {
10         Console.Write( "Enter a character: " );
11         char character = Convert.ToChar( Console.ReadLine() );
12
13         Console.WriteLine( "is digit: {0}", Char.IsDigit( character ) );
14         Console.WriteLine( "is letter: {0}", Char.IsLetter( character ) );
15         Console.WriteLine( "is letter or digit: {0}",
16             Char.IsLetterOrDigit( character ) );
17         Console.WriteLine( "is lower case: {0}",
18             Char.IsLower( character ) );
19         Console.WriteLine( "is upper case: {0}",
20             Char.IsUpper( character ) );
21         Console.WriteLine( "to upper case: {0}",
22             Char.ToUpper( character ) );
23         Console.WriteLine( "to lower case: {0}",
24             Char.ToLower( character ) );

```

---

**Fig. 16.15** | Char’s static character-testing and case-conversion methods. (Part I of 3.)

- 
2. Just as keyword **string** is an alias for class **String**, keyword **char** is an alias for struct **Char**. In this text, we use the term **Char** when calling a **static** method of struct **Char** and the term **char** elsewhere.

```
25     Console.WriteLine( "is punctuation: {0}",  
26         Char.IsPunctuation( character ) );  
27     Console.WriteLine( "is symbol: {0}", Char.IsSymbol( character ) );  
28 } // end Main  
29 } // end class StaticCharMethods
```

```
Enter a character: A  
is digit: False  
is letter: True  
is letter or digit: True  
is lower case: False  
is upper case: True  
to upper case: A  
to lower case: a  
is punctuation: False  
is symbol: False
```

```
Enter a character: 8  
is digit: True  
is letter: False  
is letter or digit: True  
is lower case: False  
is upper case: False  
to upper case: 8  
to lower case: 8  
is punctuation: False  
is symbol: False
```

```
Enter a character: @  
is digit: False  
is letter: False  
is letter or digit: False  
is lower case: False  
is upper case: False  
to upper case: @  
to lower case: @  
is punctuation: True  
is symbol: False
```

```
Enter a character: m  
is digit: False  
is letter: True  
is letter or digit: True  
is lower case: True  
is upper case: False  
to upper case: M  
to lower case: m  
is punctuation: False  
is symbol: False
```

**Fig. 16.15** | Char's static character-testing and case-conversion methods. (Part 2 of 3.)

```
Enter a character: +
is digit: False
is letter: False
is letter or digit: False
is lower case: False
is upper case: False
to upper case: +
to lower case: +
is punctuation: False
is symbol: True
```

**Fig. 16.15** | Char's static character-testing and case-conversion methods. (Part 3 of 3.)

After the user enters a character, lines 13–27 analyze it. Line 13 uses Char method `IsDigit` to determine whether character is defined as a digit. If so, the method returns `true`; otherwise, it returns `false` (note again that `bool` values are output capitalized). Line 14 uses Char method `IsLetter` to determine whether character `character` is a letter. Line 16 uses Char method `IsLetterOrDigit` to determine whether character `character` is a letter or a digit.

Line 18 uses Char method `IsLower` to determine whether character `character` is a *lowercase* letter. Line 20 uses Char method `IsUpper` to determine whether character `character` is an *uppercase* letter. Line 22 uses Char method `ToUpper` to convert character `character` to its *uppercase* equivalent. The method returns the converted character if the character has an uppercase equivalent; otherwise, the method returns its *original* argument. Line 24 uses Char method `ToLower` to convert character `character` to its *lowercase* equivalent. The method returns the converted character if the character has a lowercase equivalent; otherwise, the method returns its *original* argument.

Line 26 uses Char method `IsPunctuation` to determine whether character is a punctuation mark, such as "!", ":" or ")". Line 27 uses Char method `IsSymbol` to determine whether character `character` is a symbol, such as "+", "=" or "^".

Structure type `Char` also contains other methods not shown in this example. Many of the `static` methods are similar—for instance, `IsWhiteSpace` is used to determine whether a certain character is a whitespace character (e.g., newline, tab or space). The struct also contains several `public` instance methods; many of these, such as methods `ToString` and `Equals`, are methods that we have seen before in other classes. This group includes method `CompareTo`, which is used to compare one character value with another.

## 16.15 (Online) Introduction to Regular Expressions

This online section is available via the book's Companion Website at

[www.pearsonhighered.com/deitel](http://www.pearsonhighered.com/deitel)

In this section, we introduce **regular expressions**—specially formatted strings used to find patterns in text. They can be used to ensure that data is in a particular format. For example, a U.S. zip code must consist of five digits, or five digits followed by a dash followed by four more digits. Compilers use regular expressions to *validate* program syntax. If the program code does *not* match the regular expression, the compiler indicates that there's a syntax error. We discuss classes `Regex` and `Match` from the `System.Text.RegularExpressions`

namespace as well as the symbols used to form regular expressions. We then demonstrate how to find patterns in a string, match entire strings to patterns, replace characters in a string that match a pattern and split strings at delimiters specified as a pattern in a regular expression.

## 16.16 Wrap-Up

In this chapter, you learned about the Framework Class Library's string- and character-processing capabilities. We overviewed the fundamentals of characters and strings. You saw how to determine the length of strings, copy strings, access the individual characters in strings, search strings, obtain substrings from larger strings, compare strings, concatenate strings, replace characters in strings and convert strings to uppercase or lowercase letters.

We showed how to use class `StringBuilder` to build strings dynamically. You learned how to determine and specify the size of a `StringBuilder` object, and how to append, insert, remove and replace characters in a `StringBuilder` object. We then introduced the character-testing methods of type `Char` that enable a program to determine whether a character is a digit, a letter, a lowercase letter, an uppercase letter, a punctuation mark or a symbol other than a punctuation mark, and the methods for converting a character to uppercase or lowercase.

In the online Regex section, we discussed classes `Regex`, `Match` and `MatchCollection` from namespace `System.Text.RegularExpressions` and the symbols that are used to form regular expressions. You learned how to find patterns in a `string` and match entire `strings` to patterns with `Regex` methods `Match` and `Matches`, how to replace characters in a `string` with `Regex` method `Replace` and how to split `strings` at delimiters with `Regex` method `Split`. In the next chapter, you'll learn how to read data from and write data to files.

## Summary

### *Section 16.2 Fundamentals of Characters and Strings*

- Characters are the fundamental building blocks of C# program code. Every program is composed of a sequence of characters that's interpreted by the compiler as a series of instructions used to accomplish a task.
- A `string` is a series of characters treated as a single unit. A `string` may include letters, digits and the various special characters: `+`, `-`, `*`, `/`, `$` and others.

### *Section 16.3 string Constructors*

- Class `string` provides eight constructors.
- All `strings` are immutable—their character contents cannot be changed after they're created.

### *Section 16.4 string Indexer, Length Property and CopyTo Method*

- Property `Length` determines the number of characters in a `string`.
- The `string` indexer receives an integer argument as the *position number* and returns the character at that position. The first element of a `string` is considered to be at position 0.
- Attempting to access a character that's outside a `string`'s bounds results in an `IndexOutOfRangeException`.
- Method `CopyTo` copies a specified number of characters from a `string` into a `char` array.

**Section 16.5 Comparing strings**

- When the computer compares two strings, it uses word sorting rules that depend on the computer's currently selected culture.
- Method Equals and the overloaded equality operator (==) can each be used to compare the contents of two strings.
- Method CompareTo returns 0 if the strings are equal, a negative number if the string that invokes CompareTo is less than the string passed as an argument and a positive number if the string that invokes CompareTo is greater than the string passed as an argument.
- string methods StartsWith and EndsWith determine whether a string starts or ends with the characters specified as an argument, respectively.

**Section 16.6 Locating Characters and Substrings in strings**

- string method IndexOf locates the first occurrence of a character or a substring in a string. Method LastIndexOf locates the last occurrence of a character or a substring in a string.

**Section 16.7 Extracting Substrings from strings**

- Class string provides two Substring methods to enable a new string to be created by copying part of an existing string.

**Section 16.8 Concatenating strings**

- The static method Concat of class string concatenates two strings and returns a new string containing the characters from both original strings.

**Section 16.10 Class StringBuilder**

- Once a string is created, its contents can never change. Class StringBuilder (namespace System.Text) is available for creating and manipulating strings that can change.

**Section 16.11 Length and Capacity Properties, EnsureCapacity Method and Indexer of Class StringBuilder**

- Class StringBuilder provides Length and Capacity properties to return, respectively, the number of characters currently in a StringBuilder and the number of characters that can be stored in a StringBuilder without allocating more memory. These properties also can be used to increase or decrease the length or the capacity of the StringBuilder.
- Method EnsureCapacity allows you to guarantee that a StringBuilder has a minimum capacity.

**Section 16.12 Append and AppendFormat Methods of Class StringBuilder**

- Class StringBuilder provides Append methods to allow various types of values to be added to the end of a StringBuilder.
- Format items have the form {X[,Y][:FormatString]}. X is the number of the argument to be formatted, counting from zero. Y is an optional positive or negative argument that indicates how many characters should be in the result of formatting. If the resulting string has fewer characters than this number, it will be padded with spaces. A positive integer means the string will be right aligned; a negative one means the string will be left aligned. The optional FormatString indicates other formatting to apply—currency, decimal or scientific, among others.

**Section 16.13 Insert, Remove and Replace Methods of Class StringBuilder**

- Class StringBuilder provides 18 overloaded Insert methods to allow various types of values to be inserted at any position in a StringBuilder. Versions are provided for each of the simple types and for character arrays, strings and Objects.
- Class StringBuilder also provides method Remove for deleting any portion of a StringBuilder.

- `StringBuilder` method `Replace` searches for a specified `string` or character and substitutes another in its place.

### **Section 16.14 Char Methods**

- C# provides a concept called a `struct` (short for structure) that's similar to a class.
- `structs` represent value types.
- `structs` can have methods and properties and can use the access modifiers `public` and `private`.
- `struct` members are accessed via the member-access operator (`.`).
- The simple types are actually aliases for `struct` types.
- All `struct` types derive from class `ValueType`, which in turn derives from `object`.
- All `struct` types are implicitly `sealed`, so they do not support `virtual` or `abstract` methods, and their members cannot be declared `protected` or `protected internal`.
- `Char` is a `struct` that represents characters.
- Method `Char.IsDigit` determines whether a character is a defined Unicode digit.
- Method `Char.IsLetter` determines whether a character is a letter.
- Method `Char.IsLetterOrDigit` determines whether a character is a letter or a digit.
- Method `Char.ToLower` determines whether a character is a lowercase letter.
- Method `Char.ToUpper` determines whether a character is an uppercase letter.
- Method `Char.ToUpper` converts a lowercase character to its uppercase equivalent.
- Method `Char.ToLower` converts an uppercase character to its lowercase equivalent.
- Method `Char.IsPunctuation` determines whether a character is a punctuation mark.
- Method `Char.IsSymbol` determines whether a character is a symbol.
- Method `Char.IsWhiteSpace` determines whether a character is a whitespace character.
- Method `Char.CompareTo` compares two character values.

## **Terminology**

|                                                                        |                                                                  |
|------------------------------------------------------------------------|------------------------------------------------------------------|
| @ verbatim string character                                            | format string                                                    |
| + operator                                                             | immutable string                                                 |
| += concatenation operator                                              | <code>IndexOf</code> method of class <code>string</code>         |
| == equality operator                                                   | <code>IndexOfAny</code> method of class <code>string</code>      |
| alphabetizing                                                          | <code>Insert</code> method of class <code>StringBuilder</code>   |
| <code>Append</code> method of class <code>StringBuilder</code>         | <code>IsDigit</code> method of struct <code>Char</code>          |
| <code>AppendFormat</code> method of class <code>StringBuilder</code>   | <code>IsLetter</code> method of struct <code>Char</code>         |
| <code>Capacity</code> property of <code>StringBuilder</code>           | <code>IsLetterOrDigit</code> method of struct <code>Char</code>  |
| char array                                                             | <code>IsLower</code> method of struct <code>Char</code>          |
| <code>Char</code> struct                                               | <code>IsPunctuation</code> method of struct <code>Char</code>    |
| character                                                              | <code>IsSymbol</code> method of struct <code>Char</code>         |
| character constant                                                     | <code>IsUpper</code> method of struct <code>Char</code>          |
| <code>CompareTo</code> method of class <code>string</code>             | <code>IsWhiteSpace</code> method of struct <code>Char</code>     |
| <code>CompareTo</code> method of struct <code>Char</code>              | <code>LastIndexOf</code> method of class <code>string</code>     |
| <code>Concat</code> method of class <code>string</code>                | <code>LastIndexOfAny</code> method of class <code>string</code>  |
| <code>CopyTo</code> method of class <code>string</code>                | <code>Length</code> property of class <code>string</code>        |
| <code>EndsWith</code> method of class <code>string</code>              | <code>Length</code> property of class <code>StringBuilder</code> |
| <code>EnsureCapacity</code> method of class <code>StringBuilder</code> | <code>Remove</code> method of class <code>StringBuilder</code>   |
| <code>Equals</code> method of class <code>string</code>                | <code>Replace</code> method of class <code>string</code>         |
| <code>Equals</code> method of struct <code>Char</code>                 | <code>Replace</code> method of class <code>StringBuilder</code>  |

|                                                            |                                                            |
|------------------------------------------------------------|------------------------------------------------------------|
| StartsWith method of class <code>string</code>             | <code>ToLower</code> method of struct <code>Char</code>    |
| <code>string</code> class                                  | <code>ToString</code> method of class <code>string</code>  |
| string literal                                             | <code>ToString</code> method of <code>StringBuilder</code> |
| string reference                                           | <code>ToUpper</code> method of class <code>string</code>   |
| <code>StringBuilder</code> class                           | <code>ToUpper</code> method of struct <code>Char</code>    |
| <code>struct</code> keyword                                | trailing whitespace characters                             |
| <code>Substring</code> method of class <code>string</code> | <code>Trim</code> method of class <code>string</code>      |
| <code>System</code> namespace                              | Unicode character set                                      |
| <code>System.Text</code> namespace                         | <code>ValueType</code> class                               |
| <code>ToLower</code> method of class <code>string</code>   | verbatim string syntax                                     |

## Self-Review Exercises

- 16.1** State whether each of the following is *true* or *false*. If *false*, explain why.
- When `strings` are compared with `==`, the result is `true` if the `strings` contain the same values.
  - A `string` can be modified after it's created.
  - `StringBuilder` method `EnsureCapacity` sets the `StringBuilder` instance's length to the argument's value.
  - Method `Equals` and the equality operator work the same for `strings`.
  - Method `Trim` removes all whitespace at the beginning and the end of a `string`.
  - It's always better to use `strings`, rather than `StringBuilders`, because `strings` containing the same value will reference the same object.
  - `string` method `ToUpper` creates a new `string` with the first letter capitalized.
- 16.2** Fill in the blanks in each of the following statements:
- To concatenate `strings`, use operator \_\_\_\_\_, `StringBuilder` method \_\_\_\_\_ or `string` method \_\_\_\_\_.
  - `StringBuilder` method \_\_\_\_\_ first formats the specified `string`, then concatenates it to the end of the `StringBuilder`.
  - If the arguments to a `Substring` method call are out of range, a(n) \_\_\_\_\_ exception is thrown.
  - A C in a format string means to output the number as \_\_\_\_\_.

## Answers to Self-Review Exercises

- 16.1** a) True. b) False. `strings` are immutable; they cannot be modified after they're created. `StringBuilder` objects can be modified after they're created. c) False. `EnsureCapacity` simply ensures that the current capacity is at least the value specified in the method call. d) True. e) True. f) False. `StringBuilder` should be used if the `string` is to be modified. g) False. `string` method `ToUpper` creates a new `string` with all of its letters capitalized.

- 16.2** a) `+`, `Append`, `Concat`. b) `AppendFormat` c) `ArgumentOutOfRangeException`. d) currency.

## Exercises

- 16.3** (*Comparing strings*) Write an app that uses `string` method `CompareTo` to compare two `strings` input by the user. Output whether the first `string` is less than, equal to or greater than the second.
- 16.4** (*Random Sentences and Story Writer*) Write an app that uses random-number generation to create sentences. Use four arrays of `strings`, called `article`, `noun`, `verb` and `preposition`. Create

a sentence by selecting a word at random from each array in the following order: article, noun, verb, preposition, article, noun. As each word is picked, concatenate it to the previous words in the sentence. The words should be separated by spaces. When the sentence is output, it should start with a capital letter and end with a period. The program should generate 10 sentences and output them to a text box.

The arrays should be filled as follows: The `article` array should contain the articles "the", "a", "one", "some" and "any"; the `noun` array should contain the nouns "boy", "girl", "dog", "town" and "car"; the `verb` array should contain the past-tense verbs "drove", "jumped", "ran", "walked" and "skipped"; and the `preposition` array should contain the prepositions "to", "from", "over", "under" and "on".

**16.5** (*Pig Latin*) Write an app that encodes English-language phrases into pig Latin. Pig Latin is a form of coded language often used for amusement. Many variations exist in the methods used to form pig Latin phrases. For simplicity, use the following algorithm:

To translate each English word into a pig Latin word, place the first letter of the English word at the end of the word and add the letters "ay." Thus, the word "jump" becomes "umpjay," the word "the" becomes "hetay" and the word "computer" becomes "omputercay." Blanks between words remain blanks. Assume the following: The English phrase consists of words separated by blanks, there are no punctuation marks and all words have two or more letters. Enable the user to input a sentence. Use techniques discussed in this chapter to divide the sentence into separate words. Method `GetPigLatin` should translate a single word into pig Latin. Keep a running display of all the converted sentences in a text box.

**16.6** (*All Possible Three-Letter Words from a Five-Letter Word*) Write a program that reads a five-letter word from the user and produces all possible three-letter combinations that can be derived from the letters of the five-letter word. For example, the three-letter words produced from the word "bathe" include the commonly used words "ate," "bat," "bet," "tab," "hat," "the" and "tea," and the 3-letter combinations "bth," "eab," etc.

**16.7** (*Capitalizing Words*) Write a program that uses regular expressions to convert the first letter of every word to uppercase. Have it do this for an arbitrary string input by the user.

## Making a Difference Exercises

**16.8** (*Project: Cooking with Healthier Ingredients*) Obesity in the United States is increasing at an alarming rate. Check the map from the Centers for Disease Control and Prevention (CDC) at [www.cdc.gov/obesity/data/facts.html](http://www.cdc.gov/obesity/data/facts.html), which shows obesity trends in the United States over the last 20 years. As obesity increases, so do occurrences of related problems (e.g., heart disease, high blood pressure, high cholesterol, type 2 diabetes). Write a program that helps users choose healthier ingredients when cooking, and helps those allergic to certain foods (e.g., nuts, gluten) find substitutes. The program should read a recipe from the user and suggest healthier replacements for some of the ingredients. For simplicity, your program should assume the recipe has no abbreviations for measures such as teaspoons, cups, and tablespoons, and uses numerical digits for quantities (e.g., 1 egg, 2 cups) rather than spelling them out (one egg, two cups). Some common substitutions are shown in Fig. 16.16. Your program should display a warning such as, "Always consult your physician before making significant changes to your diet."

Your program should take into consideration that replacements are not always one-for-one. For example, if a cake recipe calls for three eggs, it might reasonably use six egg whites instead. Conversion data for measurements and substitutes can be obtained at websites such as:

[chinesefood.about.com/od/recipeconversionfaqs/f/usmetricrecipes.htm](http://chinesefood.about.com/od/recipeconversionfaqs/f/usmetricrecipes.htm)  
[www.pioneerthinking.com/eggsub.html](http://www.pioneerthinking.com/eggsub.html)  
[www.gourmetsleuth.com/conversions.htm](http://www.gourmetsleuth.com/conversions.htm)

| Ingredient             | Substitution                                                                                                       |
|------------------------|--------------------------------------------------------------------------------------------------------------------|
| 1 cup sour cream       | 1 cup yogurt                                                                                                       |
| 1 cup milk             | 1/2 cup evaporated milk and 1/2 cup water                                                                          |
| 1 teaspoon lemon juice | 1/2 teaspoon vinegar                                                                                               |
| 1 cup sugar            | 1/2 cup honey, 1 cup molasses<br>or 1/4 cup agave nectar                                                           |
| 1 cup butter           | 1 cup margarine or yogurt                                                                                          |
| 1 cup flour            | 1 cup rye or rice flour                                                                                            |
| 1 cup mayonnaise       | 1 cup cottage cheese<br>or 1/8 cup mayonnaise and 7/8 cup yogurt                                                   |
| 1 egg                  | 2 tablespoons cornstarch, arrowroot flour<br>or potato starch or 2 egg whites<br>or 1/2 of a large banana (mashed) |
| 1 cup milk             | 1 cup soy milk                                                                                                     |
| 1/4 cup oil            | 1/4 cup applesauce                                                                                                 |
| white bread            | whole-grain bread                                                                                                  |
| 1 cup sour cream       | 1 cup yogurt                                                                                                       |

**Fig. 16.16** | Common ingredient substitutions.

Your program should consider the user's health concerns, such as high cholesterol, high blood pressure, weight loss, gluten allergy, and so on. For high cholesterol, the program should suggest substitutes for eggs and dairy products; if the user wishes to lose weight, low-calorie substitutes for ingredients such as sugar should be suggested.

**16.9** (*Project: Spam Scanner*) Spam (or junk e-mail) costs U.S. organizations billions of dollars a year in spam-prevention software, equipment, network resources, bandwidth, and lost productivity. Research online some of the most common spam e-mail messages and words, and check your own junk e-mail folder. Create a list of 30 words and phrases commonly found in spam messages. Write an app in which the user enters an e-mail message. Then, scan the message for each of the 30 keywords or phrases. For each occurrence of one of these within the message, add a point to the message's "spam score." Next, rate the likelihood that the message is spam, based on the number of points it received.

**16.10** (*Project: SMS Language*) Short Message Service (SMS) is a communications service that allows sending text messages of 160 or fewer characters between mobile phones. With the proliferation of mobile phone use worldwide, SMS is being used in many developing nations for political purposes (e.g., voicing opinions and opposition), reporting news about natural disasters, and so on. For example, check out [comunica.org/radio2.0/archives/87](http://comunica.org/radio2.0/archives/87). Since the length of SMS messages is limited, SMS Language—abbreviations of common words and phrases in mobile text messages, e-mails, instant messages, etc.—is often used. For example, "in my opinion" is "IMO" in SMS Language. Research SMS Language online. Write a program in which the user can enter a message using SMS Language, then the program should translate it into English (or your own language). Also provide a mechanism to translate text written in English (or your own language) into SMS Language. One potential problem is that one SMS abbreviation could expand into a variety of phrases. For example, IMO (as used above) could also stand for "International Maritime Organization," "in memory of," etc.

# Files and Streams



*I can only assume that a “Do Not File” document is filed in a “Do Not File” file.*

—Senator Frank Church  
Senate Intelligence Subcommittee  
Hearing, 1975

*Consciousness ... does not appear to itself chopped up in bits. ... A “river” or a “stream” are the metaphors by which it is most naturally described.*

—William James

## Objectives

In this chapter you'll learn:

- To create, read, write and update files.
- To use classes `File` and `Directory` to obtain information about files and directories on your computer.
- To use LINQ to search through directories.
- To become familiar with sequential-access file processing.
- To use classes `FileStream`, `StreamReader` and `StreamWriter` to read text from and write text to files.
- To use classes `FileStream` and `BinaryFormatter` to read objects from and write objects to files.

- |                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>17.1</b> Introduction<br><b>17.2</b> Data Hierarchy<br><b>17.3</b> Files and Streams<br><b>17.4</b> Classes File and Directory<br><b>17.5</b> Creating a Sequential-Access Text File<br><b>17.6</b> Reading Data from a Sequential-Access Text File | <b>17.7</b> Case Study: Credit Inquiry Program<br><b>17.8</b> Serialization<br><b>17.9</b> Creating a Sequential-Access File Using Object Serialization<br><b>17.10</b> Reading and Deserializing Data from a Binary File<br><b>17.11</b> Wrap-Up |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#) | [Making a Difference Exercise](#)

## 17.1 Introduction

Variables and arrays offer only *temporary* storage of data—the data is lost when a local variable “goes out of scope” or when the program terminates. By contrast, **files** (and databases, which we cover in Chapter 22) are used for long-term retention of large amounts of data, even after the program that created the data terminates. Data maintained in files often is called **persistent data**. Computers store files on **secondary storage devices**, such as magnetic disks, optical disks, flash memory and magnetic tapes. In this chapter, we explain how to create, update and process data files in C# programs.

We begin with an overview of the data hierarchy from bits to files. Next, we overview some of the Framework Class Library’s file-processing classes. We then present examples that show how you can determine information about the files and directories on your computer. The remainder of the chapter shows how to write to and read from *text files* that are *human readable* and binary files that store entire objects in binary format.

## 17.2 Data Hierarchy

Ultimately, all data items that computers process are reduced to combinations of 0s and 1s. This occurs because it’s simple and economical to build electronic devices that can assume two stable states—one state represents 0 and the other represents 1. It’s remarkable that the impressive functions performed by computers involve only the most fundamental manipulations of 0s and 1s.

### Bits

The smallest data item that computers support is called a **bit** (short for “**binary digit**”—a digit that can assume one of *two* values). Each bit can assume either the value 0 or the value 1. Computer circuitry performs various simple **bit manipulations**, such as examining the value of a bit, setting the value of a bit and reversing a bit (from 1 to 0 or from 0 to 1).

### Characters

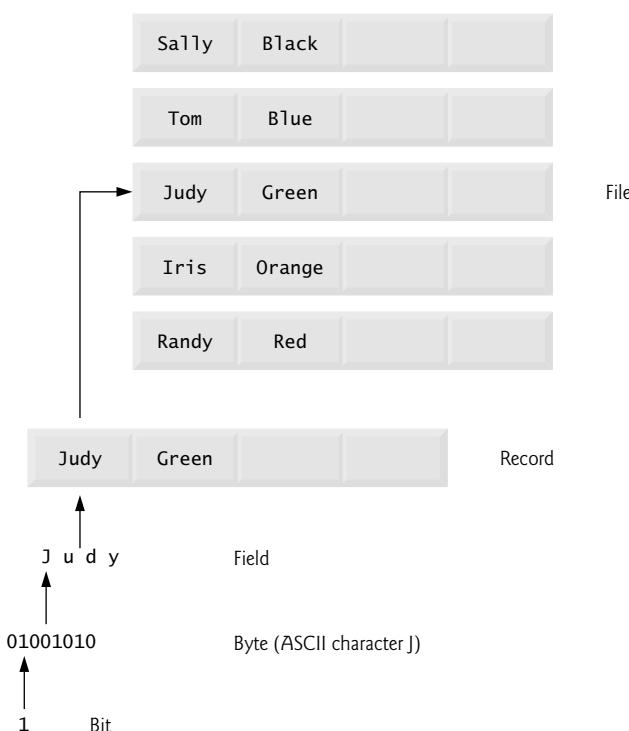
Programming with data in the low-level form of bits is cumbersome. It’s preferable to program with data in forms such as **decimal digits** (i.e., 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9), **letters** (i.e., A–Z and a–z) and **special symbols** (i.e., \$, @, %, &, \*, (, ), -, +, :, ?, / and many others). Digits, letters and special symbols are referred to as **characters**. The set of all characters used to write programs and represent data items on a particular computer is called

that computer's **character set**. Because computers can process only 0s and 1s, every character in a computer's character set is represented as a pattern of 0s and 1s. **Bytes** are composed of eight bits. C# uses the **Unicode® character set** ([www.unicode.org](http://www.unicode.org)). Programmers create programs and data items with characters; computers manipulate and process these characters as patterns of bits.

### Fields

Just as characters are composed of bits, fields are composed of characters. A **field** is a group of characters that conveys meaning. For example, a field consisting of uppercase and lowercase letters can represent a person's name.

Data items processed by computers form a **data hierarchy** (Fig. 17.1), in which data items become larger and more complex in structure as we progress from bits to characters to fields to larger data aggregates.



**Fig. 17.1** | Data hierarchy.

### Records and Files

Typically, a **record** (which can be represented as a **class**) is composed of several related fields. In a payroll system, for example, a record for a particular employee might include the following fields:

1. Employee identification number
2. Name

3. Address
4. Hourly pay rate
5. Number of exemptions claimed
6. Year-to-date earnings
7. Amount of taxes withheld

In the preceding example, each field is associated with the same employee. A file is a group of related records.<sup>1</sup> A company's payroll file normally contains one record for each employee. A payroll file for a small company might contain only 22 records, whereas one for a large company might contain 100,000. It's not unusual for a company to have many files, some containing millions, billions or even trillions of characters of information.

### *Record Key*

To facilitate the retrieval of specific records from a file, at least one field in each record is chosen as a **record key**, which identifies a record as belonging to a particular person or entity and distinguishes that record from all others. For example, in a payroll record, the employee identification number normally would be the record key.

### *Sequential Files*

There are many ways to organize records in a file. A common organization is called a **sequential file**, in which records typically are stored in order by a *record-key field*. In a payroll file, records usually are placed in order by employee identification number. The first employee record in the file contains the lowest employee identification number, and subsequent records contain increasingly higher ones.

### *Databases*

Most businesses use many different files to store data. For example, a company might have payroll files, accounts-receivable files (listing money due from clients), accounts-payable files (listing money due to suppliers), inventory files (listing facts about all the items handled by the business) and many other files. Related data are often stored in a **database**. A collection of programs designed to create and manage databases is called a **database management system (DBMS)**. We discuss databases in Chapter 22.

## 17.3 Files and Streams

C# views each file as a sequential stream of bytes (Fig. 17.2). Each file ends either with an **end-of-file marker** or at a specific byte number that's recorded in a system-maintained administrative data structure. When a file is opened, an object is created and a stream is associated with the object. When a console app executes, the runtime environment creates three stream objects that are accessible via properties **Console.Out**, **Console.In** and **Console.Error**, respectively. These objects use streams to facilitate communication between a program and a particular file or device. **Console.In** refers to the **standard input stream object**, which

---

1. Generally, a file can contain arbitrary data in arbitrary formats. In some operating systems, a file is viewed as nothing more than a collection of bytes, and any organization of the bytes in a file (such as organizing the data into records) is a view created by the app programmer.

enables a program to input data from the keyboard. `Console.Out` refers to the **standard output stream object**, which enables a program to output data to the screen. `Console.Error` refers to the **standard error stream object**, which enables a program to output error messages to the screen. We've been using `Console.Out` and `Console.In` in our console apps, `Console` methods `Write` and `WriteLine` use `Console.Out` to perform output, and `Console` methods `Read` and `ReadLine` use `Console.In` to perform input.



**Fig. 17.2** | C#'s view of an  $n$ -byte file.

There are many file-processing classes in the Framework Class Library. The `System.IO` namespace includes stream classes such as `StreamReader` (for text input from a file), `StreamWriter` (for text output to a file) and `FileStream` (for both input from and output to a file). These stream classes inherit from abstract classes `TextReader`, `TextWriter` and `Stream`, respectively. Actually, properties `Console.In` and `Console.Out` are of type `TextReader` and `TextWriter`, respectively. The system creates objects of `TextReader` and `TextWriter` derived classes to initialize `Console` properties `Console.In` and `Console.Out`.

Abstract class `Stream` provides functionality for representing streams as bytes. Classes `FileStream`, `MemoryStream` and `BufferedStream` (all from namespace `System.IO`) inherit from class `Stream`. Class `FileStream` can be used to write data to and read data from files. Class `MemoryStream` enables the transfer of data directly to and from memory—this is much faster than reading from and writing to external devices. Class `BufferedStream` uses **buffering** to transfer data to or from a stream. Buffering is an I/O performance-enhancement technique, in which each output operation is directed to a region in memory, called a **buffer**, that's large enough to hold the data from *many* output operations. Then actual transfer to the output device is performed in one large **physical output operation** each time the buffer fills. The output operations directed to the output buffer in memory often are called **logical output operations**. Buffering can also be used to speed input operations by initially reading more data than is required into a buffer, so subsequent reads get data from high-speed memory rather than a slower external device.

In this chapter, we use key stream classes to implement file-processing programs that create and manipulate sequential-access files.

## 17.4 Classes File and Directory

Information is stored in files, which are organized in directories (also called folders). Classes `File` and `Directory` enable programs to manipulate files and directories on disk. Class `File` can determine information about files and can be used to open files for reading or writing. We discuss techniques for writing to and reading from files in subsequent sections.

Figure 17.3 lists several of class `File`'s static methods for manipulating and determining information about files. We demonstrate several of these methods in Fig. 17.5.

| static Method     | Description                                                                                                                  |
|-------------------|------------------------------------------------------------------------------------------------------------------------------|
| AppendText        | Returns a <code>StreamWriter</code> that appends text to an existing file or creates a file if one does not exist.           |
| Copy              | Copies a file to a new file.                                                                                                 |
| Create            | Creates a file and returns its associated <code>FileStream</code> .                                                          |
| CreateText        | Creates a text file and returns its associated <code>StreamWriter</code> .                                                   |
| Delete            | Deletes the specified file.                                                                                                  |
| Exists            | Returns <code>true</code> if the specified file exists and <code>false</code> otherwise.                                     |
| GetCreationTime   | Returns a <code>DateTime</code> object representing when the file was created.                                               |
| GetLastAccessTime | Returns a <code>DateTime</code> object representing when the file was last accessed.                                         |
| GetLastWriteTime  | Returns a <code>DateTime</code> object representing when the file was last modified.                                         |
| Move              | Moves the specified file to a specified location.                                                                            |
| Open              | Returns a <code>FileStream</code> associated with the specified file and equipped with the specified read/write permissions. |
| OpenRead          | Returns a read-only <code>FileStream</code> associated with the specified file.                                              |
| OpenText          | Returns a <code>StreamReader</code> associated with the specified file.                                                      |
| OpenWrite         | Returns a write <code>FileStream</code> associated with the specified file.                                                  |

**Fig. 17.3** | File class static methods (partial list).

Class **Directory** provides capabilities for manipulating directories. Figure 17.4 lists some of class **Directory**'s static methods for directory manipulation. Figure 17.5 demonstrates several of these methods, as well. The  **DirectoryInfo** object returned by method **CreateDirectory** contains information about a directory. Much of the information contained in class  **DirectoryInfo** also can be accessed via the methods of class **Directory**.

| static Method     | Description                                                                                                |
|-------------------|------------------------------------------------------------------------------------------------------------|
| CreateDirectory   | Creates a directory and returns its associated <code> DirectoryInfo</code> object.                         |
| Delete            | Deletes the specified directory.                                                                           |
| Exists            | Returns <code>true</code> if the specified directory exists and <code>false</code> otherwise.              |
| GetDirectories    | Returns a <code>string</code> array containing the names of the subdirectories in the specified directory. |
| .GetFiles         | Returns a <code>string</code> array containing the names of the files in the specified directory.          |
| GetCreationTime   | Returns a <code>DateTime</code> object representing when the directory was created.                        |
| GetLastAccessTime | Returns a <code>DateTime</code> object representing when the directory was last accessed.                  |
| GetLastWriteTime  | Returns a <code>DateTime</code> object representing when items were last written to the directory.         |
| Move              | Moves the specified directory to a specified location.                                                     |

**Fig. 17.4** | Directory class static methods.

### Demonstrating Classes File and Directory

Class `FileTestForm` (Fig. 17.5) uses `File` and `Directory` methods to access file and directory information. The Form contains the `inputTextBox`, in which the user enters a file or directory name. For each key that the user presses while typing in the `TextBox`, the program calls `inputTextBox_KeyDown` (lines 19–75). If the user presses the *Enter* key (line 22), this method displays either the file's or directory's contents, depending on the text the user input. (If the user does not press the *Enter* key, this method returns without displaying any content.) Line 28 uses `File` method `Exists` to determine whether the user-specified text is the name of an existing file. If so, line 31 invokes private method `GetInformation` (lines 79–97), which calls `File` methods `GetCreationTime` (line 88), `GetLastWriteTime` (line 92) and `GetLastAccessTime` (line 96) to access file information. When method `GetInformation` returns, line 38 instantiates a `StreamReader` for reading text from the file. The `StreamReader` constructor takes as an argument a `string` containing the name and path of the file to open. Line 40 calls `StreamReader` method `ReadToEnd` to read the entire contents of the file as a `string`, then appends the `string` to `outputTextBox`. Once the file has been read, the `using` block terminates and disposes of the corresponding object, which closes the file.

```

1 // Fig. 17.5: FileTestForm.cs
2 // Using classes File and Directory.
3 using System;
4 using System.Windows.Forms;
5 using System.IO;
6
7 namespace FileTest
8 {
9     // displays contents of files and directories
10    public partial class FileTestForm : Form
11    {
12        // parameterless constructor
13        public FileTestForm()
14        {
15            InitializeComponent();
16        } // end constructor
17
18        // invoked when user presses key
19        private void inputTextBox_KeyDown( object sender, KeyEventArgs e )
20        {
21            // determine whether user pressed Enter key
22            if ( e.KeyCode == Keys.Enter )
23            {
24                // get user-specified file or directory
25                string fileName = inputTextBox.Text;
26
27                // determine whether fileName is a file
28                if ( File.Exists( fileName ) )
29                {
30                    // get file's creation date, modification date, etc.
31                    GetInformation( fileName );
32                    StreamReader stream = null; // declare StreamReader
33

```

**Fig. 17.5** | Using classes `File` and `Directory`. (Part I of 3.)

```
34          // display file contents through StreamReader
35      try
36      {
37          // obtain reader and file contents
38          using ( stream = new StreamReader( fileName ) )
39          {
40              outputTextBox.AppendText( stream.ReadToEnd() );
41          } // end using
42      } // end try
43      catch ( IOException )
44      {
45          MessageBox.Show( "Error reading from file",
46                          "File Error", MessageBoxButtons.OK,
47                          MessageBoxIcon.Error );
48      } // end catch
49  } // end if
50  // determine whether fileName is a directory
51 else if ( Directory.Exists( fileName ) )
52 {
53     // get directory's creation date,
54     // modification date, etc.
55     GetInformation( fileName );
56
57     // obtain directory list of specified directory
58     string[] directoryList =
59         Directory.GetDirectories( fileName );
60
61     outputTextBox.AppendText( "Directory contents:\n" );
62
63     // output directoryList contents
64     foreach ( var directory in directoryList )
65         outputTextBox.AppendText( directory + "\n" );
66 } // end else if
67 else
68 {
69     // notify user that neither file nor directory exists
70     MessageBox.Show( inputTextBox.Text +
71                     " does not exist", "File Error",
72                     MessageBoxButtons.OK, MessageBoxIcon.Error );
73 } // end else
74 } // end if
75 } // end method inputTextBox_KeyDown
76
77 // get information on file or directory,
78 // and output it to outputTextBox
79 private void GetInformation( string fileName )
80 {
81     outputTextBox.Clear();
82
83     // output that file or directory exists
84     outputTextBox.AppendText( fileName + " exists\n" );
85 }
```

---

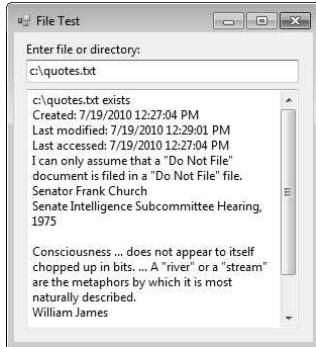
Fig. 17.5 | Using classes File and Directory. (Part 2 of 3.)

```

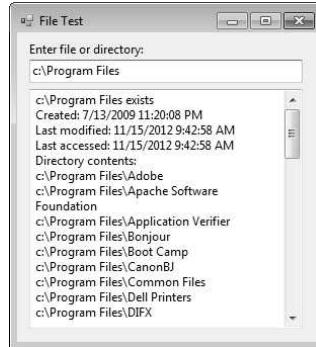
86         // output when file or directory was created
87         outputTextBox.AppendText( "Created: " +
88             File.GetCreationTime( fileName ) + "\n" );
89
90         // output when file or directory was last modified
91         outputTextBox.AppendText( "Last modified: " +
92             File.GetLastWriteTime( fileName ) + "\n" );
93
94         // output when file or directory was last accessed
95         outputTextBox.AppendText( "Last accessed: " +
96             File.GetLastAccessTime( fileName ) + "\n" );
97     } // end method GetInformation
98 } // end class FileTestForm
99 } // end namespace FileTest

```

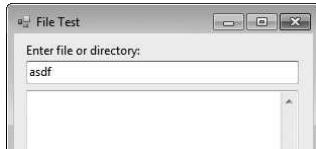
a) Viewing the contents of file "quotes.txt"



b) Viewing all files in directory C:\Program Files\



c) User gives invalid input



d) Error message is displayed

**Fig. 17.5** | Using classes File and Directory. (Part 3 of 3.)

If line 28 determines that the user-specified text is not a file, line 51 determines whether it's a directory using `Directory` method `Exists`. If the user specified an *existing* directory, line 55 invokes method `GetInformation` to access the directory information. Line 59 calls `Directory` method `GetDirectories` to obtain a `string` array containing the names of the subdirectories in the specified directory. Lines 64–65 display each element in the `string` array. Note that, if line 51 determines that the user-specified text is *not* a directory name, lines 70–72 notify the user (via a `MessageBox`) that the name the user entered does not exist as a file or directory.

### *Searching Directories with LINQ*

We now consider another example that uses file- and directory-manipulation capabilities. Class `LINQToFileDirectoryForm` (Fig. 17.6) uses LINQ with classes `File`, `Path` and

Directory to report the number of files of each file type that exist in the specified directory path. The program also serves as a “clean-up” utility—when it finds a file that has the .bak file-name extension (i.e., a *backup* file), the program displays a MessageBox asking the user whether that file should be removed, then responds appropriately to the user’s input. This example also uses *LINQ to Objects* to help delete the backup files.

When the user clicks **Search Directory**, the program invokes `searchButton_Click` (lines 25–65), which searches recursively through the directory path specified by the user. If the user inputs text in the `TextBox`, line 29 calls `Directory` method `Exists` to determine whether that text is a valid directory. If it’s not, lines 32–33 notify the user of the error.

---

```

1 // Fig. 17.6: LINQToFileDirectoryForm.cs
2 // Using LINQ to search directories and determine file types.
3 using System;
4 using System.Collections.Generic;
5 using System.Linq;
6 using System.Windows.Forms;
7 using System.IO;
8
9 namespace LINQToFileDirectory
10 {
11     public partial class LINQToFileDirectoryForm : Form
12     {
13         string currentDirectory; // directory to search
14
15         // store extensions found, and number of each extension found
16         Dictionary<string, int> found = new Dictionary<string, int>();
17
18         // parameterless constructor
19         public LINQToFileDirectoryForm()
20         {
21             InitializeComponent();
22         } // end constructor
23
24         // handles the Search Directory Button's Click event
25         private void searchButton_Click( object sender, EventArgs e )
26         {
27             // check whether user specified path exists
28             if ( pathTextBox.Text != string.Empty &&
29                 !Directory.Exists( pathTextBox.Text ) )
30             {
31                 // show error if user does not specify valid directory
32                 MessageBox.Show( "Invalid Directory", "Error",
33                                 MessageBoxButtons.OK, MessageBoxIcon.Error );
34             } // end if
35             else
36             {
37                 // use current directory if no directory is specified
38                 if ( pathTextBox.Text == string.Empty )
39                     currentDirectory = Directory.GetCurrentDirectory();

```

---

**Fig. 17.6** | Using LINQ to search directories and determine file types. (Part I of 4.)

```
40         else
41             currentDirectory = pathTextBox.Text;
42
43             directoryTextBox.Text = currentDirectory; // show directory
44
45             // clear TextBoxes
46             pathTextBox.Clear();
47             resultsTextBox.Clear();
48
49             SearchDirectory( currentDirectory ); // search the directory
50
51             // allow user to delete .bak files
52             CleanDirectory( currentDirectory );
53
54             // summarize and display the results
55             foreach ( var current in found.Keys )
56             {
57                 // display the number of files with current extension
58                 resultsTextBox.AppendText( string.Format(
59                     "* Found {0} {1} files.\r\n",
60                     found[ current ], current ) );
61             } // end foreach
62
63             found.Clear(); // clear results for new search
64         } // end else
65     } // end method searchButton_Click
66
67     // search directory using LINQ
68     private void SearchDirectory( string folder )
69     {
70         // files contained in the directory
71         string[] files = Directory.GetFiles( folder );
72
73         // subdirectories in the directory
74         string[] directories = Directory.GetDirectories( folder );
75
76         // find all file extensions in this directory
77         var extensions =
78             ( from file in files
79               select Path.GetExtension( file ) ).Distinct();
80
81         // count the number of files using each extension
82         foreach ( var extension in extensions )
83         {
84
85             // count the number of files with the extension
86             var extensionCount =
87                 ( from file in files
88                   where Path.GetExtension( file ) == extension
89                   select file ).Count();
90
91 }
```

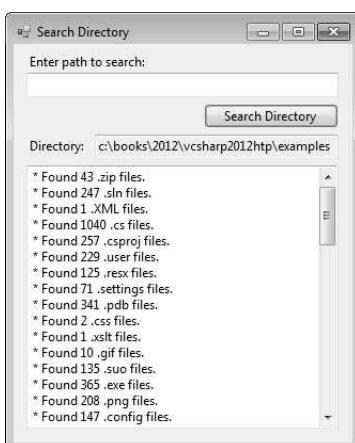
**Fig. 17.6** | Using LINQ to search directories and determine file types. (Part 2 of 4.)

```
92         // if the Dictionary already contains a key for the extension
93         if ( found.ContainsKey( extension ) )
94             found[ extension ] += extensionCount; // update the count
95         else
96             found.Add( extension, extensionCount ); // add new count
97     } // end foreach
98
99     // recursive call to search subdirectories
100    foreach ( var subdirectory in directories )
101        SearchDirectory( subdirectory );
102    } // end method SearchDirectory
103
104    // allow user to delete backup files (.bak)
105    private void CleanDirectory( string folder )
106    {
107        // files contained in the directory
108        string[] files = Directory.GetFiles( folder );
109
110        // subdirectories in the directory
111        string[] directories = Directory.GetDirectories( folder );
112
113        // select all the backup files in this directory
114        var backupFiles =
115            from file in files
116            where Path.GetExtension( file ) == ".bak"
117            select file;
118
119        // iterate over all backup files (.bak)
120        foreach ( var backup in backupFiles )
121        {
122            DialogResult result = MessageBox.Show( "Found backup file " +
123                Path.GetFileName( backup ) + ". Delete?", "Delete Backup",
124                MessageBoxButtons.YesNo, MessageBoxIcon.Question );
125
126            // delete file if user clicked 'yes'
127            if ( result == DialogResult.Yes )
128            {
129                File.Delete( backup ); // delete backup file
130                --found[ ".bak" ]; // decrement count in Dictionary
131
132                // if there are no .bak files, delete key from Dictionary
133                if ( found[ ".bak" ] == 0 )
134                    found.Remove( ".bak" );
135            } // end if
136        } // end foreach
137
138        // recursive call to clean subdirectories
139        foreach ( var subdirectory in directories )
140            CleanDirectory( subdirectory );
141    } // end method CleanDirectory
142 } // end class LINQToFileDirectoryForm
143 } // end namespace LINQToFileDirectory
```

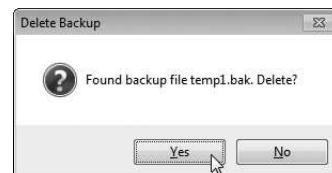
---

**Fig. 17.6** | Using LINQ to search directories and determine file types. (Part 3 of 4.)

a) GUI after entering a directory to search and pressing **Search Directory**



b) Dialog that appears to confirm deletion of a .bak file



**Fig. 17.6** | Using LINQ to search directories and determine file types. (Part 4 of 4.)

### Method **SearchDirectory**

Lines 38–41 get the current directory (if the user did not specify a path) or the specified directory. Line 49 passes the directory name to *recursive* method **SearchDirectory** (lines 68–102). Line 71 calls **Directory** method **GetFiles** to get a *string* array containing file names in the specified directory. Line 74 calls **Directory** method **GetDirectories** to get a *string* array containing the subdirectory names in the specified directory.

Lines 78–79 use LINQ to get the *Distinct* file-name extensions in the **files** array. **Path** method **GetExtension** obtains the extension for the specified file name. For each file-name extension returned by the LINQ query, lines 82–97 determine the number of occurrences of that extension in the **files** array. The LINQ query at lines 87–89 compares each file-name extension in the **files** array with the current extension being processed (line 89). All matches are included in the result. We then use LINQ method **Count** to determine the total number of files that matched the current extension.

Class **LINQToFileDirectoryForm** uses a **Dictionary** (declared in line 16) to store each file-name extension and the corresponding number of file names with that extension. A **Dictionary** (namespace **System.Collections.Generic**) is a collection of *key–value pairs*, in which each *key* has a corresponding *value*. Class **Dictionary** is a *generic class* like class **List** (presented in Section 9.4). Line 16 indicates that the **Dictionary** found contains pairs of *strings* and *ints*, which represent the file-name extensions and the number of files with those extensions, respectively. Line 93 uses **Dictionary** method **ContainsKey** to determine whether the specified file-name extension has been placed in the **Dictionary** previously. If this method returns *true*, line 94 adds the *extensionCount* determined in lines 88–90 to the current total for that extension that's stored in the **Dictionary**. Otherwise, line 96 uses **Dictionary** method **Add** to insert a new *key–value pair* into the **Dictionary** for the new file-name extension and its *extensionCount*. Lines 100–101 recursively call **SearchDirectory** for each subdirectory in the current directory.

### Method **CleanDirectory**

When method **SearchDirectory** returns, line 52 calls **CleanDirectory** (lines 105–141) to search for all files with extension **.bak**. Lines 108 and 111 obtain the list of file names and

list of directory names in the current directory, respectively. The LINQ query in lines 115–117 locates all file names in the current directory that have the .bak extension. Lines 120–136 iterate through the results and ask the user whether each file should be deleted. If the user clicks **Yes** in the dialog, line 129 uses **File** method **Delete** to remove the file from disk, and line 130 subtracts 1 from the total number of .bak files. If the number of .bak files remaining is 0, line 134 uses **Dictionary** method **Remove** to delete the key–value pair for .bak files from the **Dictionary**. Lines 139–140 recursively call **CleanDirectory** for each subdirectory in the current directory. After each subdirectory has been checked for .bak files, method **CleanDirectory** returns, and lines 55–61 display the summary of file-name extensions and the number of files with each extension. Line 55 uses **Dictionary** property **Keys** to get all the keys. Line 60 uses the **Dictionary**’s indexer to get the value for the current key. Finally, line 63 uses **Dictionary** method **Clear** to delete the contents of the **Dictionary**.

## 17.5 Creating a Sequential-Access Text File

C# imposes *no* structure on files. Thus, the concept of a “record” does *not* exist in C# files. This means that you must structure files to meet the requirements of your apps. The next few examples use text and special characters to organize our own concept of a “record.”

### *Class BankUIForm*

The following examples demonstrate file processing in a bank-account maintenance app. These programs have similar user interfaces, so we created reusable class **BankUIForm** (Fig. 17.7) to encapsulate a base-class GUI (see the screen capture in Fig. 17.7). Class **BankUIForm** (part of the **BankLibrary** project with this chapter’s examples) contains four **Labels** and four **TextBoxes**. Methods **ClearTextBoxes** (lines 28–40), **SetTextBoxValues** (lines 43–64) and **GetTextBoxValues** (lines 67–78) clear, set the values of and get the values of the text in the **TextBoxes**, respectively.

---

```

1 // Fig. 17.7: BankUIForm.cs
2 // A reusable Windows Form for the examples in this chapter.
3 using System;
4 using System.Windows.Forms;
5
6 namespace BankLibrary
7 {
8     public partial class BankUIForm : Form
9     {
10         protected int TextBoxCount = 4; // number of TextBoxes on Form
11
12         // enumeration constants specify TextBox indices
13         public enum TextBoxIndices
14         {
15             ACCOUNT,
16             FIRST,
17             LAST,
18             BALANCE
19         } // end enum
20

```

**Fig. 17.7** | Base class for GUIs in our file-processing apps. (Part I of 3.)

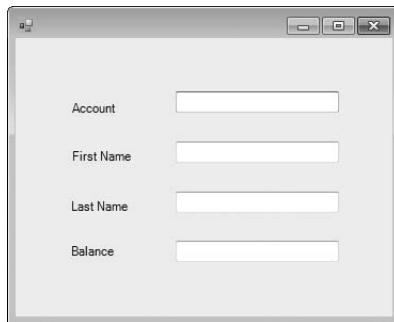
```
21     // parameterless constructor
22     public BankUIForm()
23     {
24         InitializeComponent();
25     } // end constructor
26
27     // clear all TextBoxes
28     public void ClearTextBoxes()
29     {
30         // iterate through every Control on form
31         foreach ( Control guiControl in Controls )
32         {
33             // determine whether Control is TextBox
34             if ( guiControl is TextBox )
35             {
36                 // clear TextBox
37                 ( ( TextBox ) guiControl ).Clear();
38             } // end if
39         } // end for
40     } // end method ClearTextBoxes
41
42     // set text box values to string-array values
43     public void SetTextBoxValues( string[] values )
44     {
45         // determine whether string array has correct length
46         if ( values.Length != TextBoxCount )
47         {
48             // throw exception if not correct length
49             throw ( new ArgumentException( "There must be " +
50                     ( TextBoxCount ) + " strings in the array" ) );
51         } // end if
52         // set array values if array has correct length
53     else
54     {
55         // set array values to TextBox values
56         accountTextBox.Text =
57             values[ ( int ) TextBoxIndices.ACCOUNT ];
58         firstNameTextBox.Text =
59             values[ ( int ) TextBoxIndices.FIRST ];
60         lastNameTextBox.Text = values[ ( int ) TextBoxIndices.LAST ];
61         balanceTextBox.Text =
62             values[ ( int ) TextBoxIndices.BALANCE ];
63     } // end else
64 } // end method SetTextBoxValues
65
66     // return TextBox values as string array
67     public string[] GetTextBoxValues()
68     {
69         string[] values = new string[ TextBoxCount ];
70
71         // copy TextBox fields to string array
72         values[ ( int ) TextBoxIndices.ACCOUNT ] = accountTextBox.Text;
73         values[ ( int ) TextBoxIndices.FIRST ] = firstNameTextBox.Text;
```

**Fig. 17.7** | Base class for GUIs in our file-processing apps. (Part 2 of 3.)

```

74         values[ ( int ) TextBoxIndices.LAST ] = lastNameTextBox.Text;
75         values[ ( int ) TextBoxIndices.BALANCE ] = balanceTextBox.Text;
76
77         return values;
78     } // end method GetTextBoxValues
79 } // end class BankUIForm
80 } // end namespace BankLibrary

```



**Fig. 17.7** | Base class for GUIs in our file-processing apps. (Part 3 of 3.)

Using *visual inheritance* (Section 15.13), you can extend this class to create the GUIs for several examples in this chapter. Recall that to reuse class `BankUIForm`, you must compile the GUI into a class library, then add a reference to the new class library in each project that will reuse it. This library (`BankLibrary`) is provided with the code for this chapter. You might need to re-add the references to this library in our examples when you copy them to your system, since the library most likely will reside in a different location on your system.

### Class Record

Figure 17.8 contains class `Record` that Figs. 17.9, 17.11 and 17.12 use for maintaining the information in each record that's written to or read from a file. This class also belongs to the `BankLibrary` DLL, so it's located in the same project as class `BankUIForm`.

```

1 // Fig. 17.8: Record.cs
2 // Class that represents a data record.
3
4 namespace BankLibrary
5 {
6     public class Record
7     {
8         // auto-implemented Account property
9         public int Account { get; set; }
10
11        // auto-implemented FirstName property
12        public string FirstName { get; set; }
13
14        // auto-implemented LastName property
15        public string LastName { get; set; }

```

**Fig. 17.8** | Record for sequential-access file-processing apps. (Part 1 of 2.)

---

```

16      // auto-implemented Balance property
17      public decimal Balance { get; set; }
18
19
20      // parameterless constructor sets members to default values
21      public Record()
22          : this( 0, string.Empty, string.Empty, 0M )
23      {
24      } // end constructor
25
26      // overloaded constructor sets members to parameter values
27      public Record( int accountValue, string firstNameValue,
28                      string lastNameValue, decimal balanceValue )
29      {
30          Account = accountValue;
31          FirstName = firstNameValue;
32          LastName = lastNameValue;
33          Balance = balanceValue;
34      } // end constructor
35  } // end class Record
36 } // end namespace BankLibrary

```

---

**Fig. 17.8** | Record for sequential-access file-processing apps. (Part 2 of 2.)

Class *Record* contains *auto-implemented properties* for instance variables *Account*, *FirstName*, *LastName* and *Balance* (lines 9–18), which collectively represent all the information for a record. The parameterless constructor (lines 21–24) sets these members by calling the four-argument constructor with 0 for the account number, `string.Empty` for the first and last name and `0.0M` for the balance. The four-argument constructor (lines 27–34) sets these members to the specified parameter values.

### *Using a Character Stream to Create an Output File*

Class *CreateFileForm* (Fig. 17.9) uses instances of class *Record* to create a *sequential-access file* that might be used in an accounts-receivable system—i.e., a program that organizes data regarding money owed by a company’s credit clients. For each client, the program obtains an account number and the client’s first name, last name and balance (i.e., the amount of money that the client owes to the company for previously received goods and services). The data obtained for each client constitutes a record for that client. In this app, the account number is used as the *record key*—files are created and maintained in account-number order. This program assumes that the user enters records in account-number order. However, a comprehensive accounts-receivable system would provide a *sorting* capability, so the user could enter the records in any order.

---

```

1 // Fig. 17.9: CreateFileForm.cs
2 // Creating a sequential-access file.
3 using System;
4 using System.Windows.Forms;
5 using System.IO;

```

---

**Fig. 17.9** | Creating and writing to a sequential-access file. (Part 1 of 5.)

```
6  using BankLibrary;
7
8  namespace CreateFile
9  {
10     public partial class CreateFileForm : BankUIForm
11     {
12         private StreamWriter fileWriter; // writes data to text file
13
14         // parameterless constructor
15         public CreateFileForm()
16         {
17             InitializeComponent();
18         } // end constructor
19
20         // event handler for Save Button
21         private void saveButton_Click( object sender, EventArgs e )
22         {
23             // create and show dialog box enabling user to save file
24             DialogResult result; // result of SaveFileDialog
25             string fileName; // name of file containing data
26
27             using ( SaveFileDialog fileChooser = new SaveFileDialog() )
28             {
29                 fileChooser.CheckFileExists = false; // let user create file
30                 result = fileChooser.ShowDialog();
31                 fileName = fileChooser.FileName; // name of file to save data
32             } // end using
33
34             // ensure that user clicked "OK"
35             if ( result == DialogResult.OK )
36             {
37                 // show error if user specified invalid file
38                 if ( fileName == string.Empty )
39                     MessageBox.Show( "Invalid File Name", "Error",
40                         MessageBoxButtons.OK, MessageBoxIcon.Error );
41                 else
42                 {
43                     // save file via FileStream if user specified valid file
44                     try
45                     {
46                         // open file with write access
47                         FileStream output = new FileStream( fileName,
48                             FileMode.OpenOrCreate, FileAccess.Write );
49
50                         // sets file to where data is written
51                         fileWriter = new StreamWriter( output );
52
53                         // disable Save button and enable Enter button
54                         saveButton.Enabled = false;
55                         enterButton.Enabled = true;
56                     } // end try
57                     // handle exception if there's a problem opening the file
```

---

**Fig. 17.9** | Creating and writing to a sequential-access file. (Part 2 of 5.)

```
58         catch ( IOException )  
59         {  
60             // notify user if file does not exist  
61             MessageBox.Show( "Error opening file", "Error",  
62                             MessageBoxButtons.OK, MessageBoxIcon.Error );  
63         } // end catch  
64     } // end else  
65 } // end if  
66 } // end method saveButton_Click  
67  
68 // handler for enterButton Click  
69 private void enterButton_Click( object sender, EventArgs e )  
{  
    // store TextBox values string array  
    string[] values = GetTextBoxValues();  
      
    // Record containing TextBox values to output  
    Record record = new Record();  
      
    // determine whether TextBox account field is empty  
    if ( values[ ( int ) TextBoxIndices.ACCOUNT ] != string.Empty )  
    {  
        // store TextBox values in Record and output it  
        try  
        {  
            // get account-number value from TextBox  
            int accountNumber = Int32.Parse(  
                values[ ( int ) TextBoxIndices.ACCOUNT ] );  
              
            // determine whether accountNumber is valid  
            if ( accountNumber > 0 )  
            {  
                // store TextBox fields in Record  
                record.Account = accountNumber;  
                record.FirstName = values[ ( int )  
                    TextBoxIndices.FIRST ];  
                record.LastName = values[ ( int )  
                    TextBoxIndices.LAST ];  
                record.Balance = Decimal.Parse(  
                    values[ ( int ) TextBoxIndices.BALANCE ] );  
                  
                // write Record to file, fields separated by commas  
                fileWriter.WriteLine(  
                    record.Account + "," + record.FirstName + "," +  
                    record.LastName + "," + record.Balance );  
            } // end if  
            else  
            {  
                // notify user if invalid account number  
                MessageBox.Show( "Invalid Account Number", "Error",  
                                MessageBoxButtons.OK, MessageBoxIcon.Error );  
            } // end else  
        } // end try
```

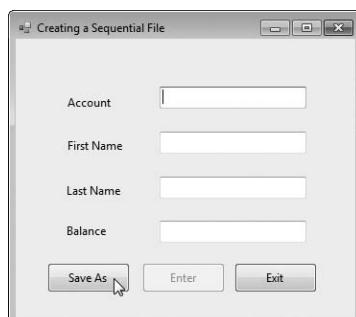
**Fig. 17.9** | Creating and writing to a sequential-access file. (Part 3 of 5.)

```

111         // notify user if error occurs during the output operation
112     catch ( IOException )
113     {
114         MessageBox.Show( "Error Writing to File", "Error",
115                         MessageBoxButtons.OK, MessageBoxIcon.Error );
116     } // end catch
117     // notify user if error occurs regarding parameter format
118     catch ( FormatException )
119     {
120         MessageBox.Show( "Invalid Format", "Error",
121                         MessageBoxButtons.OK, MessageBoxIcon.Error );
122     } // end catch
123 } // end if
124
125     ClearTextBoxes(); // clear TextBox values
126 } // end method enterButton_Click
127
128 // handler for exitButton Click
129 private void exitButton_Click( object sender, EventArgs e )
130 {
131     // determine whether file exists
132     if ( fileWriter != null )
133     {
134         try
135         {
136             // close StreamWriter and underlying file
137             fileWriter.Close();
138         } // end try
139         // notify user of error closing file
140         catch ( IOException )
141         {
142             MessageBox.Show( "Cannot close file", "Error",
143                             MessageBoxButtons.OK, MessageBoxIcon.Error );
144         } // end catch
145     } // end if
146
147     Application.Exit();
148 } // end method exitButton_Click
149 } // end class CreateFileForm
150 } // end namespace CreateFile

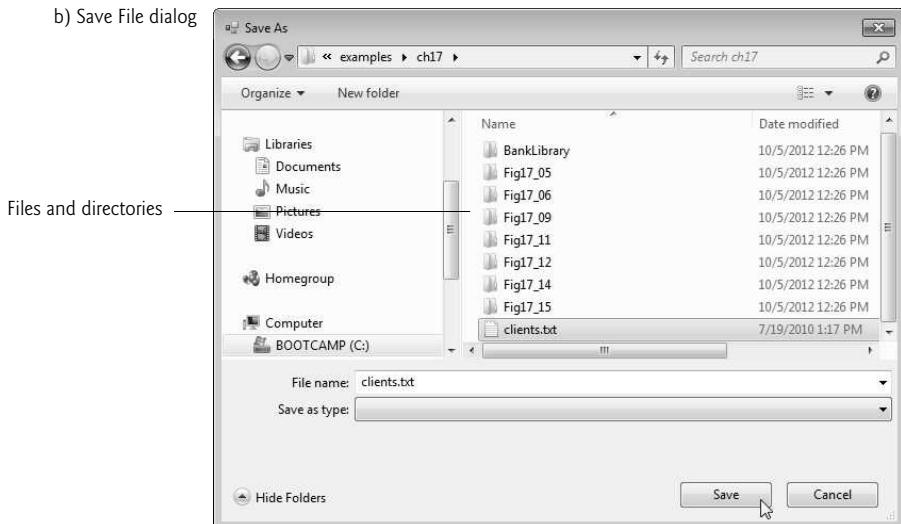
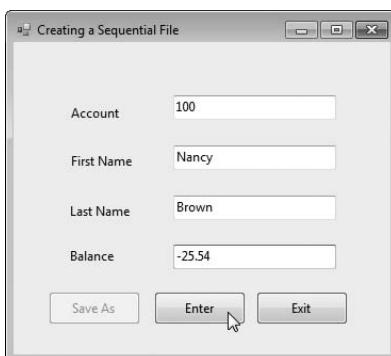
```

- a) BankUI graphical user interface with three additional controls



**Fig. 17.9** | Creating and writing to a sequential-access file. (Part 4 of 5.)

b) Save File dialog

c) Account 100,  
"Nancy Brown",  
saved with a  
balance of -25.54**Fig. 17.9** | Creating and writing to a sequential-access file. (Part 5 of 5.)

Class `CreateFileDialog` either creates or opens a file (depending on whether one exists), then allows the user to write records to it. The `using` directive in line 6 enables us to use the classes of the `BankLibrary` namespace; this namespace contains class `BankUIForm`, from which class `CreateFileDialog` inherits (line 10). Class `CreateFileDialog`'s GUI enhances that of class `BankUIForm` with buttons `Save As`, `Enter` and `Exit`.

#### ***Method saveButton\_Click***

When the user clicks the `Save As` button, the program invokes the event handler `saveButton_Click` (lines 21–66). Line 27 instantiates an object of class `SaveFileDialog` (namespace `System.Windows.Forms`). By placing this object in a `using` statement (lines 27–32), we can ensure that the dialog's `Dispose` method is called to release its resources as soon as the program has retrieved user input from it. `SaveFileDialog` objects are used for selecting files (see the second screen in Fig. 17.9). Line 29 indicates that the dialog should not check if the file name specified by the user already exists (this is actually the default).

Line 30 calls `SaveFileDialog` method `ShowDialog` to display the dialog. When displayed, a `SaveFileDialog` prevents the user from interacting with any other window in the program until the user closes the `SaveFileDialog` by clicking either `Save` or `Cancel`. Dialogs that behave in this manner are called **modal dialogs**. The user selects the appropriate drive, directory and file name, then clicks `Save`. Method `ShowDialog` returns a  `DialogResult` specifying which button (`Save` or `Cancel`) the user clicked to close the dialog. This is assigned to  `DialogResult` variable `result` (line 30). Line 31 gets the file name from the dialog. Line 35 tests whether the user clicked `OK` by comparing this value to  `DialogResult.OK`. If the values are equal, method  `saveButton_Click` continues.

You can open files to perform text manipulation by creating objects of class `FileStream`. In this example, we want the file to be opened for *output*, so lines 47–48 create a `FileStream` object. The `FileStream` constructor that we use receives three arguments—a string containing the path and name of the file to open, a constant describing how to open the file and a constant describing the file permissions. The constant  `FileMode.OpenOrCreate` (line 48) indicates that the `FileStream` object should open the file if it *exists* or create the file if it *does not exist*. Note that the contents of an existing file are *overwritten* by the `StreamWriter`. To *preserve* the original contents of a file, use  `FileMode.Append`. There are other  `FileMode` constants describing how to open files; we introduce these constants as we use them in examples. The constant  `FileAccess.Write` indicates that the program can perform only *write* operations with the `FileStream` object. There are two other constants for the third constructor parameter— `FileAccess.Read` for read-only access and  `FileAccess.ReadWrite` for both read and write access. Line 58 catches an  `IOException` if there's a problem opening the file or creating the  `StreamWriter`. If so, the program displays an error message (lines 61–62). If no exception occurs, the file is open for writing.



### Good Programming Practice 17.1

*When opening files, use the `FileAccess` enumeration to control user access to these files.*



### Common Programming Error 17.1

*Failure to open a file before attempting to use it in a program is a logic error.*

#### ***Method `enterButton_Click`***

After typing information into each  `TextBox`, the user clicks  `Enter`, which calls  `enterButton_Click` (lines 69–126) to save the data from the  `TextBoxes` into the user-specified file. If the user entered a *valid* account number (i.e., an integer greater than zero), lines 91–97 store the  `TextBox` values in an object of type  `Record` (created at line 75). If the user entered *invalid* data in one of the  `TextBoxes` (such as nonnumeric characters in the  `Balance` field), the program throws a `FormatException`. The catch block in lines 118–122 handles such exceptions by notifying the user (via a  `MessageBox`) of the improper format.

If the user entered *valid* data, lines 100–102 write the record to the file by invoking method  `WriteLine` of the  `StreamWriter` object that was created at line 51. Method  `WriteLine` writes a sequence of characters to a file. The  `StreamWriter` object is constructed with a  `FileStream` argument that specifies the file to which the  `StreamWriter` will output text. Class  `StreamWriter` (like most of the classes we discuss in this chapter) belongs to the  `System.IO` namespace.

**Method exitButton\_Click**

When the user clicks Exit, `exitButton_Click` (lines 129–148) executes. Line 137 closes the `StreamWriter`, which automatically closes the `FileStream`. Then, line 147 terminates the program. Note that method `Close` is called in a `try` block. Method `Close` throws an `IOException` if the file or stream cannot be closed properly. In this case, it's important to notify the user that the information in the file or stream might be *corrupted*.

**Performance Tip 17.1**

*Close each file explicitly when the program no longer needs to use it. This can reduce resource usage in programs that continue executing long after they finish using a specific file. The practice of explicitly closing files also improves program clarity.*

**Performance Tip 17.2**

*Releasing resources explicitly when they're no longer needed makes them immediately available for reuse by other programs, thus improving resource utilization.*

**Sample Data**

To test the program, we entered information for the accounts shown in Fig. 17.10. The program does not depict how the data records are stored in the file. To verify that the file has been created successfully, we create a program in the next section to read and display the file. Since this is a *text file*, you can actually open it in any *text editor* to see its contents.

| Account number | First name | Last name | Balance |
|----------------|------------|-----------|---------|
| 100            | Nancy      | Brown     | -25.54  |
| 200            | Stacey     | Dunn      | 314.33  |
| 300            | Doug       | Barker    | 0.00    |
| 400            | Dave       | Smith     | 258.34  |
| 500            | Sam        | Stone     | 34.98   |

**Fig. 17.10** | Sample data for the program of Fig. 17.9.

## 17.6 Reading Data from a Sequential-Access Text File

The previous section demonstrated how to create a file for use in sequential-access apps. In this section, we discuss how to read (or retrieve) data sequentially from a file.

Class `ReadSequentialAccessFileForm` (Fig. 17.11) reads records from the file created by the program in Fig. 17.9, then displays the contents of each record. Much of the code in this example is similar to that of Fig. 17.9, so we discuss only the unique aspects of the app.

---

```

1 // Fig. 17.11: ReadSequentialAccessFileForm.cs
2 // Reading a sequential-access file.
3 using System;

```

---

**Fig. 17.11** | Reading sequential-access files. (Part I of 4.)

```
4  using System.Windows.Forms;
5  using System.IO;
6  using BankLibrary;
7
8  namespace ReadSequentialAccessFile
9  {
10     public partial class ReadSequentialAccessFileForm : BankUIForm
11     {
12         private StreamReader fileReader; // reads data from a text file
13
14         // parameterless constructor
15         public ReadSequentialAccessFileForm()
16         {
17             InitializeComponent();
18         } // end constructor
19
20         // invoked when user clicks the Open button
21         private void openButton_Click( object sender, EventArgs e )
22         {
23             // create and show dialog box enabling user to open file
24             DialogResult result; // result of OpenFileDialog
25             string fileName; // name of file containing data
26
27             using ( OpenFileDialog fileChooser = new OpenFileDialog() )
28             {
29                 result = fileChooser.ShowDialog();
30                 fileName = fileChooser.FileName; // get specified name
31             } // end using
32
33             // ensure that user clicked "OK"
34             if ( result == DialogResult.OK )
35             {
36                 ClearTextBoxes();
37
38                 // show error if user specified invalid file
39                 if ( fileName == string.Empty )
40                     MessageBox.Show( "Invalid File Name", "Error",
41                         MessageBoxButtons.OK, MessageBoxIcon.Error );
42                 else
43                 {
44                     try
45                     {
46                         // create FileStream to obtain read access to file
47                         FileStream input = new FileStream(
48                             fileName, FileMode.Open, FileAccess.Read );
49
50                         // set file from where data is read
51                         fileReader = new StreamReader( input );
52
53                         openButton.Enabled = false; // disable Open File button
54                         nextButton.Enabled = true; // enable Next Record button
55                     } // end try
56                 } // end else
57             } // end if
58         } // end openButton_Click
59
60         // invoked when user clicks the Next Record button
61         private void nextButton_Click( object sender, EventArgs e )
62         {
63             // read data from file
64             string line = fileReader.ReadLine();
65
66             // if there is no more data, then disable Next Record button
67             if ( line == null )
68                 nextButton.Enabled = false;
69             else
70                 label1.Text = line;
71
72             // read next line
73             fileReader.ReadLine();
74
75         } // end nextButton_Click
76     } // end class
77 }
78
79 
```

**Fig. 17.11** | Reading sequential-access files. (Part 2 of 4.)

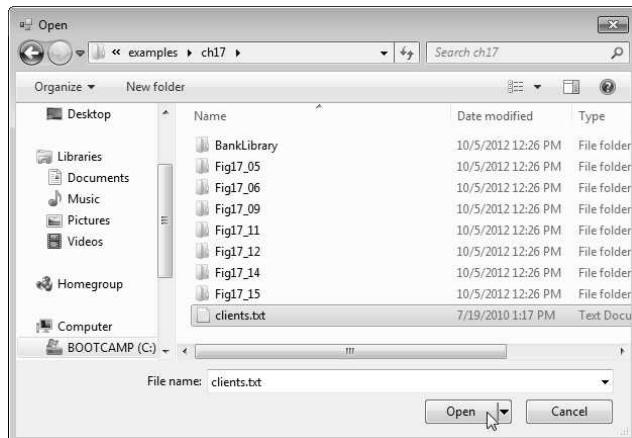
```
56         catch ( IOException )  
57     {  
58         MessageBox.Show( "Error reading from file",  
59                         "File Error", MessageBoxButtons.OK,  
60                         MessageBoxIcon.Error );  
61     } // end catch  
62 } // end else  
63 } // end if  
64 } // end method openButton_Click  
65  
66 // invoked when user clicks Next button  
67 private void nextButton_Click( object sender, EventArgs e )  
68 {  
69     try  
70     {  
71         // get next record available in file  
72         string inputRecord = fileReader.ReadLine();  
73         string[] inputFields; // will store individual pieces of data  
74  
75         if ( inputRecord != null )  
76         {  
77             inputFields = inputRecord.Split( ',' );  
78  
79             Record record = new Record(  
80                 Convert.ToInt32( inputFields[ 0 ] ), inputFields[ 1 ],  
81                 inputFields[ 2 ],  
82                 Convert.ToDecimal( inputFields[ 3 ] ) );  
83  
84             // copy string-array values to TextBox values  
85             SetTextBoxValues( inputFields );  
86         } // end if  
87     }  
88     else  
89     {  
90         // close StreamReader and underlying file  
91         fileReader.Close();  
92         openButton.Enabled = true; // enable Open File button  
93         nextButton.Enabled = false; // disable Next Record button  
94         ClearTextBoxes();  
95  
96         // notify user if no records in file  
97         MessageBox.Show( "No more records in file", string.Empty,  
98                         MessageBoxButtons.OK, MessageBoxIcon.Information );  
99     } // end else  
100 } // end try  
101 catch ( IOException )  
102 {  
103     MessageBox.Show( "Error Reading from File", "Error",  
104                         MessageBoxButtons.OK, MessageBoxIcon.Error );  
105 } // end catch  
106 } // end method nextButton_Click  
107 } // end class ReadSequentialAccessFileForm  
108 } // end namespace ReadSequentialAccessFile
```

**Fig. 17.11** | Reading sequential-access files. (Part 3 of 4.)

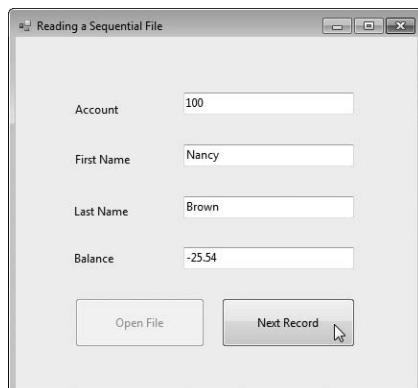
a) BankUI graphical user interface with an Open File button



b) OpenFileDialog window



c) Reading account 100



d) User is shown a messagebox when all records have been read

**Fig. 17.11** | Reading sequential-access files. (Part 4 of 4.)

***Method openButton\_Click***

When the user clicks **Open File**, the program calls event handler `openButton_Click` (lines 21–64). Line 27 creates an `OpenFileDialog`, and line 29 calls its `ShowDialog` method to display the **Open** dialog (see the second screenshot in Fig. 17.11). The behavior and GUI for the **Save** and **Open** dialog types are identical, except that **Save** is replaced by **Open**. If the user selects a *valid* file name, lines 47–48 create a `FileStream` object and assign it to reference `input`. We pass constant  `FileMode.Open` as the second argument to the `FileStream` constructor to indicate that the `FileStream` should open the file if it exists or throw a `FileNotFoundException` if it does not. (In this example, the `FileStream` constructor will *not* throw a `FileNotFoundException`, because the `OpenFileDialog` is configured to check that the file exists.) In the last example (Fig. 17.9), we wrote text to the file using a `FileStream` object with *write-only access*. In this example (Fig. 17.11), we specify *read-only access* to the file by passing constant  `FileAccess.Read` as the third argument to the `FileStream` constructor. This `FileStream` object is used to create a `StreamReader` object in line 51. The `FileStream` object specifies the file from which the `StreamReader` object will read text.

**Error-Prevention Tip 17.1**

*Open a file with the `FileAccess.Read` file-open mode if its contents should not be modified. This prevents unintentional modification of the contents.*

***Method nextButton\_Click***

When the user clicks the **Next Record** button, the program calls event handler `nextButton_Click` (lines 67–105), which reads the next record from the user-specified file. (The user must click **Next Record** after opening the file to view the first record.) Line 72 calls `StreamReader` method `ReadLine` to read the next record. If an error occurs while reading the file, an  `IOException` is thrown (caught at line 100), and the user is notified (lines 102–103). Otherwise, line 75 determines whether `StreamReader` method `ReadLine` returned `null` (i.e., there's no more text in the file). If not, line 77 uses method `Split` of class `string` to separate the stream of characters that was read from the file into tokens (`strings`) that represent the `Record`'s properties—the second argument indicates that the tokens are delimited by commas in this file. These properties are then stored by constructing a `Record` object using the properties as arguments (lines 79–82). Line 85 displays the `Record` values in the `TextBoxes`. If `ReadLine` returns `null`, the program closes the `StreamReader` object (line 90), automatically closing the `FileStream` object, then notifies the user that there are no more records (lines 96–97).

## 17.7 Case Study: Credit Inquiry Program

To retrieve data *sequentially* from a file, programs normally start from the *beginning* of the file, reading consecutively until the desired data is found. It sometimes is necessary to process a file *sequentially* several times (from the *beginning* of the file) during the execution of a program. A `FileStream` object can *reposition* its *file-position pointer* (which contains the byte number of the next byte to be read from or written to the file) to *any* position in the file. When a `FileStream` object is opened, its *file-position pointer* is set to *byte position 0* (i.e., the *beginning* of the file).

We now present a program that builds on the concepts employed in Fig. 17.11. Class `CreditInquiryForm` (Fig. 17.12) is a credit-inquiry program that enables a credit manager

to search for and display account information for those customers with credit balances (i.e., customers to whom the company owes money), zero balances (i.e., customers who do not owe the company money) and debit balances (i.e., customers who owe the company money for previously received goods and services). We use a RichTextBox in the program to display the account information. RichTextboxes provide more functionality than regular TextBoxes—for example, RichTextboxes offer method `Find` for searching individual strings and method `LoadFile` for displaying file contents. Classes `RichTextBox` and `TextBox` both inherit from abstract class `System.Windows.Forms.TextBoxBase`. In this example, we chose a `RichTextBox`, because it displays multiple lines of text by default, whereas a regular `TextBox` displays only one. Alternatively, we could have specified that a `TextBox` object display *multiple* lines of text by setting its `Multiline` property to `true`.

The program displays buttons that enable a credit manager to obtain credit information. The **Open File** button opens a file for gathering data. The **Credit Balances** button displays a list of accounts that have credit balances, the **Debit Balances** button displays a list of accounts that have debit balances and the **Zero Balances** button displays a list of accounts that have zero balances. The **Done** button exits the app.

---

```

1 // Fig. 17.12: CreditInquiryForm.cs
2 // Read a file sequentially and display contents based on
3 // account type specified by user ( credit, debit or zero balances ).
4 using System;
5 using System.Windows.Forms;
6 using System.IO;
7 using BankLibrary;
8
9 namespace CreditInquiry
10 {
11     public partial class CreditInquiryForm : Form
12     {
13         private FileStream input; // maintains the connection to the file
14         private StreamReader fileReader; // reads data from text file
15
16         // name of file that stores credit, debit and zero balances
17         private string fileName;
18
19         // parameterless constructor
20         public CreditInquiryForm()
21         {
22             InitializeComponent();
23         } // end constructor
24
25         // invoked when user clicks Open File button
26         private void openButton_Click( object sender, EventArgs e )
27         {
28             // create dialog box enabling user to open file
29             DialogResult result;
30
31             using ( OpenFileDialog fileChooser = new OpenFileDialog() )
32             {

```

---

**Fig. 17.12** | Credit-inquiry program. (Part 1 of 5.)

```
33         result = fileChooser.ShowDialog();
34         fileName = fileChooser.FileName;
35     } // end using
36
37     // exit event handler if user clicked Cancel
38     if ( result == DialogResult.OK )
39     {
40         // show error if user specified invalid file
41         if ( fileName == string.Empty )
42             MessageBox.Show( "Invalid File Name", "Error",
43                             MessageBoxButtons.OK, MessageBoxIcon.Error );
44     }
45     else
46     {
47         // create FileStream to obtain read access to file
48         input = new FileStream( fileName,
49                             FileMode.Open, FileAccess.Read );
50
51         // set file from where data is read
52         fileReader = new StreamReader( input );
53
54         // enable all GUI buttons, except for Open File button
55         openButton.Enabled = false;
56         creditButton.Enabled = true;
57         debitButton.Enabled = true;
58         zeroButton.Enabled = true;
59     } // end else
60 } // end if
61 } // end method openButton_Click
62
63 // invoked when user clicks credit balances,
64 // debit balances or zero balances button
65 private void getBalances_Click( object sender, System.EventArgs e )
66 {
67     // convert sender explicitly to object of type button
68     Button senderButton = ( Button ) sender;
69
70     // get text from clicked Button, which stores account type
71     string accountType = senderButton.Text;
72
73     // read and display file information
74     try
75     {
76         // go back to the beginning of the file
77         input.Seek( 0, SeekOrigin.Begin );
78
79         displayTextBox.Text = "The accounts are:\r\n";
80
81         // traverse file until end of file
82         while ( true )
83         {
84             string[] inputFields; // stores individual pieces of data
85             Record record; // store each Record as file is read
86             decimal balance; // store each Record's balance
```

**Fig. 17.12** | Credit-inquiry program. (Part 2 of 5.)

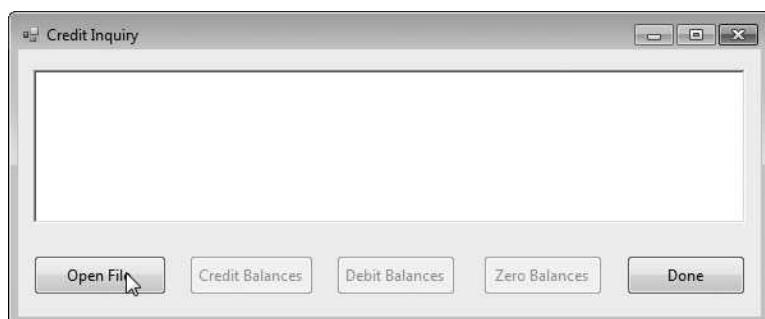
```
86          // get next Record available in file
87          string inputRecord = fileReader.ReadLine();
88
89          // when at the end of file, exit method
90          if ( inputRecord == null )
91              return;
92
93          inputFields = inputRecord.Split( ',' ); // parse input
94
95          // create Record from input
96          record = new Record(
97              Convert.ToInt32( inputFields[ 0 ] ), inputFields[ 1 ],
98              inputFields[ 2 ], Convert.ToDecimal( inputFields[ 3 ] ) );
99
100         // store record's last field in balance
101         balance = record.Balance;
102
103         // determine whether to display balance
104         if ( ShouldDisplay( balance, accountType ) )
105         {
106             // display record
107             string output = record.Account + "\t" +
108                 record.FirstName + "\t" + record.LastName + "\t";
109
110             // display balance with correct monetary format
111             output += String.Format( "{0:F}", balance ) + "\r\n";
112
113             // copy output to screen
114             displayTextBox.AppendText( output );
115         } // end if
116     } // end while
117 } // end try
118 // handle exception when file cannot be read
119 catch ( IOException )
120 {
121     MessageBox.Show( "Cannot Read File", "Error",
122                     MessageBoxButtons.OK, MessageBoxIcon.Error );
123 } // end catch
124 } // end method getBalances_Click
125
126 // determine whether to display given record
127 private bool ShouldDisplay( decimal balance, string accountType )
128 {
129     if ( balance > 0M )
130     {
131         // display credit balances
132         if ( accountType == "Credit Balances" )
133             return true;
134     } // end if
135     else if ( balance < 0M )
136     {
137 }
```

---

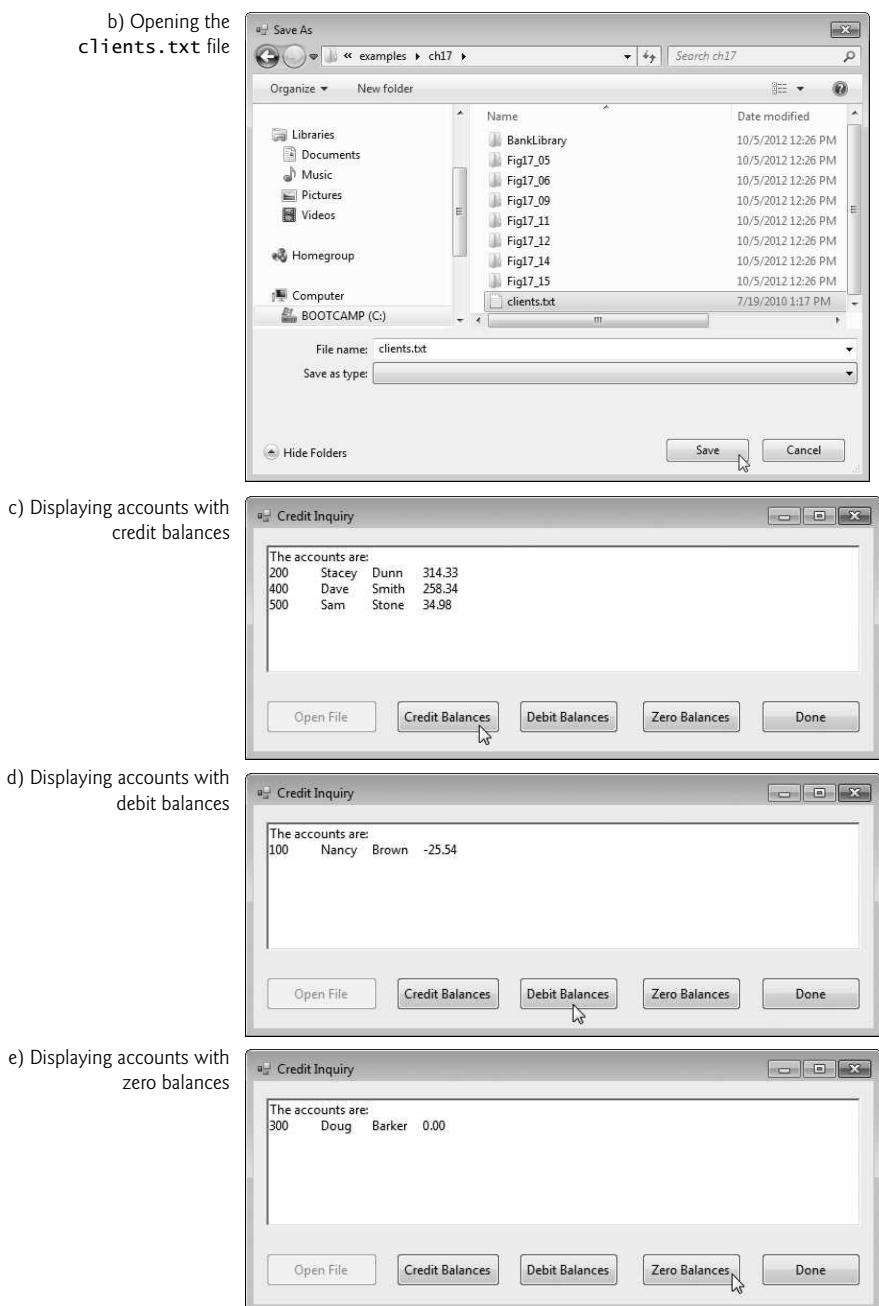
Fig. 17.12 | Credit-inquiry program. (Part 3 of 5.)

```
138         // display debit balances
139         if ( accountType == "Debit Balances" )
140             return true;
141     } // end else if
142     else // balance == 0
143     {
144         // display zero balances
145         if ( accountType == "Zero Balances" )
146             return true;
147     } // end else
148
149     return false;
150 } // end method ShouldDisplay
151
152 // invoked when user clicks Done button
153 private void doneButton_Click( object sender, EventArgs e )
154 {
155     if ( input != null )
156     {
157         // close file and StreamReader
158         try
159         {
160             // close StreamReader and underlying file
161             fileReader.Close();
162         } // end try
163         // handle exception if FileStream does not exist
164         catch ( IOException )
165         {
166             // notify user of error closing file
167             MessageBox.Show( "Cannot close file", "Error",
168                             MessageBoxButtons.OK, MessageBoxIcon.Error );
169         } // end catch
170     } // end if
171
172     Application.Exit();
173 } // end method doneButton_Click
174 } // end class CreditInquiryForm
175 } // end namespace CreditInquiry
```

a) GUI when the app first executes



**Fig. 17.12** | Credit-inquiry program. (Part 4 of 5.)



**Fig. 17.12** | Credit-inquiry program. (Part 5 of 5.)

When the user clicks the **Open File** button, the program calls the event handler `openButton_Click` (lines 26–60). Line 31 creates an `OpenFileDialog`, and line 33 calls its

`ShowDialog` method to display the **Open** dialog, in which the user selects the file to open. Lines 47–48 create a `FileStream` object with *read-only file access* and assign it to reference `input`. Line 51 creates a `StreamReader` object that we use to read text from the `FileStream`.

When the user clicks **Credit Balances**, **Debit Balances** or **Zero Balances**, the program invokes method `getBalances_Click` (lines 64–125). Line 67 casts the `sender` parameter, which is an object reference to the control that generated the event, to a `Button` object. Line 70 extracts the `Button` object's text, which the program uses to determine which type of accounts to display. Line 76 uses `FileStream` method **Seek** to reset the *file-position pointer* back to the *beginning* of the file. `FileStream` method `Seek` allows you to reset the *file-position pointer* by specifying the number of bytes it should be *offset* from the file's *beginning*, *end* or *current* position. The part of the file you want to be *offset* from is chosen using constants from the **SeekOrigin** enumeration. In this case, our stream is offset by 0 bytes from the file's *beginning* (`SeekOrigin.Begin`). Lines 81–117 define a `while` loop that uses private method `ShouldDisplay` (lines 128–150) to determine whether to display each record in the file. The `while` loop obtains each record by repeatedly calling `StreamReader` method `ReadLine` (line 88) and splitting the text into *tokens* (line 94) that are used to initialize object `record` (lines 97–99). Line 91 determines whether the *file-position pointer* has reached the end of the file, in which case `ReadLine` returns `null`. If so, the program returns from method `getBalances_Click` (line 92).

## 17.8 Serialization

Section 17.5 demonstrated how to write the individual fields of a `Record` object to a text file, and Section 17.6 demonstrated how to read those fields from a file and place their values in a `Record` object in memory. In the examples, `Record` was used to *aggregate* the information for one record. When the instance variables for a `Record` were output to a disk file, certain information was lost, such as the type of each value. For instance, if the value "3" is read from a file, there's no way to tell if the value came from an `int`, a `string` or a `decimal`. We have only data, not type information, on disk. If the program that's going to read this data "knows" what object type the data corresponds to, then the data can be read directly into objects of that type. For example, in Fig. 17.11, we know that we are inputting an `int` (the account number), followed by two `strings` (the first and last name) and a `decimal` (the balance). We also know that these values are separated by commas, with only one record on each line. So, we are able to parse the strings and convert the account number to an `int` and the balance to a `decimal`. Sometimes it would be easier to read or write entire objects. C# provides such a mechanism, called **object serialization**. A *serialized object* is an object represented as a sequence of bytes that includes the *object's data*, as well as information about the *object's type* and the *types of data stored in the object*. After a *serialized object* has been written to a file, it can be read from the file and *deserialized*—that is, the type information and bytes that represent the object and its data can be used to *recreate* the object in memory.

Class **BinaryFormatter** (namespace `System.Runtime.Serialization.Formatters.Binary`) enables entire objects to be written to or read from a stream. `BinaryFormatter` method **Serialize** writes an object's representation to a file. `BinaryFormatter` method **Deserialize** reads this representation from a file and *reconstructs* the original object. Both methods throw a **SerializationException** if an error occurs during *serialization* or *deserialization*. Both methods require a `Stream` object (e.g., the `FileStream`) as a parameter so that the `BinaryFormatter` can access the correct stream.

In Sections 17.9–17.10, we create and manipulate *sequential-access files* using *object serialization*. Object serialization is performed with *byte-based streams*, so the sequential files created and manipulated will be *binary files*. Binary files are not human readable. For this reason, we write a separate app that reads and displays *serialized objects*.

## 17.9 Creating a Sequential-Access File Using Object Serialization

We begin by creating and writing *serialized objects* to a *sequential-access file*. In this section, we reuse much of the code from Section 17.5, so we focus only on the new features.

### *Defining the RecordSerializable Class*

Let's modify class Record (Fig. 17.8) so that objects of this class can be *serialized*. Class RecordSerializable (Fig. 17.13; part of the BankLibrary project) is marked with the **[Serializable]** attribute (line 7), which indicates to the CLR that RecordSerializable objects can be *serialized*. Classes that represent serializable types must include this attribute in their declarations or must implement *interface ISerializable*.

---

```

1 // Fig. 17.13: RecordSerializable.cs
2 // Serializable class that represents a data record.
3 using System;
4
5 namespace BankLibrary
6 {
7     [Serializable]
8     public class RecordSerializable
9     {
10         // automatic Account property
11         public int Account { get; set; }
12
13         // automatic FirstName property
14         public string FirstName { get; set; }
15
16         // automatic LastName property
17         public string LastName { get; set; }
18
19         // automatic Balance property
20         public decimal Balance { get; set; }
21
22         // default constructor sets members to default values
23         public RecordSerializable()
24             : this( 0, string.Empty, string.Empty, 0M )
25         {
26     } // end constructor
27
28         // overloaded constructor sets members to parameter values
29         public RecordSerializable( int accountValue, string firstNameValue,
30             string lastNameValue, decimal balanceValue )
31         {
32             Account = accountValue;

```

---

**Fig. 17.13** | RecordSerializable class for serializable objects. (Part 1 of 2.)

---

```

33     FirstName = firstNameValue;
34     LastName = lastNameValue;
35     Balance = balanceValue;
36 } // end constructor
37 } // end class RecordSerializable
38 } // end namespace BankLibrary

```

---

**Fig. 17.13** | RecordSerializable class for serializable objects. (Part 2 of 2.)

In a class that's marked with the `[Serializable]` attribute or that implements interface `ISerializable`, you must ensure that every instance variable of the class is also *serializable*. All simple-type variables and strings are *serializable*. For variables of *reference types*, you must check the class declaration (and possibly its base classes) to ensure that the type is *serializable*. By default, array objects are *serializable*. However, if the array contains references to other objects, those objects may or may not be *serializable*.

#### *Using a Serialization Stream to Create an Output File*

Next, we'll create a sequential-access file with *serialization* (Fig. 17.14). To test this program, we used the sample data from Fig. 17.10 to create a file named `clients.ser`. Since the sample screen captures are the same as Fig. 17.9, they are not shown here. Line 15 creates a `BinaryFormatter` for writing *serialized objects*. Lines 53–54 open the `FileStream` to which this program writes the *serialized objects*. The `string` argument that's passed to the `FileStream`'s constructor represents the name and path of the file to be opened. This specifies the file to which the *serialized objects* will be written.

This program assumes that data is input correctly and in the proper record-number order. Event handler `enterButton_Click` (lines 72–127) performs the write operation. Line 78 creates a `RecordSerializable` object, which is assigned values in lines 94–100. Line 103 calls method `Serialize` to write the `RecordSerializable` object to the output file. Method `Serialize` takes the `FileStream` object as the first argument so that the `BinaryFormatter` can write its second argument to the correct file. Only one statement is required to write the entire object. If a problem occurs during *serialization*, a `SerializationException` occurs—we catch this exception in lines 113–117.

In the sample execution for the program in Fig. 17.14, we entered information for five accounts—the same information shown in Fig. 17.10. The program does not show how the data records actually appear in the file. Remember that we are now using *binary files*, which are *not* human readable. To verify that the file was created successfully, the next section presents a program to read the file's contents.

---

```

1 // Fig. 17.14: CreateFileForm.cs
2 // Creating a sequential-access file using serialization.
3 using System;
4 using System.Windows.Forms;
5 using System.IO;
6 using System.Runtime.Serialization.Formatters.Binary;
7 using System.Runtime.Serialization;
8 using BankLibrary;
9

```

---

**Fig. 17.14** | Sequential file created using serialization. (Part 1 of 4.)

```
10  namespace CreateFile
11  {
12      public partial class CreateFileForm : BankUIForm
13      {
14          // object for serializing RecordSerializables in binary format
15          private BinaryFormatter formatter = new BinaryFormatter();
16          private FileStream output; // stream for writing to a file
17
18          // parameterless constructor
19          public CreateFileForm()
20          {
21              InitializeComponent();
22          } // end constructor
23
24          // handler for saveButton_Click
25          private void saveButton_Click( object sender, EventArgs e )
26          {
27              // create and show dialog box enabling user to save file
28              DialogResult result;
29              string fileName; // name of file to save data
30
31              using ( SaveFileDialog fileChooser = new SaveFileDialog() )
32              {
33                  fileChooser.CheckFileExists = false; // let user create file
34
35                  // retrieve the result of the dialog box
36                  result = fileChooser.ShowDialog();
37                  fileName = fileChooser.FileName; // get specified file name
38              } // end using
39
40              // ensure that user clicked "OK"
41              if ( result == DialogResult.OK )
42              {
43                  // show error if user specified invalid file
44                  if ( fileName == string.Empty )
45                      MessageBox.Show( "Invalid File Name", "Error",
46                                      MessageBoxButtons.OK, MessageBoxIcon.Error );
47              }
48
49              // save file via FileStream if user specified valid file
50              try
51              {
52                  // open file with write access
53                  output = new FileStream( fileName,
54                                         FileMode.OpenOrCreate, FileAccess.Write );
55
56                  // disable Save button and enable Enter button
57                  saveButton.Enabled = false;
58                  enterButton.Enabled = true;
59              } // end try
60              // handle exception if there's a problem opening the file
61              catch ( IOException )
62              {
```

---

**Fig. 17.14** | Sequential file created using serialization. (Part 2 of 4.)

```
63          // notify user if file could not be opened
64          MessageBox.Show( "Error opening file", "Error",
65                           MessageBoxButtons.OK, MessageBoxIcon.Error );
66      } // end catch
67  } // end else
68 } // end if
69 } // end method saveButton_Click
70
71 // handler for enterButton Click
72 private void enterButton_Click( object sender, EventArgs e )
73 {
74     // store TextBox values string array
75     string[] values = GetTextBoxValues();
76
77     // RecordSerializable containing TextBox values to serialize
78     RecordSerializable record = new RecordSerializable();
79
80     // determine whether TextBox account field is empty
81     if ( values[ ( int ) TextBoxIndices.ACCOUNT ] != string.Empty )
82     {
83         // store TextBox values in RecordSerializable and serialize it
84         try
85         {
86             // get account-number value from TextBox
87             int accountNumber = Int32.Parse(
88                 values[ ( int ) TextBoxIndices.ACCOUNT ] );
89
90             // determine whether accountNumber is valid
91             if ( accountNumber > 0 )
92             {
93                 // store TextBox fields in RecordSerializable
94                 record.Account = accountNumber;
95                 record.FirstName = values[ ( int )
96                               TextBoxIndices.FIRST ];
97                 record.LastName = values[ ( int )
98                               TextBoxIndices.LAST ];
99                 record.Balance = Decimal.Parse( values[
100                               ( int ) TextBoxIndices.BALANCE ] );
101
102             // write Record to FileStream ( serialize object )
103             formatter.Serialize( output, record );
104         } // end if
105     } // end else
106     else
107     {
108         // notify user if invalid account number
109         MessageBox.Show( "Invalid Account Number", "Error",
110                         MessageBoxButtons.OK, MessageBoxIcon.Error );
111     } // end else
112 } // end try
113 // notify user if error occurs in serialization
114 catch ( SerializationException )
115 {
```

**Fig. 17.14** | Sequential file created using serialization. (Part 3 of 4.)

```
115             MessageBox.Show( "Error Writing to File", "Error",
116                         MessageBoxButtons.OK, MessageBoxIcon.Error );
117         } // end catch
118         // notify user if error occurs regarding parameter format
119         catch ( FormatException )
120         {
121             MessageBox.Show( "Invalid Format", "Error",
122                         MessageBoxButtons.OK, MessageBoxIcon.Error );
123         } // end catch
124     } // end if
125
126     ClearTextBoxes(); // clear TextBox values
127 } // end method enterButton_Click
128
129 // handler for exitButton Click
130 private void exitButton_Click( object sender, EventArgs e )
131 {
132     // determine whether file exists
133     if ( output != null )
134     {
135         // close file
136         try
137         {
138             output.Close(); // close FileStream
139         } // end try
140         // notify user of error closing file
141         catch ( IOException )
142         {
143             MessageBox.Show( "Cannot close file", "Error",
144                             MessageBoxButtons.OK, MessageBoxIcon.Error );
145         } // end catch
146     } // end if
147
148     Application.Exit();
149 } // end method exitButton_Click
150 } // end class CreateFileForm
151 } // end namespace CreateFile
```

---

**Fig. 17.14** | Sequential file created using serialization. (Part 4 of 4.)

## 17.10 Reading and Deserializing Data from a Binary File

The preceding section showed how to create a *sequential-access file* using *object serialization*. In this section, we discuss how to read serialized objects sequentially from a file.

Figure 17.15 reads and displays the contents of the *clients.ser* file created by the program in Fig. 17.14. The sample screen captures are identical to those of Fig. 17.11, so they are not shown here. Line 15 creates the *BinaryFormatter* that will be used to read objects. The program opens the file for input by creating a *FileStream* object (lines 49–50). The name of the file to open is specified as the first argument to the *FileStream* constructor.

The program reads objects from a file in event handler *nextButton\_Click* (lines 59–92). We use method *Deserialize* (of the *BinaryFormatter* created in line 15) to read the data (lines 65–66). Note that we cast the result of *Deserialize* to type *RecordSerializ-*

able (line 66)—this cast is necessary, because `Deserialize` returns a reference of type `object` and we need to access properties that belong to class `RecordSerializable`. If an error occurs during `deserialization` or the end of the file is reached, a `SerializationException` is thrown, and the `FileStream` object is closed (line 82).

```
1 // Fig. 17.15: ReadSequentialAccessFileForm.cs
2 // Reading a sequential-access file using deserialization.
3 using System;
4 using System.Windows.Forms;
5 using System.IO;
6 using System.Runtime.Serialization.Formatters.Binary;
7 using System.Runtime.Serialization;
8 using BankLibrary;
9
10 namespace ReadSequentialAccessFile
11 {
12     public partial class ReadSequentialAccessFileForm : BankUIForm
13     {
14         // object for deserializing RecordSerializable in binary format
15         private BinaryFormatter reader = new BinaryFormatter();
16         private FileStream input; // stream for reading from a file
17
18         // parameterless constructor
19         public ReadSequentialAccessFileForm()
20         {
21             InitializeComponent();
22         } // end constructor
23
24         // invoked when user clicks the Open button
25         private void openButton_Click( object sender, EventArgs e )
26         {
27             // create and show dialog box enabling user to open file
28             DialogResult result; // result of OpenFileDialog
29             string fileName; // name of file containing data
30
31             using ( OpenFileDialog fileChooser = new OpenFileDialog() )
32             {
33                 result = fileChooser.ShowDialog();
34                 fileName = fileChooser.FileName; // get specified name
35             } // end using
36
37             // ensure that user clicked "OK"
38             if ( result == DialogResult.OK )
39             {
40                 ClearTextBoxes();
41
42                 // show error if user specified invalid file
43                 if ( fileName == string.Empty )
44                     MessageBox.Show( "Invalid File Name", "Error",
45                         MessageBoxButtons.OK, MessageBoxIcon.Error );
46                 else
47                 {
```

**Fig. 17.15** | Sequential file read using deserialization. (Part I of 2.)

```
48         // create FileStream to obtain read access to file
49         input = new FileStream(
50             fileName, FileMode.Open, FileAccess.Read );
51
52         openButton.Enabled = false; // disable Open File button
53         nextButton.Enabled = true; // enable Next Record button
54     } // end else
55 } // end if
56 } // end method openButton_Click
57
58 // invoked when user clicks Next button
59 private void nextButton_Click( object sender, EventArgs e )
60 {
61     // deserialize RecordSerializable and store data in TextBoxes
62     try
63     {
64         // get next RecordSerializable available in file
65         RecordSerializable record =
66             ( RecordSerializable ) reader.Deserialize( input );
67
68         // store RecordSerializable values in temporary string array
69         string[] values = new string[] {
70             record.Account.ToString(),
71             record.FirstName.ToString(),
72             record.LastName.ToString(),
73             record.Balance.ToString()
74         };
75
76         // copy string-array values to TextBox values
77         SetTextBoxValues( values );
78     } // end try
79     // handle exception when there are no RecordSerializables in file
80     catch ( SerializationException )
81     {
82         input.Close(); // close FileStream
83         openButton.Enabled = true; // enable Open File button
84         nextButton.Enabled = false; // disable Next Record button
85
86         ClearTextBoxes();
87
88         // notify user if no RecordSerializables in file
89         MessageBox.Show( "No more records in file", string.Empty,
90                         MessageBoxButtons.OK, MessageBoxIcon.Information );
91     } // end catch
92 } // end method nextButton_Click
93 } // end class ReadSequentialAccessFileForm
94 } // end namespace ReadSequentialAccessFile
```

---

**Fig. 17.15** | Sequential file read using deserialization. (Part 2 of 2.)

## 17.11 Wrap-Up

In this chapter, you learned how to use file processing to manipulate persistent data. You learned that data is stored in computers as 0s and 1s, and that combinations of these values

are used to form bytes, fields, records and eventually files. We overviewed several file-processing classes from the `System.IO` namespace. You used class `File` to manipulate files, and classes `Directory` and `DirectoryInfo` to manipulate directories. Next, you learned how to use sequential-access file processing to manipulate records in text files. We then discussed the differences between text-file processing and object serialization, and used serialization to store entire objects in and retrieve entire objects from files.

In Chapter 18, we begin our four chapter discussion of algorithms and data structures. Chapter 18 presents various searching algorithms for locating items in arrays and sorting algorithms for arranging the elements in arrays into ascending order. We also use Big O notation to represent the worst-case runtime for an algorithm.

---

## Summary

### *Section 17.1 Introduction*

- Files are used for long-term retention of large amounts of data.
- Data stored in files often is called persistent data.
- Computers store files on secondary storage devices.

### *Section 17.2 Data Hierarchy*

- All data items that computers process are reduced to combinations of 0s and 1s.
- The smallest data item that computers support is called a bit and can assume the value 0 or 1.
- Digits, letters and special symbols are referred to as characters. The set of all characters used to write programs and represent data items on a particular computer is that computer's character set.
- Bytes are composed of eight bits
- C# uses the Unicode character set.
- A field is a group of characters that conveys meaning. Typically, a record is composed of several related fields.
- A file is a group of related records.
- At least one field in each record is chosen as a record key, which identifies a record as belonging to a particular person or entity and distinguishes that record from all others.
- The most common type of file organization is a sequential file, in which records typically are stored in order by record-key field.

### *Section 17.3 Files and Streams*

- C# views each file as a sequential stream of bytes.
- Files are opened by creating an object that has a stream associated with it.
- Streams provide communication channels between files and programs.
- To perform file processing in C#, the `System.IO` namespace must be imported.
- Class `Stream` provides functionality for representing streams as bytes. This class is abstract, so objects of this class cannot be instantiated.
- Classes `FileStream`, `MemoryStream` and `BufferedStream` inherit from class `Stream`.
- Class `FileStream` can be used to read data to and write data from sequential-access files.
- Class `MemoryStream` enables the transfer of data directly to and from memory—this is much faster than other types of data transfer (e.g., to and from disk).

- Class `BufferedStream` uses buffering to transfer data to or from a stream. Buffering enhances I/O performance by directing each output operation to a buffer that's large enough to hold the data from many outputs. Then the actual transfer to the output device is performed in one large physical output operation each time the buffer fills. Buffering can also be used to speed input operations.

#### **Section 17.4 Classes File and Directory**

- Information on computers is stored in files, which are organized in directories. Classes `File` and `Directory` enable programs to manipulate files and directories on disk.
- Class `File` provides static methods for determining information about files and can be used to open files for reading or writing.
- Class `Directory` provides static methods for manipulating directories.
- The `DirectoryInfo` object returned by `Directory` method `CreateDirectory` contains information about a directory. Much of the information contained in class `DirectoryInfo` also can be accessed via the methods of class `Directory`.
- `File` method `Exists` determines whether a `string` is the name and path of an existing file.
- A `StreamReader` reads text from a file. Its constructor takes a `string` containing the name of the file to open and its path. `StreamReader` method `ReadToEnd` reads the entire contents of a file.
- `Directory` method `Exists` determines whether a `string` is the name of an existing directory.
- `Directory` method `GetDirectories` obtains a `string` array containing the names of subdirectories in the specified directory.
- `Directory` method `.GetFiles` returns a `string` array containing file names in the specified directory.
- `Path` method `GetExtension` obtains the extension for the specified file name.
- A `Dictionary` (namespace `System.Collections.Generic`) is a collection of key–value pairs, in which each key has a corresponding value. Class `Dictionary` is a generic class like class `List`.
- `Dictionary` method `ContainsKey` determines whether the specified key exists in the `Dictionary`.
- `Dictionary` method `Add` inserts a key–value pair into a `Dictionary`.
- `File` method `Delete` removes the specified file from disk.
- `Dictionary` property `Keys` returns all the keys in a `Dictionary`.
- `Dictionary` method `Clear` deletes the contents of a `Dictionary`.

#### **Section 17.5 Creating a Sequential-Access Text File**

- C# imposes no structure on files. You must structure files to meet your app's requirements.
- A `SaveFileDialog` is a modal dialog—the user must interact with the dialog to dismiss it.
- A `StreamWriter`'s constructor receives a `FileStream` that specifies the file in which to write text.

#### **Section 17.6 Reading Data from a Sequential-Access Text File**

- Data is stored in files so that it can be retrieved for processing when it's needed.
- To retrieve data sequentially from a file, programs normally start from the beginning of the file, reading consecutively until the desired data is found. It sometimes is necessary to process a file sequentially several times during the execution of a program.
- An `OpenFileDialog` allows a user to select files to open. Method `ShowDialog` displays the dialog.

#### **Section 17.7 Case Study: Credit Inquiry Program**

- `Stream` method `Seek` moves the file-position pointer in a file. You specify the number of bytes it should be offset from the file's beginning, end or current position. The part of the file you want to be offset from is chosen using constants from the `SeekOrigin` enumeration.

### **Section 17.8 *Serialization***

- A serialized object is represented as a sequence of bytes that includes the object's data, as well as information about the object's type and the types of data stored in the object.
- After a serialized object has been written to a file, it can be read from the file and deserialized (recreated in memory).
- Class **BinaryFormatter** (namespace `System.Runtime.Serialization.Formatters.Binary`), which supports the **ISerializable** interface, enables entire objects to be read from or written to a stream.
- **BinaryFormatter** methods **Serialize** and **Deserialize** write objects to and read objects from streams, respectively.
- Both method **Serialize** and method **Deserialize** require a **Stream** object (e.g., the **FileStream**) as a parameter so that the **BinaryFormatter** can access the correct file.

### **Section 17.9 *Creating a Sequential-Access File Using Object Serialization***

- Classes that are marked with the **Serializable** attribute or implement the **ISerializable** interface indicate to the CLR that objects of the class can be serialized. Objects that we wish to write to or read from a stream must include this attribute or implement the **ISerializable** interface in their class definitions.
- In a serializable class, you must ensure that every instance variable of the class is also serializable. By default, all simple-type variables are serializable. For reference-type variables, you must check the declaration of the class (and possibly its superclasses) to ensure that the type is serializable.

### **Section 17.10 *Reading and Deserializing Data from a Binary File***

- Method **Deserialize** (of class **BinaryFormatter**) reads a serialized object from a stream and reforms the object in memory.
- Method **Deserialize** returns a reference of type **object** which must be cast to the appropriate type to manipulate the object.
- If an error occurs during deserialization, a **SerializationException** is thrown.

## **Terminology**

|                                                  |                                                    |
|--------------------------------------------------|----------------------------------------------------|
| Add method of class <b>Dictionary</b>            | Delete method of class <b>File</b>                 |
| binary digit (bit)                               | Deserialize method of class <b>BinaryFormatter</b> |
| <b>BinaryFormatter</b> class                     | deserialized object                                |
| bit manipulation                                 | <b>Dictionary</b> class                            |
| buffer                                           | <b>Directory</b> class                             |
| <b>BufferedStream</b> class                      | <b>DirectoryInfo</b> class                         |
| buffering                                        | end-of-file marker                                 |
| Close method of class <b>StreamWriter</b>        | Error property of class <b>Console</b>             |
| closing a file                                   | Exists method of class <b>Directory</b>            |
| ContainsKey method of class <b>Dictionary</b>    | field                                              |
| Copy method of class <b>File</b>                 | file                                               |
| Create method of class <b>File</b>               | <b>File</b> class                                  |
| CreateDirectory method of class <b>Directory</b> | file-processing programs                           |
| CreateText method of class <b>File</b>           | <b>FileAccess</b> enumeration                      |
| data hierarchy                                   | <b>FileNotFoundException</b> class                 |
| database                                         | file-position pointer                              |
| database management system (DBMS)                | <b>FileStream</b> class                            |
| Delete method of class <b>Directory</b>          | fixed-length records                               |

|                                                                       |                                                                     |
|-----------------------------------------------------------------------|---------------------------------------------------------------------|
| GetCreationTime method of class <code>Directory</code>                | <code>ReadLine</code> method of class <code>Console</code>          |
| GetCreationTime method of class <code>File</code>                     | <code>ReadLine</code> method of class <code>StreamReader</code>     |
| <code>GetDirectories</code> method of class <code>Directory</code>    | record                                                              |
| <code>GetExtension</code> method of class <code>Path</code>           | record key                                                          |
| <code>GetFiles</code> method of class <code>Directory</code>          | <code>SaveFileDialog</code> class                                   |
| <code>GetLastAccessTime</code> method of class <code>Directory</code> | <code>Seek</code> method of class <code>Stream</code>               |
| <code>GetLastAccessTime</code> method of class <code>File</code>      | <code>SeekOrigin</code> enumeration                                 |
| <code>GetLastWriteTime</code> method of class <code>Directory</code>  | sequential-access file                                              |
| <code>GetLastWriteTime</code> method of class <code>File</code>       | <code>Serializable</code> attribute                                 |
| <code>In</code> property of class <code>Console</code>                | <code>SerializationException</code>                                 |
| <code>IOException</code>                                              | <code>Serialize</code> method of class <code>BinaryFormatter</code> |
| <code>ISerializable</code> interface                                  | <code>ShowDialog</code> method of class <code>SaveFileDialog</code> |
| logical output operator                                               | standard error stream object                                        |
| <code>MemoryStream</code> class                                       | standard input stream object                                        |
| modal dialog                                                          | standard output stream object                                       |
| <code>Move</code> method of class <code>Directory</code>              | <code>Stream</code> class                                           |
| <code>Move</code> method of class <code>File</code>                   | stream of bytes                                                     |
| object serialization                                                  | <code>StreamReader</code> class                                     |
| <code>Open</code> method of class <code>File</code>                   | <code>StreamWriter</code> class                                     |
| <code>OpenFileDialog</code> class                                     | <code>System.IO</code> namespace                                    |
| <code>OpenRead</code> method of class <code>File</code>               | <code>System.Runtime.Serialization.</code>                          |
| <code>OpenText</code> method of class <code>File</code>               | <code>Formatters.Binary</code> namespace                            |
| <code>OpenWrite</code> method of class <code>File</code>              | <code>TextReader</code> class                                       |
| <code>Out</code> property of class <code>Console</code>               | <code>TextWriter</code> class                                       |
| <code>Path</code> class                                               | transaction-processing system                                       |
| persistent data                                                       | <code>Write</code> method of class <code>StreamWriter</code>        |
| physical output operation                                             | <code>WriteLine</code> method of class <code>StreamWriter</code>    |
| <code>Read</code> method of class <code>Console</code>                |                                                                     |

## Self-Review Exercises

**17.1** State whether each of the following is *true* or *false*. If *false*, explain why.

- a) You cannot instantiate objects of type `Stream`.
- b) Typically, a sequential file stores records in order by the record-key field.
- c) Class `StreamReader` inherits from class `Stream`.
- d) Any class can be serialized to a file.
- e) Method `Seek` of class `FileStream` always seeks relative to the beginning of a file.
- f) Classes `StreamReader` and `StreamWriter` are used with sequential-access files.

**17.2** Fill in the blanks in each of the following statements:

- a) Ultimately, all data items processed by a computer are reduced to combinations of \_\_\_\_\_ and \_\_\_\_\_.
- b) The smallest data item a computer can process is called a(n) \_\_\_\_\_.
- c) A(n) \_\_\_\_\_ is a group of related records.
- d) Digits, letters and special symbols are collectively referred to as \_\_\_\_\_.
- e) The \_\_\_\_\_ namespace contains the `BinaryFormatter` class.
- f) `StreamReader` method \_\_\_\_\_ reads a line of text from a file.
- g) `StreamWriter` method \_\_\_\_\_ writes a line of text to a file.
- h) Method `Serialize` of class `BinaryFormatter` takes a(n) \_\_\_\_\_ and a(n) \_\_\_\_\_ as arguments.
- i) The \_\_\_\_\_ namespace contains most of C#'s file-processing classes.

## Answers to Self-Review Exercises

**17.1** a) True. b) True. c) False. Class `StreamReader` inherits from class `TextReader`. d) False. Only classes that implement interface `ISerializable` or are declared with the `Serializable` attribute can be serialized. e) False. It seeks relative to the `SeekOrigin` enumeration member that's passed as one of the arguments. f) True.

**17.2** a) 0s, 1s. b) bit. c) file. d) characters. e) `System.Runtime.Serialization.Formatters.Binary`. f) `ReadLine`. g) `WriteLine`. h) `Stream`, `object`. i) `System.IO`.

## Exercises

**17.3** (*File of Student Grades*) Create a program that stores student grades in a text file. The file should contain the name, ID number, class taken and grade of every student. Allow the user to load a grade file and display its contents in a read-only `TextBox`. The entries should be displayed in the following format:

Last Name, First Name: ID# Class Grade

We list some sample data below:

```
Jones, Bob: 1 "Introduction to Computer Science" "A-"  
Johnson, Sarah: 2 "Data Structures" "B+"  
Smith, Sam: 3 "Data Structures" "C"
```

**17.4** (*Serializing and Deserializing*) Modify the previous program to use objects of a class that can be serialized to and deserialized from a file.

**17.5** (*Extending StreamReader and StreamWriter*) Extend classes `StreamReader` and `StreamWriter`. Make the class that derives from `StreamReader` have methods `ReadInteger`, `ReadBoolean` and `ReadString`. Make the class that derives from `StreamWriter` have methods `WriteInteger`, `WriteBoolean` and `WriteString`. Think about how to design the writing methods so that the reading methods will be able to read what was written. Design `WriteInteger` and `WriteBoolean` to write strings of uniform size so that `ReadInteger` and `ReadBoolean` can read those values accurately. Make sure `ReadString` and `WriteString` use the same character(s) to separate strings.

**17.6** (*Reading and Writing Account Information*) Create a program that combines the ideas of Fig. 17.9 and Fig. 17.11 to allow a user to write records to and read records from a file. Add an extra field of type `bool` to the record to indicate whether the account has overdraft protection.

**17.7** (*Telephone-Number Word Generator*) Standard telephone keypads contain the digits zero through nine. The numbers two through nine each have three letters associated with them (Fig. 17.16). Many people find it difficult to memorize phone numbers, so they use the correspondence between digits and letters to develop seven-letter words that correspond to their phone numbers. For example, a person whose telephone number is 686-2377 might use the correspondence indicated in Fig. 17.16 to develop the seven-letter word “NUMBERS.” Every seven-letter word corresponds to exactly one seven-digit telephone number. A restaurant wishing to increase its takeout business could surely do so with the number 825-3688 (i.e., “TAKEOUT”).

Every seven-letter phone number corresponds to many different seven-letter words. Unfortunately, most of these words represent unrecognizable juxtapositions of letters. It’s possible, however, that the owner of a barbershop would be pleased to know that the shop’s telephone number, 424-7288, corresponds to “HAIRCUT.” The owner of a liquor store would no doubt be delighted to find that the store’s number, 233-7226, corresponds to “BEERCAN.” A veterinarian with the phone number 738-2273 would be pleased to know that the number corresponds to the letters “PETCARE.” An automotive dealership would be pleased to know that its phone number, 639-2277, corresponds to “NEWCARS.”

| Digit | Letter | Digit | Letter  |
|-------|--------|-------|---------|
| 2     | A B C  | 6     | M N O   |
| 3     | D E F  | 7     | P R S   |
| 4     | G H I  | 8     | T U V   |
| 5     | J K L  | 9     | W X Y Z |

**Fig. 17.16** | Letters that correspond to the numbers on a telephone keypad .

Write a GUI program that, given a seven-digit number, uses a `StreamWriter` object to write to a file every possible seven-letter word combination corresponding to that number. There are 2,187 ( $3^7$ ) such combinations. Avoid phone numbers with the digits 0 and 1.

**17.8 (Student Poll)** Figure 8.8 contains an array of survey responses that's hard-coded into the program. Suppose we wish to process survey results that are stored in a file. First, create a Windows Form that prompts the user for survey responses and outputs each response to a file. Use `StreamWriter` to create a file called `numbers.txt`. Each integer should be written using method `Write`. Then add a `TextBox` that will output the frequency of survey responses. You should modify the code in Fig. 8.8 to read the survey responses from `numbers.txt`. The responses should be read from the file by using a `StreamReader`. Class `string`'s `Split` method should be used to split the input string into separate responses, then each response should be converted to an integer. The program should continue to read responses until it reaches the end of file. The results should be output to the `TextBox`.

## Making a Difference Exercise

**17.9 (Phishing Scanner)** Phishing is a form of identity theft in which, in an e-mail, a sender posing as a trustworthy source attempts to acquire private information, such as your user names, passwords, credit-card numbers and social security number. Phishing e-mails claiming to be from popular banks, credit-card companies, auction sites, social networks and online payment services may look quite legitimate. These fraudulent messages often provide links to spoofed (fake) websites where you're asked to enter sensitive information.

Visit sites like Security Extra ([www.securityextra.com/](http://www.securityextra.com/)), [www.snopes.com](http://www.snopes.com) and other websites to find lists of the top phishing scams. Also check out the Anti-Phishing Working Group ([www.antiphishing.org/](http://www.antiphishing.org/)), and the FBI's Cyber Investigations website ([www.fbi.gov/cyberinvest/cyberhome.htm](http://www.fbi.gov/cyberinvest/cyberhome.htm)) to find information about the latest scams and how to protect yourself.

Create a list of 30 words, phrases and company names commonly found in phishing messages. Assign a point value to each based on your estimate of its likeliness to be in a phishing message (e.g., one point if it's somewhat likely, two points if moderately likely, or three points if highly likely). Write a program that scans a file of text for these terms and phrases. For each occurrence of a keyword or phrase within the text file, add the assigned point value to the total points for that word or phrase. For each keyword or phrase found, output one line with the word or phrase, the number of occurrences and the point total. Then show the point total for the entire message. Does your program assign a high point total to some actual phishing e-mails you've received? Does it assign a high point total to some legitimate e-mails you've received? [Note: If you search online for "sample phishing emails," you'll find many examples of text that you can test with this program.]

# Searching and Sorting



*With sobs and tears  
be sorted out  
Those of the largest size ...*

—Lewis Carroll

*Attempt the end, and never  
stand to doubt;  
Nothing's so hard, but search  
will find it out.*

—Robert Herrick

*It is an immutable law in  
business that words are words,  
explanations are explanations,  
promises are promises — but  
only performance is reality.*

—Harold S. Green

## Objectives

In this chapter you'll:

- Search for a given value in an array using the linear search and binary search algorithms.
- Sort arrays using the selection and insertion sort algorithms.
- Sort arrays using the recursive merge sort algorithm.
- Determine the efficiency of searching and sorting algorithms in terms of Big O.

# Outline

|             |                      |             |                                                                  |
|-------------|----------------------|-------------|------------------------------------------------------------------|
| <b>18.1</b> | Introduction         | <b>18.4</b> | Summary of the Efficiency of<br>Searching and Sorting Algorithms |
| <b>18.2</b> | Searching Algorithms | <b>18.5</b> | Wrap-Up                                                          |
| 18.2.1      | Linear Search        |             |                                                                  |
| 18.2.2      | Binary Search        |             |                                                                  |
| <b>18.3</b> | Sorting Algorithms   |             |                                                                  |
| 18.3.1      | Selection Sort       |             |                                                                  |
| 18.3.2      | Insertion Sort       |             |                                                                  |
| 18.3.3      | Merge Sort           |             |                                                                  |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 18.1 Introduction

Searching data involves determining whether a value (referred to as the *search key*) is present in the data and, if so, finding the value's location. Two popular search algorithms are the simple *linear search* and the faster, but more complex, *binary search*. Sorting places data in order, based on one or more *sort keys*. A list of names could be sorted alphabetically, bank accounts could be sorted by account number, employee payroll records could be sorted by social security number and so on. This chapter introduces two simple sorting algorithms, the *selection sort* and the *insertion sort*, along with the more efficient, but more complex, *merge sort*. Figure 18.1 summarizes the searching and sorting algorithms discussed in this book.

| Chapter                      | Algorithm                                                                             | Location              |
|------------------------------|---------------------------------------------------------------------------------------|-----------------------|
| <i>Searching Algorithms:</i> |                                                                                       |                       |
| 18                           | Linear Search                                                                         | Section 18.2.1        |
|                              | Binary Search                                                                         | Section 18.2.2        |
|                              | Recursive Linear Search                                                               | Exercise 18.8         |
|                              | Recursive Binary Search                                                               | Exercise 18.9         |
| 21                           | BinarySearch method of class <code>Array</code>                                       | Fig. 21.3             |
|                              | Contains method of classes <code>List&lt;T&gt;</code> and <code>Stack&lt;T&gt;</code> | Fig. 21.4             |
|                              | ContainsKey method of class <code>Dictionary&lt;K, T&gt;</code>                       | Fig. 21.7             |
| <i>Sorting Algorithms:</i>   |                                                                                       |                       |
| 18                           | Selection Sort                                                                        | Section 18.3.1        |
|                              | Insertion Sort                                                                        | Section 18.3.2        |
|                              | Recursive Merge Sort                                                                  | Section 18.3.3        |
|                              | Bubble Sort                                                                           | Exercises 18.5–18.6   |
|                              | Bucket Sort                                                                           | Exercise 18.7         |
|                              | Recursive Quicksort                                                                   | Exercise 18.10        |
| 18, 21                       | Sort method of classes <code>Array</code> and <code>List&lt;T&gt;</code>              | Figs. 18.4, 21.3–21.4 |

**Fig. 18.1** | Searching and sorting capabilities in this text.

## 18.2 Searching Algorithms

Looking up a phone number, accessing a website and checking the definition of a word in a dictionary all involve searching large amounts of data. The next two sections discuss two common search algorithms—one that is easy to program yet relatively inefficient and one that is relatively efficient but more complex to program.

### 18.2.1 Linear Search

The **linear search algorithm** searches each element in an array sequentially. If the search key does not match an element in the array, the algorithm tests each element and, when the end of the array is reached, informs the user that the search key is not present. If the search key is in the array, the algorithm tests each element until it finds one that matches the search key and returns the index of that element.

As an example, consider an array containing the following values

```
34 56 2 10 77 51 93 30 5 52
```

and a method that is searching for 51. Using the linear search algorithm, the method first checks whether 34 matches the search key. It does not, so the algorithm checks whether 56 matches the search key. The method continues moving through the array sequentially, testing 2, then 10, then 77. When the method tests 51, which matches the search key, the method returns the index 5, which is the location of 51 in the array. If, after checking every array element, the method determines that the search key does not match any element in the array, the method returns -1. If there are duplicate values in the array, linear search returns the index of the first element in the array that matches the search key.

Figure 18.2 declares class `LinearArray`. This class has a `private` instance variable `data` (an array of `ints`), and a `static Random` object named `generator` to fill the array with randomly generated `ints`. When an object of class `LinearArray` is instantiated, the constructor (lines 12–19) creates and initializes the array `data` with random `ints` in the range 10–99.

---

```

1 // Fig. 18.2: LinearArray.cs
2 // Class that contains an array of random integers and a method
3 // that searches that array sequentially.
4 using System;
5
6 public class LinearArray
7 {
8     private int[] data; // array of values
9     private static Random generator = new Random();
10
11    // create array of given size and fill with random integers
12    public LinearArray( int size )
13    {
14        data = new int[ size ]; // create space for array
15

```

**Fig. 18.2** | Class that contains an array of random integers and a method that searches that array sequentially. (Part 1 of 2.)

```
16     // fill array with random ints in range 10-99
17     for ( int i = 0; i < size; ++i )
18         data[ i ] = generator.Next( 10, 100 );
19 } // end LinearArray constructor
20
21 // perform a Linear search on the data
22 public int LinearSearch( int searchKey )
23 {
24     // loop through array sequentially
25     for ( int index = 0; index < data.Length; ++index )
26         if ( data[ index ] == searchKey )
27             return index; // return index of integer
28
29     return -1; // integer was not found
30 } // end method LinearSearch
31
32 // method to output values in array
33 public override string ToString()
34 {
35     string temporary = string.Empty;
36
37     // iterate through array
38     foreach ( int element in data )
39         temporary += element + " ";
40
41     temporary += "\n"; // add newline character
42     return temporary;
43 } // end method ToString
44 } // end class LinearArray
```

---

**Fig. 18.2** | Class that contains an array of random integers and a method that searches that array sequentially. (Part 2 of 2.)

Lines 22–30 perform the linear search. The search key is passed to parameter `searchKey`. Lines 25–27 loop through the elements in the array. Line 26 compares each element in the array with `searchKey`. If the values are equal, line 27 returns the index of the element. If the loop ends without finding the value, line 29 returns -1. Lines 33–43 declare method `ToString`, which returns a `string` representation of the array.

Figure 18.3 creates `LinearArray` object `searchArray` containing an array of 10 `ints` (line 13) and allows the user to search the array for specific elements. Lines 17–18 prompt the user for the search key and store it in `searchInt`. Lines 21–37 loop until the user enters the sentinel value -1. The array holds `ints` from 10–99 (line 18 of Fig. 18.2). Line 24 calls the `LinearSearch` method to determine whether `searchInt` is in the array. If `searchInt` is found, `LinearSearch` returns the position of the element, which the method outputs in lines 27–29. If `searchInt` is not in the array, `LinearSearch` returns -1, and the method notifies the user (lines 31–32). Lines 35–36 retrieve the next integer from the user.

### *Efficiency of Linear Search*

Searching algorithms all accomplish the same goal—finding an element that matches a given search key, if such an element exists. Many things, however, differentiate search algorithms from one another. The major difference is the amount of effort required to

```
1 // Fig. 18.3: LinearSearchTest.cs
2 // Sequentially search an array for an item.
3 using System;
4
5 public class LinearSearchTest
6 {
7     public static void Main( string[] args )
8     {
9         int searchInt; // search key
10        int position; // location of search key in array
11
12        // create array and output it
13        LinearArray searchArray = new LinearArray( 10 );
14        Console.WriteLine( searchArray ); // display array
15
16        // input first int from user
17        Console.Write( "Please enter an integer value (-1 to quit): " );
18        searchInt = Convert.ToInt32( Console.ReadLine() );
19
20        // repeatedly input an integer; -1 terminates the app
21        while ( searchInt != -1 )
22        {
23            // perform linear search
24            position = searchArray.LinearSearch( searchInt );
25
26            if ( position != -1 ) // integer was found
27                Console.WriteLine(
28                    "The integer {0} was found in position {1}.\n",
29                    searchInt, position );
30            else // integer was not found
31                Console.WriteLine( "The integer {0} was not found.\n",
32                    searchInt );
33
34            // input next int from user
35            Console.Write( "Please enter an integer value (-1 to quit): " );
36            searchInt = Convert.ToInt32( Console.ReadLine() );
37        } // end while
38    } // end Main
39 } // end class LinearSearchTest
```

```
64 90 84 62 28 68 55 27 78 73
```

```
Please enter an integer value (-1 to quit): 78
The integer 78 was found in position 8.
```

```
Please enter an integer value (-1 to quit): 64
The integer 64 was found in position 0.
```

```
Please enter an integer value (-1 to quit): 65
The integer 65 was not found.
```

```
Please enter an integer value (-1 to quit): -1
```

**Fig. 18.3** | Sequentially search an array for an item.

complete the search. One way to describe this effort is with **Big O notation**, which is a measure of the *worst-case runtime* for an algorithm—that is, *how hard an algorithm may have to work* to solve a problem. For searching and sorting algorithms, this is particularly dependent on *how many elements* there are in the data set and the algorithm used.

### Constant Runtime

Suppose an algorithm is designed to test whether the first element of an array is equal to the second element. If the array has 10 elements, this algorithm requires one comparison. If the array has 1,000 elements, this algorithm still requires one comparison. In fact, this algorithm is completely independent of the number of elements in the array, and is thus said to have a **constant runtime**, which is represented in Big O notation as  $O(1)$ . An algorithm that is  $O(1)$  does not necessarily require only one comparison.  $O(1)$  just means that the number of comparisons is *constant*—it *does not grow as the size of the array increases*. An algorithm that tests whether the first element of an array is equal to any of the next three elements is still  $O(1)$ , even though it requires three comparisons.

### Linear Runtime

An algorithm that tests whether the first element of an array is equal to *any* of the other elements of the array will require at most  $n - 1$  comparisons, where  $n$  is the number of elements in the array. If the array has 10 elements, this algorithm requires up to nine comparisons. If the array has 1,000 elements, this algorithm requires up to 999 comparisons. As  $n$  grows larger, the  $n$  part of the expression *dominates*, and subtracting one becomes inconsequential. Big O is designed to highlight these dominant terms and ignore terms that become unimportant as  $n$  grows. For this reason, an algorithm that requires a total of  $n - 1$  comparisons (such as the one we described earlier) is said to be  $O(n)$ . An  $O(n)$  algorithm is referred to as having a **linear runtime**.  $O(n)$  is often pronounced “on the order of  $n$ ” or more simply “order  $n$ .”

### Quadratic Runtime

Now suppose you have an algorithm that tests whether *any* element of an array is duplicated elsewhere in the array. The first element must be compared with every other element in the array. The second element must be compared with every other element except the first (it was already compared to the first). The third element must be compared with every other element except the first two. In the end, this algorithm will end up making  $(n - 1) + (n - 2) + \dots + 2 + 1$  or  $n^2/2 - n/2$  comparisons. As  $n$  increases, the  $n^2$  term dominates and the  $n$  term becomes inconsequential. Again, Big O notation highlights the  $n^2$  term, leaving  $n^2/2$ . But as we’ll soon see, constant factors are omitted in Big O notation.

Big O is concerned with how an algorithm’s runtime grows in relation to the number of items processed. Suppose an algorithm requires  $n^2$  comparisons. With four elements, the algorithm will require 16 comparisons; with eight elements, the algorithm will require 64 comparisons. With this algorithm, doubling the number of elements quadruples the number of comparisons. Consider a similar algorithm requiring  $n^2/2$  comparisons. With four elements, the algorithm will require eight comparisons; with eight elements, 32 comparisons. Again, *doubling* the number of elements *quadruples* the number of comparisons. Both of these algorithms grow as the square of  $n$ , so Big O ignores the constant, and both algorithms are considered to be  $O(n^2)$ , referred to as **quadratic runtime** and pronounced “on the order of  $n$ -squared” or more simply “order  $n$ -squared.”

When  $n$  is small,  $O(n^2)$  algorithms (running on today's billions-of-operations-per-second personal computers) will not noticeably affect performance. But as  $n$  grows, you'll start to notice the performance degradation. An  $O(n^2)$  algorithm running on a million-element array would require a trillion "operations" (where each could actually require several machine instructions to execute). This could require many minutes to execute. A billion-element array would require a quintillion operations, a number so large that the algorithm could take decades!  $O(n^2)$  algorithms are easy to write, as you'll see shortly. You'll also see algorithms with more favorable Big O measures. These efficient algorithms often take more cleverness and effort to create, but their superior performance can be well worth the extra effort, especially as  $n$  gets large.

### *Linear Search Runtime*

The linear search algorithm runs in  $O(n)$  time. The worst case in this algorithm is that every element must be checked to determine whether the search item exists in the array. If the size of the array is doubled, the number of comparisons that the algorithm must perform is also doubled. Linear search can provide outstanding performance if the element matching the search key happens to be at or near the front of the array. But we seek algorithms that perform well, on average, across *all* searches, including those where the element matching the search key is near the end of the array.

Linear search is the easiest search algorithm to program, but it can be slow compared to other search algorithms. If an app needs to perform many searches on large arrays, it may be better to implement a different, more efficient algorithm, such as the binary search, which we present in the next section.



#### **Performance Tip 18.1**

*Sometimes the simplest algorithms perform poorly. Their virtue is that they're easy to program, test and debug. Sometimes more complex algorithms are required to realize maximum performance.*

### **18.2.2 Binary Search**

The **binary search algorithm** is more efficient than the linear search algorithm, but it requires that the array first be *sorted*. The first iteration of this algorithm tests the middle element in the array. If this matches the search key, the algorithm ends. Assuming the array is sorted in ascending order, if the search key is less than the middle element, the search key cannot match any element in the second half of the array and the algorithm continues with only the first half of the array (i.e., the first element up to, but not including, the middle element). If the search key is greater than the middle element, the search key cannot match any element in the first half of the array, and the algorithm continues with only the second half of the array (i.e., the element after the middle element through the last element). Each iteration tests the middle value of the remaining portion of the array, called a *subarray*. A subarray can have no elements, or it can encompass the entire array. If the search key does not match the element, the algorithm eliminates half of the remaining elements. The algorithm ends by either finding an element that matches the search key or reducing the subarray to zero size.

As an example, consider the sorted 15-element array

|   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|
| 2 | 3 | 5 | 10 | 27 | 30 | 34 | 51 | 56 | 65 | 77 | 81 | 82 | 93 | 99 |
|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|

and a search key of 65. An app implementing the binary search algorithm would first check whether 51 is the search key (because 51 is the middle element of the array). The search key (65) is larger than 51, so 51 is “discarded” (i.e., eliminated from consideration) along with the first half of the array (all elements smaller than 51.) Next, the algorithm checks whether 81 (the middle element of the remainder of the array) matches the search key. The search key (65) is smaller than 81, so 81 is discarded along with the elements larger than 81. After just two tests, the algorithm has narrowed the number of values to check to three (56, 65 and 77). The algorithm then checks 65 (which indeed matches the search key) and returns the index of the array element containing 65. This algorithm required just three comparisons to determine whether the search key matched an element of the array. Using a linear search algorithm would have required 10 comparisons. [Note: In this example, we have chosen to use an array with 15 elements so that there will always be an obvious middle element in the array. With an even number of elements, the middle of the array lies between two elements. We implement the algorithm to choose the higher of the two elements.]

### *Implementing Binary Search*

Figure 18.4 declares class `BinaryArray`. This class is similar to `LinearArray`—it has a private instance variable `data` (an array of `ints`), a static `Random` object named `generator` to fill the array with randomly generated `ints`, a constructor, a search method (`BinarySearch`), a `RemainingElements` method (which creates a `string` containing the elements not yet searched) and a `ToString` method. Lines 12–21 declare the constructor. After initializing the array with random `ints` from 10–99 (lines 17–18), line 20 calls method `Array.Sort` on the array `data`. Method `Sort` is a static method of class `Array` that sorts the elements in an array in *ascending* order. Recall that the binary search algorithm works only on *sorted* arrays.

---

```

1 // Fig. 18.4: BinaryArray.cs
2 // Class that contains an array of random integers and a method
3 // that uses binary search to find an integer.
4 using System;
5
6 public class BinaryArray
7 {
8     private int[] data; // array of values
9     private static Random generator = new Random();
10
11    // create array of given size and fill with random integers
12    public BinaryArray( int size )
13    {
14        data = new int[ size ]; // create space for array
15
16        // fill array with random ints in range 10-99
17        for ( int i = 0; i < size; ++i )
18            data[ i ] = generator.Next( 10, 100 );
19
20        Array.Sort( data );
21    } // end BinaryArray constructor
22

```

**Fig. 18.4** | Class that contains an array of random integers and a method that uses binary search to find an integer. (Part I of 3.)

```
23 // perform a binary search on the data
24 public int BinarySearch( int searchElement )
25 {
26     int low = 0; // low end of the search area
27     int high = data.Length - 1; // high end of the search area
28     int middle = ( low + high + 1 ) / 2; // middle element
29     int location = -1; // return value; -1 if not found
30
31     do // loop to search for element
32     {
33         // display remaining elements of array
34         Console.WriteLine( RemainingElements( low, high ) );
35
36         // output spaces for alignment
37         for ( int i = 0; i < middle; ++i )
38             Console.Write( "    " );
39
40         Console.WriteLine( " * " ); // indicate current middle
41
42         // if the element is found at the middle
43         if ( searchElement == data[ middle ] )
44             location = middle; // location is the current middle
45
46         // middle element is too high
47         else if ( searchElement < data[ middle ] )
48             high = middle - 1; // eliminate the higher half
49         else // middle element is too low
50             low = middle + 1; // eliminate the lower half
51
52         middle = ( low + high + 1 ) / 2; // recalculate the middle
53     } while ( ( low <= high ) && ( location == -1 ) );
54
55     return location; // return location of search key
56 } // end method BinarySearch
57
58 // method to output certain values in array
59 public string RemainingElements( int low, int high )
60 {
61     string temporary = string.Empty;
62
63     // output spaces for alignment
64     for ( int i = 0; i < low; ++i )
65         temporary += "    ";
66
67     // output elements left in array
68     for ( int i = low; i <= high; ++i )
69         temporary += data[ i ] + " ";
70
71     temporary += "\n";
72     return temporary;
73 } // end method RemainingElements
```

**Fig. 18.4** | Class that contains an array of random integers and a method that uses binary search to find an integer. (Part 2 of 3.)

```
74 // method to output values in array
75 public override string ToString()
76 {
77     return RemainingElements( 0, data.Length - 1 );
78 } // end method ToString
79 } // end class BinaryArray
```

**Fig. 18.4** | Class that contains an array of random integers and a method that uses binary search to find an integer. (Part 3 of 3.)

Lines 24–56 declare method `BinarySearch`. The search key is passed into parameter `searchElement` (line 24). Lines 26–28 calculate the `low` end index, `high` end index and `middle` index of the portion of the array that the app is currently searching. At the beginning of the method, the `low` end is 0, the `high` end is the length of the array minus 1 and the `middle` is the average of these two values. Line 29 initializes the `location` of the element to `-1`—the value that will be returned if the element is not found. Lines 31–53 loop until `low` is greater than `high` (this occurs when the element is not found) or `location` does not equal `-1` (indicating that the search key was found). Line 43 tests whether the value in the `middle` element is equal to `searchElement`. If this is `true`, line 44 assigns `middle` to `location`. Then the loop terminates, and `location` is returned to the caller. Each iteration of the loop tests a single value (line 43) and eliminates half of the remaining values in the array (line 48 or 50).

Lines 22–40 of Fig. 18.5 loop until the user enters `-1`. For each other number the user enters, the app performs a binary search to determine whether the number matches an element in the array. The first line of output from this app is the array of `ints`, in increasing order. When the user instructs the app to search for `72`, the app first tests the `middle` element (indicated by `*` in the sample output of Fig. 18.5), which is `52`. The search key is greater than `52`, so the app eliminates from consideration the first half of the array and tests the `middle` element from the second half. The search key is smaller than `82`, so the app eliminates from consideration the second half of the subarray, leaving only three elements. Finally, the app checks `72` (which matches the search key) and returns the index `9`.

---

```
1 // Fig. 18.5: BinarySearchTest.cs
2 // Using binary search to locate an item in an array.
3 using System;
4
5 public class BinarySearchTest
6 {
7     public static void Main( string[] args )
8     {
9         int searchInt; // search key
10        int position; // Location of search key in array
11
12        // create array and output it
13        BinaryArray searchArray = new BinaryArray( 15 );
```

**Fig. 18.5** | Using binary search to locate an item in an array. (Part 1 of 2.)

```

14     Console.WriteLine( searchArray );
15
16     // prompt and input first int from user
17     Console.Write( "Please enter an integer value (-1 to quit): " );
18     searchInt = Convert.ToInt32( Console.ReadLine() );
19     Console.WriteLine();
20
21     // repeatedly input an integer; -1 terminates the app
22     while ( searchInt != -1 )
23     {
24         // use binary search to try to find integer
25         position = searchArray.BinarySearch( searchInt );
26
27         // return value of -1 indicates integer was not found
28         if ( position == -1 )
29             Console.WriteLine( "The integer {0} was not found.\n",
30                     searchInt );
31         else
32             Console.WriteLine(
33                 "The integer {0} was found in position {1}. \n",
34                 searchInt, position );
35
36         // prompt and input next int from user
37         Console.Write( "Please enter an integer value (-1 to quit): " );
38         searchInt = Convert.ToInt32( Console.ReadLine() );
39         Console.WriteLine();
40     } // end while
41 } // end Main
42 } // end class BinarySearchTest

```

```

12 17 22 25 30 39 40 52 56 72 76 82 84 91 93
Please enter an integer value (-1 to quit): 72
12 17 22 25 30 39 40 52 56 72 76 82 84 91 93
*
      56 72 76 82 84 91 93
*
      56 72 76
*
The integer 72 was found in position 9.

Please enter an integer value (-1 to quit): 13
12 17 22 25 30 39 40 52 56 72 76 82 84 91 93
*
12 17 22 25 30 39 40
*
12 17 22
*
12
*
The integer 13 was not found.

Please enter an integer value (-1 to quit): -1

```

**Fig. 18.5** | Using binary search to locate an item in an array. (Part 2 of 2.)

### *Efficiency of Binary Search*

In the worst-case scenario, searching a sorted array of 1,023 elements will take only 10 comparisons when using a binary search. Repeatedly dividing 1,023 by 2 (because after each comparison, we are able to eliminate half of the array) and rounding down (because we also remove the middle element) yields the values 511, 255, 127, 63, 31, 15, 7, 3, 1 and 0. The number  $1023 (2^{10} - 1)$  is divided by 2 only 10 times to get the value 0, which indicates that there are no more elements to test. Dividing by 2 is equivalent to one comparison in the binary search algorithm. Thus, an array of 1,048,575 ( $2^{20} - 1$ ) elements takes a maximum of 20 comparisons to find the key, and an array of one billion elements (which is less than  $2^{30} - 1$ ) takes a maximum of 30 comparisons to find the key. This is a tremendous improvement in performance over the linear search. For a one-billion-element array, this is a difference between an average of 500 million comparisons for the linear search and a maximum of only 30 comparisons for the binary search! The maximum number of comparisons needed for the binary search of any sorted array is the exponent of the first power of 2 greater than the number of elements in the array, which is represented as  $\log_2 n$ . All logarithms grow at roughly the same rate, so in Big O notation the base can be omitted. This results in a big O of  $O(\log n)$  for a binary search, which is also known as **logarithmic runtime**.

## 18.3 Sorting Algorithms

Sorting data (i.e., placing the data in some particular order, such as *ascending* or *descending*) is one of the most important computing applications. A bank sorts all checks by account number so that it can prepare individual bank statements at the end of each month. Telephone companies sort their lists of accounts by last name and, further, by first name to make it easy to find phone numbers. Virtually every organization must sort some data—often, massive amounts of it. Sorting data is an intriguing, compute-intensive problem that has attracted substantial research efforts.

It's important to understand about sorting that the *end result*—the sorted array—will be the *same* no matter which (correct) algorithm you use to sort the array. The choice of algorithm affects only the *runtime* and *memory use* of the app. The rest of the chapter introduces three common sorting algorithms. The first two—*selection sort* and *insertion sort*—are simple to program, but inefficient. The last—*merge sort*—is much faster than selection sort and insertion sort but more difficult to program. We focus on sorting arrays of simple-type data, namely `ints`. It's possible to sort arrays of objects as well—we discuss this in Chapter 21, Collections.

### 18.3.1 Selection Sort

**Selection sort** is a simple, but inefficient, sorting algorithm. The first iteration of the algorithm selects the *smallest element* in the array and swaps it with the first element. The second iteration selects the *second-smallest element* (which is the smallest of the remaining elements) and swaps it with the second element. The algorithm continues until the last iteration selects the *second-largest element* and, if necessary, swaps it with the *second-to-last element*, leaving the *largest element* in the *last* position. After the  $i$ th iteration, the smallest  $i$  elements of the array will be sorted in increasing order in the first  $i$  positions of the array.

As an example, consider the array

|    |    |   |    |    |    |    |    |   |    |
|----|----|---|----|----|----|----|----|---|----|
| 34 | 56 | 4 | 10 | 77 | 51 | 93 | 30 | 5 | 52 |
|----|----|---|----|----|----|----|----|---|----|

An app that implements selection sort first determines the smallest element (4) of this array, which is contained in index 2 (i.e., position 3). The app swaps 4 with 34, resulting in

|   |    |    |    |    |    |    |    |   |    |
|---|----|----|----|----|----|----|----|---|----|
| 4 | 56 | 34 | 10 | 77 | 51 | 93 | 30 | 5 | 52 |
|---|----|----|----|----|----|----|----|---|----|

The app then determines the smallest value of the *remaining* elements (all elements except 4), which is 5, contained in index 8. The app swaps 5 with 56, resulting in

|   |   |    |    |    |    |    |    |    |    |
|---|---|----|----|----|----|----|----|----|----|
| 4 | 5 | 34 | 10 | 77 | 51 | 93 | 30 | 56 | 52 |
|---|---|----|----|----|----|----|----|----|----|

On the third iteration, the app determines the next smallest value (10) and swaps it with 34.

|   |   |    |    |    |    |    |    |    |    |
|---|---|----|----|----|----|----|----|----|----|
| 4 | 5 | 10 | 34 | 77 | 51 | 93 | 30 | 56 | 52 |
|---|---|----|----|----|----|----|----|----|----|

The process continues until the array is fully sorted.

|   |   |    |    |    |    |    |    |    |    |
|---|---|----|----|----|----|----|----|----|----|
| 4 | 5 | 10 | 30 | 34 | 51 | 52 | 56 | 77 | 93 |
|---|---|----|----|----|----|----|----|----|----|

After the first iteration, the smallest element is in the first position. After the second iteration, the two smallest elements are in order in the first two positions. After the third iteration, the three smallest elements are in order in the first three positions.

Figure 18.6 declares class `SelectionSort`, which has an instance variable `data` (an array of `ints`) and a `static Random` object generator to generate random integers to fill the array. When an object of class `SelectionSort` is instantiated, the constructor (lines 12–19) creates and initializes array `data` with random `ints` in the range 10–99.

---

```

1 // Fig. 18.6: SelectionSort.cs
2 // Class that creates an array filled with random integers.
3 // Provides a method to sort the array with selection sort.
4 using System;
5
6 public class SelectionSort
7 {
8     private int[] data; // array of values
9     private static Random generator = new Random();
10
11    // create array of given size and fill with random integers
12    public SelectionSort( int size )
13    {
14        data = new int[ size ]; // create space for array
15
16        // fill array with random ints in range 10-99
17        for ( int i = 0; i < size; ++i )
18            data[ i ] = generator.Next( 10, 100 );
19    } // end SelectionSort constructor
20
21    // sort array using selection sort
22    public void Sort()
23    {
24        int smallest; // index of smallest element

```

**Fig. 18.6** | Class that creates an array filled with random integers. Provides a method to sort the array with selection sort. (Part I of 3.)

```
25 // loop over data.Length - 1 elements
26 for ( int i = 0; i < data.Length - 1; ++i )
27 {
28     smallest = i; // first index of remaining array
29
30     // loop to find index of smallest element
31     for ( int index = i + 1; index < data.Length; ++index )
32         if ( data[ index ] < data[ smallest ] )
33             smallest = index;
34
35     Swap( i, smallest ); // swap smallest element into position
36     PrintPass( i + 1, smallest ); // output pass of algorithm
37 } // end outer for
38 } // end method Sort
39
40 // helper method to swap values in two elements
41 public void Swap( int first, int second )
42 {
43     int temporary = data[ first ]; // store first in temporary
44     data[ first ] = data[ second ]; // replace first with second
45     data[ second ] = temporary; // put temporary in second
46 } // end method Swap
47
48 // display a pass of the algorithm
49 public void PrintPass( int pass, int index )
50 {
51     Console.Write( "after pass {0}: ", pass );
52
53     // output elements through the selected item
54     for ( int i = 0; i < index; ++i )
55         Console.Write( data[ i ] + " " );
56
57     Console.Write( data[ index ] + "* " ); // indicate swap
58
59     // finish outputting array
60     for ( int i = index + 1; i < data.Length; ++i )
61         Console.Write( data[ i ] + " " );
62
63     Console.WriteLine( "\n" ); // for alignment
64
65     // indicate amount of array that is sorted
66     for( int j = 0; j < pass; ++j )
67         Console.Write( "-- " );
68     Console.WriteLine( "\n" ); // skip a line in output
69 } // end method PrintPass
70
71
72 // method to output values in array
73 public override string ToString()
74 {
75     string temporary = string.Empty;
```

**Fig. 18.6** | Class that creates an array filled with random integers. Provides a method to sort the array with selection sort. (Part 2 of 3.)

---

```

76         // iterate through array
77         foreach ( int element in data )
78             temporary += element + " ";
79
80             temporary += "\n"; // add newline character
81             return temporary;
82     } // end method ToString
83 }
84 } // end class SelectionSort

```

---

**Fig. 18.6** | Class that creates an array filled with random integers. Provides a method to sort the array with selection sort. (Part 3 of 3.)

Lines 22–39 declare the Sort method. Line 24 declares variable `smallest`, which will store the index of the smallest element in the remaining array. Lines 27–38 loop `data.Length - 1` times. Line 29 initializes the index of the smallest element to the current item. Lines 32–34 loop over the remaining elements in the array. For each of these elements, line 33 compares its value to the value of the smallest element. If the current element is smaller than the smallest element, line 34 assigns the current element's index to `smallest`. When this loop finishes, `smallest` will contain the index of the smallest element in the remaining array. Line 36 calls method Swap (lines 42–47) to place the smallest remaining element in the next spot in the array.

Line 10 of Fig. 18.7 creates a `SelectionSort` object with 10 elements. Line 13 implicitly calls method `ToString` to output the unsorted object. Line 15 calls method `Sort` (Fig. 18.6, lines 22–39), which sorts the elements using selection sort. Then lines 17–18 output the sorted object. The output uses dashes to indicate the portion of the array that is sorted after each pass (Fig. 18.6, lines 67–68). An asterisk is placed next to the position of the element that was swapped with the smallest element on that pass. On each pass, the element next to the asterisk and the element above the rightmost set of dashes were the two values that were swapped.

---

```

1 // Fig. 18.7: SelectionSortTest.cs
2 // Testing the selection sort class.
3 using System;
4
5 public class SelectionSortTest
6 {
7     public static void Main( string[] args )
8     {
9         // create object to perform selection sort
10        SelectionSort sortArray = new SelectionSort( 10 );
11
12        Console.WriteLine( "Unsorted array:" );
13        Console.WriteLine( sortArray ); // display unsorted array
14
15        sortArray.Sort(); // sort array
16

```

---

**Fig. 18.7** | Testing the selection sort class. (Part I of 2.)

---

```

17     Console.WriteLine( "Sorted array:" );
18     Console.WriteLine( sortArray ); // display sorted array
19 } // end Main
20 } // end class SelectionSortTest

```

|                 |                                |
|-----------------|--------------------------------|
| Unsorted array: | 86 97 83 45 19 31 86 13 57 61  |
| after pass 1:   | 13 97 83 45 19 31 86 86* 57 61 |
|                 | --                             |
| after pass 2:   | 13 19 83 45 97* 31 86 86 57 61 |
|                 | -- --                          |
| after pass 3:   | 13 19 31 45 97 83* 86 86 57 61 |
|                 | -- -- --                       |
| after pass 4:   | 13 19 31 45* 97 83 86 86 57 61 |
|                 | -- -- -- --                    |
| after pass 5:   | 13 19 31 45 57 83 86 86 97* 61 |
|                 | -- -- -- -- --                 |
| after pass 6:   | 13 19 31 45 57 61 86 86 97 83* |
|                 | -- -- -- -- -- --              |
| after pass 7:   | 13 19 31 45 57 61 83 86 97 86* |
|                 | -- -- -- -- -- -- --           |
| after pass 8:   | 13 19 31 45 57 61 83 86* 97 86 |
|                 | -- -- -- -- -- -- -- --        |
| after pass 9:   | 13 19 31 45 57 61 83 86 86 97* |
|                 | -- -- -- -- -- -- -- -- --     |
| Sorted array:   | 13 19 31 45 57 61 83 86 86 97  |

**Fig. 18.7** | Testing the selection sort class. (Part 2 of 2.)

### Efficiency of Selection Sort

The selection sort algorithm runs in  $O(n^2)$  time. Method Sort in lines 22–39 of Fig. 18.6, which implements the selection sort algorithm, contains *nested for loops*. The outer for loop (lines 27–38) iterates over the first  $n - 1$  elements in the array, swapping the smallest remaining element to its sorted position. The inner for loop (lines 32–34) iterates over each element in the remaining array, searching for the smallest. This loop executes  $n - 1$  times during the first iteration of the outer loop,  $n - 2$  times during the second iteration, then  $n - 3, \dots, 3, 2, 1$ . This inner loop will iterate a total of  $n(n - 1) / 2$  or  $(n^2 - n)/2$ . In Big O notation, smaller terms drop out and constants are ignored, leaving a final Big O of  $O(n^2)$ .

### 18.3.2 Insertion Sort

Insertion sort is another *simple*, but *inefficient*, sorting algorithm. Its first iteration takes the second element in the array and, if it's less than the first, swaps them. The second iteration looks at the third element and inserts it in the correct position with respect to the first two elements (moving them as necessary), so all three elements are in order. At the  $i$ th iteration of this algorithm, the first  $i$  elements in the original array will be sorted.

Consider as an example the following array, which is identical to the array we used in the discussions of selection sort and merge sort.

|    |    |   |    |    |    |    |    |   |    |
|----|----|---|----|----|----|----|----|---|----|
| 34 | 56 | 4 | 10 | 77 | 51 | 93 | 30 | 5 | 52 |
|----|----|---|----|----|----|----|----|---|----|

An app that implements the insertion sort algorithm first looks at the first two elements of the array, 34 and 56. These are already in order, so the app continues (if they were out of order, it would swap them).

In the next iteration, the app looks at the third value, 4. This value is less than 56, so the app stores 4 in a temporary variable and moves 56 one element to the right. The app then checks and determines that 4 is less than 34, so it moves 34 one element to the right. The app has now reached the beginning of the array, so it places 4 in the zeroth position. The array now is

|   |    |    |    |    |    |    |    |   |    |
|---|----|----|----|----|----|----|----|---|----|
| 4 | 34 | 56 | 10 | 77 | 51 | 93 | 30 | 5 | 52 |
|---|----|----|----|----|----|----|----|---|----|

In the next iteration, the app stores the value 10 in a temporary variable. Then the app compares 10 to 56 and moves 56 one element to the right because it's larger than 10. The app then compares 10 to 34, moving 34 one element to the right. When the app compares 10 to 4, it observes that 10 is larger than 4 and places 10 in element 1. The array now is

|   |    |    |    |    |    |    |    |   |    |
|---|----|----|----|----|----|----|----|---|----|
| 4 | 10 | 34 | 56 | 77 | 51 | 93 | 30 | 5 | 52 |
|---|----|----|----|----|----|----|----|---|----|

Using this algorithm, at the  $i$ th iteration, the original array's first  $i$  elements are sorted, but they may not be in their final locations—smaller values may be located later in the array.

Figure 18.8 declares the `InsertionSort` class. Lines 22–46 declare the `Sort` method. Line 24 declares variable `insert`, which holds the element to be inserted while the other elements are moved. Lines 27–45 loop through `data.Length - 1` items in the array. In each iteration, line 30 stores in variable `insert` the value of the element that will be inserted in the sorted portion of the array. Line 33 declares and initializes variable `moveItem`, which keeps track of where to insert the element. Lines 36–41 loop to locate the correct position to insert the element. The loop will terminate either when the app reaches the front of the array or when it reaches an element that is less than the value to be inserted. Line 39 moves an element to the right, and line 40 decrements the position at which to insert the next element. After the loop ends, line 43 inserts the element in place. Figure 18.9 is the same as Fig. 18.7 except that it creates and uses an `InsertionSort` object. The output of this app uses dashes to indicate the portion of the array that is sorted after each pass (lines 66–67 of Fig. 18.8). An asterisk is placed next to the element that was inserted in place on that pass.

---

```

1 // Fig. 18.8: InsertionSort.cs
2 // Class that creates an array filled with random integers.
3 // Provides a method to sort the array with insertion sort.
4 using System;
5
6 public class InsertionSort
7 {

```

**Fig. 18.8** | Class that creates an array filled with random integers. Provides a method to sort the array with insertion sort. (Part I of 3.)

```
8  private int[] data; // array of values
9  private static Random generator = new Random();
10
11 // create array of given size and fill with random integers
12 public InsertionSort( int size )
13 {
14     data = new int[ size ]; // create space for array
15
16     // fill array with random ints in range 10-99
17     for ( int i = 0; i < size; ++i )
18         data[ i ] = generator.Next( 10, 100 );
19 } // end InsertionSort constructor
20
21 // sort array using insertion sort
22 public void Sort()
23 {
24     int insert; // temporary variable to hold element to insert
25
26     // loop over data.Length - 1 elements
27     for ( int next = 1; next < data.Length; ++next )
28     {
29         // store value in current element
30         insert = data[ next ];
31
32         // initialize location to place element
33         int moveItem = next;
34
35         // search for place to put current element
36         while ( moveItem > 0 && data[ moveItem - 1 ] > insert )
37         {
38             // shift element right one slot
39             data[ moveItem ] = data[ moveItem - 1 ];
40             moveItem--;
41         } // end while
42
43         data[ moveItem ] = insert; // place inserted element
44         PrintPass( next, moveItem ); // output pass of algorithm
45     } // end for
46 } // end method Sort
47
48 // display a pass of the algorithm
49 public void PrintPass( int pass, int index )
50 {
51     Console.Write( "after pass {0}: ", pass );
52
53     // output elements till swapped item
54     for ( int i = 0; i < index; ++i )
55         Console.Write( data[ i ] + " " );
56
57     Console.Write( data[ index ] + "* " ); // indicate swap
58 }
```

---

**Fig. 18.8** | Class that creates an array filled with random integers. Provides a method to sort the array with insertion sort. (Part 2 of 3.)

---

```

59         // finish outputting array
60         for ( int i = index + 1; i < data.Length; ++i )
61             Console.Write( data[ i ] + " " );
62
63         Console.WriteLine( "\n" ); // for alignment
64
65         // indicate amount of array that is sorted
66         for( int i = 0; i <= pass; ++i )
67             Console.Write( "-- " );
68         Console.WriteLine( "\n" ); // skip a line in output
69     } // end method PrintPass
70
71     // method to output values in array
72     public override string ToString()
73     {
74         string temporary = string.Empty;
75
76         // iterate through array
77         foreach ( int element in data )
78             temporary += element + " ";
79
80         temporary += "\n"; // add newline character
81         return temporary;
82     } // end method ToString
83 } // end class InsertionSort

```

---

**Fig. 18.8** | Class that creates an array filled with random integers. Provides a method to sort the array with insertion sort. (Part 3 of 3.)

---

```

1 // Fig. 18.9: InsertionSortTest.cs
2 // Testing the insertion sort class.
3 using System;
4
5 public class InsertionSortTest
6 {
7     public static void Main( string[] args )
8     {
9         // create object to perform insertion sort
10        InsertionSort sortArray = new InsertionSort( 10 );
11
12        Console.WriteLine( "Unsorted array:" );
13        Console.WriteLine( sortArray ); // display unsorted array
14
15        sortArray.Sort(); // sort array
16
17        Console.WriteLine( "Sorted array:" );
18        Console.WriteLine( sortArray ); // display sorted array
19    } // end Main
20 } // end class InsertionSortTest

```

---

**Fig. 18.9** | Testing the insertion sort class. (Part 1 of 2.)

| Unsorted array:                              |    |    |    |    |    |    |    |    |    |  |  |
|----------------------------------------------|----|----|----|----|----|----|----|----|----|--|--|
| 12                                           | 27 | 36 | 28 | 33 | 92 | 11 | 93 | 59 | 62 |  |  |
| after pass 1: 12 27* 36 28 33 92 11 93 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- |    |    |    |    |    |    |    |    |  |  |
| after pass 2: 12 27 36* 28 33 92 11 93 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- |    |    |    |    |    |    |    |  |  |
| after pass 3: 12 27 28* 36 33 92 11 93 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- |    |    |    |    |    |  |  |
| after pass 4: 12 27 28 33* 36 92 11 93 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- | -- |    |    |    |    |  |  |
| after pass 5: 12 27 28 33 36 92* 11 93 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- | -- | -- |    |    |    |  |  |
| after pass 6: 11* 12 27 28 33 36 92 93 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- | -- | -- | -- | -- | -- |  |  |
| after pass 7: 11 12 27 28 33 36 92 93* 59 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- | -- | -- | -- | -- | -- |  |  |
| after pass 8: 11 12 27 28 33 36 59* 92 93 62 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- | -- | -- | -- | -- | -- |  |  |
| after pass 9: 11 12 27 28 33 36 59 62* 92 93 |    |    |    |    |    |    |    |    |    |  |  |
| --                                           | -- | -- | -- | -- | -- | -- | -- | -- | -- |  |  |
| Sorted array:                                |    |    |    |    |    |    |    |    |    |  |  |
| 11                                           | 12 | 27 | 28 | 33 | 36 | 59 | 62 | 92 | 93 |  |  |

**Fig. 18.9** | Testing the insertion sort class. (Part 2 of 2.)

## *Efficiency of Insertion Sort*

The insertion sort algorithm also runs in  $O(n^2)$  time. Like selection sort, the implementation of insertion sort (lines 22–46 of Fig. 18.8) contains *nested loops*. The `for` loop (lines 27–45) iterates `data.Length - 1` times, inserting an element in the appropriate position in the elements sorted so far. For the purposes of this app, `data.Length - 1` is equivalent to  $n - 1$  (as `data.Length` is the size of the array). The `while` loop (lines 36–41) iterates over the preceding elements in the array. In the *worst case*, this `while` loop will require  $n - 1$  comparisons. Each individual loop runs in  $O(n)$  time. In Big O notation, *nested loops* mean that you must *multiply* the number of iterations of each loop. For each iteration of an outer loop, there will be a certain number of iterations of the inner loop. In this algorithm, for each  $O(n)$  iterations of the outer loop, there will be  $O(n)$  iterations of the inner loop. Multiplying these values results in a Big O of  $O(n^2)$ .

### 18.3.3 Merge Sort

Merge sort is an *efficient* sorting algorithm but is conceptually more *complex* than selection sort and insertion sort. The merge sort algorithm sorts an array by *splitting* it into two

equal-sized subarrays, *sorting* each subarray and *merging* them in one larger array. With an odd number of elements, the algorithm creates the two subarrays such that one has one more element than the other.

The implementation of merge sort in this example is *recursive*. The base case is an array with one element. A one-element array is, of course, sorted, so merge sort immediately returns when it's called with a one-element array. The *recursion step* splits an array in two approximately equal-length pieces, recursively *sorts* them and *merges* the two sorted arrays in one larger, sorted array.

Suppose the algorithm has already merged smaller arrays to create sorted arrays A:

```
4   10   34   56   77
```

and B:

```
5   30   51   52   93
```

Merge sort combines these two arrays in one larger, sorted array. The smallest element in A is 4 (located in the zeroth element of A). The smallest element in B is 5 (located in the zeroth element of B). In order to determine the smallest element in the larger array, the algorithm compares 4 and 5. The value from A is smaller, so 4 becomes the first element in the merged array. The algorithm continues by comparing 10 (the second element in A) to 5 (the first element in B). The value from B is smaller, so 5 becomes the second element in the larger array. The algorithm continues by comparing 10 to 30, with 10 becoming the third element in the array, and so on.

Lines 22–25 of Fig. 18.10 declare the Sort method. Line 24 calls method SortArray with 0 and data.Length - 1 as the arguments—these are the beginning and ending indices of the array to be sorted. These values tell method SortArray to operate on the entire array.

---

```

1 // Fig. 18.10: MergeSort.cs
2 // Class that creates an array filled with random integers.
3 // Provides a method to sort the array with merge sort.
4 using System;
5
6 public class MergeSort
7 {
8     private int[] data; // array of values
9     private static Random generator = new Random();
10
11    // create array of given size and fill with random integers
12    public MergeSort( int size )
13    {
14        data = new int[ size ]; // create space for array
15
16        // fill array with random ints in range 10-99
17        for ( int i = 0; i < size; ++i )
18            data[ i ] = generator.Next( 10, 100 );
19    } // end MergeSort constructor
20

```

---

**Fig. 18.10** | Class that creates an array filled with random integers. Provides a method to sort the array with merge sort. (Part I of 3.)

```

21 // calls recursive SortArray method to begin merge sorting
22 public void Sort()
23 {
24     SortArray( 0, data.Length - 1 ); // sort entire array
25 } // end method Sort
26
27 // splits array, sorts subarrays and merges subarrays into sorted array
28 private void SortArray( int low, int high )
29 {
30     // test base case; size of array equals 1
31     if ( ( high - low ) >= 1 ) // if not base case
32     {
33         int middle1 = ( low + high ) / 2; // calculate middle of array
34         int middle2 = middle1 + 1; // calculate next element over
35
36         // output split step
37         Console.WriteLine( "split:    " + Subarray( low, high ) );
38         Console.WriteLine( "           " + Subarray( low, middle1 ) );
39         Console.WriteLine( "           " + Subarray( middle2, high ) );
40         Console.WriteLine();
41
42         // split array in half; sort each half (recursive calls)
43         SortArray( low, middle1 ); // first half of array
44         SortArray( middle2, high ); // second half of array
45
46         // merge two sorted arrays after split calls return
47         Merge( low, middle1, middle2, high );
48     } // end if
49 } // end method SortArray
50
51 // merge two sorted subarrays into one sorted subarray
52 private void Merge( int left, int middle1, int middle2, int right )
53 {
54     int leftIndex = left; // index into left subarray
55     int rightIndex = middle2; // index into right subarray
56     int combinedIndex = left; // index into temporary working array
57     int[] combined = new int[ data.Length ]; // working array
58
59     // output two subarrays before merging
60     Console.WriteLine( "merge:    " + Subarray( left, middle1 ) );
61     Console.WriteLine( "           " + Subarray( middle2, right ) );
62
63     // merge arrays until reaching end of either
64     while ( leftIndex <= middle1 && rightIndex <= right )
65     {
66         // place smaller of two current elements into result
67         // and move to next space in arrays
68         if ( data[ leftIndex ] <= data[ rightIndex ] )
69             combined[ combinedIndex++ ] = data[ leftIndex++ ];
70         else
71             combined[ combinedIndex++ ] = data[ rightIndex++ ];
72     } // end while

```

**Fig. 18.10** | Class that creates an array filled with random integers. Provides a method to sort the array with merge sort. (Part 2 of 3.)

```

73
74     // if left array is empty
75     if ( leftIndex == middle2 )
76         // copy in rest of right array
77         while ( rightIndex <= right )
78             combined[ combinedIndex++ ] = data[ rightIndex++ ];
79     else // right array is empty
80         // copy in rest of left array
81         while ( leftIndex <= middle1 )
82             combined[ combinedIndex++ ] = data[ leftIndex++ ];
83
84     // copy values back into original array
85     for ( int i = left; i <= right; ++i )
86         data[ i ] = combined[ i ];
87
88     // output merged array
89     Console.WriteLine( "           " + Subarray( left, right ) );
90     Console.WriteLine();
91 } // end method Merge
92
93 // method to output certain values in array
94 public string Subarray( int low, int high )
95 {
96     string temporary = string.Empty;
97
98     // output spaces for alignment
99     for ( int i = 0; i < low; ++i )
100        temporary += "   ";
101
102    // output elements left in array
103    for ( int i = low; i <= high; ++i )
104        temporary += " " + data[ i ];
105
106    return temporary;
107 } // end method Subarray
108
109 // method to output values in array
110 public override string ToString()
111 {
112     return Subarray( 0, data.Length - 1 );
113 } // end method ToString
114 } // end class MergeSort

```

**Fig. 18.10** | Class that creates an array filled with random integers. Provides a method to sort the array with merge sort. (Part 3 of 3.)

Method `SortArray` is declared in lines 28–49. Line 31 tests the base case. If the size of the array is 1, the array is *already sorted*, so the method simply returns immediately. If the size of the array is greater than 1, the method splits the array in two, recursively calls method `SortArray` to sort the two subarrays and merges them. Line 43 recursively calls method `SortArray` on the first half of the array, and line 44 recursively calls method `SortArray` on the second half of the array. When these two method calls return, each half of

the array has been sorted. Line 47 calls method `Merge` (lines 52–91) on the two halves of the array to combine the two sorted arrays in one larger sorted array.

Lines 64–72 in method `Merge` loop until the app reaches the end of either subarray. Line 68 tests which element at the beginning of the arrays is smaller. If the element in the left array is smaller or equal, line 69 places it in position in the combined array. If the element in the right array is smaller, line 71 places it in position in the combined array. When the `while` loop has completed (line 72), one entire subarray is placed in the combined array, but the other subarray still contains data. Line 75 tests whether the left array has reached the end. If so, lines 77–78 fill the combined array with the remaining elements of the right array. If the left array has not reached the end, then the right array has, and lines 81–82 fill the combined array with the remaining elements of the left array. Finally, lines 85–86 copy the combined array into the original array. Figure 18.11 creates and uses a `MergeSort` object. The output from this app displays the splits and merges performed by merge sort, showing the progress of the sort at each step of the algorithm.

```

1 // Fig. 18.11: MergeSortTest.cs
2 // Testing the merge sort class.
3 using System;
4
5 public class MergeSortTest
6 {
7     public static void Main( string[] args )
8     {
9         // create object to perform merge sort
10        MergeSort sortArray = new MergeSort( 10 );
11
12        // display unsorted array
13        Console.WriteLine( "Unsorted: {0}\n\n", sortArray );
14
15        sortArray.Sort(); // sort array
16
17        // display sorted array
18        Console.WriteLine( "Sorted: {0}", sortArray );
19    } // end Main
20 } // end class MergeSortTest

```

```

Unsorted: 36 38 81 93 85 72 31 11 33 74

split:   36 38 81 93 85 72 31 11 33 74
          36 38 81 93 85
                      72 31 11 33 74

split:   36 38 81 93 85
          36 38 81
                      93 85

split:   36 38 81
          36 38
                      81

```

**Fig. 18.11** | Testing the merge sort class. (Part I of 2.)

```
split:    36 38
          36
          38

merge:    36
          38
          36 38

merge:    36 38
          81
          36 38 81

split:      93 85
          93
          85

merge:      93
          85
          85 93

merge:    36 38 81
          85 93
          36 38 81 85 93

split:      72 31 11 33 74
          72 31 11
          33 74

split:      72 31 11
          72 31
          11

split:      72 31
          72
          31

merge:      72
          31
          31 72

merge:      31 72
          11
          11 31 72

split:      33 74
          33
          74

merge:      33
          74
          33 74

merge:      11 31 72
          33 74
          11 31 33 72 74

merge:    36 38 81 85 93
          11 31 33 36 38 72 74 81 85 93

Sorted:   11 31 33 36 38 72 74 81 85 93
```

**Fig. 18.11** | Testing the merge sort class. (Part 2 of 2.)

***Efficiency of Merge Sort***

Merge sort is a *far more efficient* algorithm than either insertion sort or selection sort when sorting *large* sets of data. Consider the first (*nonrecursive*) call to method `SortArray`. This results in two *recursive* calls to method `SortArray` with subarrays each approximately *half* the size of the original array, and a single call to method `Merge`. This call to method `Merge` requires, at worst,  $n - 1$  comparisons to fill the original array, which is  $O(n)$ . (Recall that each element in the array can be chosen by comparing one element from each of the subarrays.) The two calls to method `SortArray` result in four more *recursive* calls to `SortArray`, each with a subarray approximately a quarter the size of the original array, along with two calls to method `Merge`. These two calls to method `Merge` each require, at worst,  $n/2 - 1$  comparisons for a total number of comparisons of  $(n/2 - 1) + (n/2 - 1) = n - 2$ , which is  $O(n)$ . This process continues, each call to `SortArray` generating two additional calls to method `SortArray` and a call to `Merge`, until the algorithm has split the array into one-element subarrays. At each level,  $O(n)$  comparisons are required to merge the subarrays. Each level *splits* the size of the arrays in half, so *doubling* the size of the array requires only *one* more level. *Quadrupling* the size of the array requires only *two* more levels. This pattern is *logarithmic* and results in  $\log_2 n$  levels. This results in a total efficiency of  $O(n \log n)$ .

## 18.4 Summary of the Efficiency of Searching and Sorting Algorithms

Figure 18.12 summarizes many of the searching and sorting algorithms covered in this book and lists the Big O of each. Figure 18.13 lists the Big O expressions covered in this chapter, along with a number of values for  $n$  to highlight the differences in the growth rates.

| Algorithm                    | Location            | Big O         |
|------------------------------|---------------------|---------------|
| <i>Searching Algorithms:</i> |                     |               |
| Linear Search                | Section 18.2.1      | $O(n)$        |
| Binary Search                | Section 18.2.2      | $O(\log n)$   |
| Recursive Linear Search      | Exercise 18.8       | $O(n)$        |
| Recursive Binary Search      | Exercise 18.9       | $O(\log n)$   |
| <i>Sorting Algorithms:</i>   |                     |               |
| Selection Sort               | Section 18.3.1      | $O(n^2)$      |
| Insertion Sort               | Section 18.3.2      | $O(n^2)$      |
| Merge Sort                   | Section 18.3.3      | $O(n \log n)$ |
| Bubble Sort                  | Exercises 18.5–18.6 | $O(n^2)$      |

**Fig. 18.12** | Searching and sorting algorithms with Big O values.

| $n =$ | $O(\log n)$ | $O(n)$ | $O(n \log n)$ | $O(n^2)$ |
|-------|-------------|--------|---------------|----------|
| 1     | 0           | 1      | 0             | 1        |

**Fig. 18.13** | Number of comparisons for common Big O notations. (Part 1 of 2.)

| $n =$         | $O(\log n)$ | $O(n)$     | $O(n \log n)$ | $O(n^2)$  |
|---------------|-------------|------------|---------------|-----------|
| 2             | 1           | 2          | 2             | 4         |
| 3             | 1           | 3          | 3             | 9         |
| 4             | 1           | 4          | 4             | 16        |
| 5             | 1           | 5          | 5             | 25        |
| 10            | 1           | 10         | 10            | 100       |
| 100           | 2           | 100        | 200           | 10000     |
| 1,000         | 3           | 1000       | 3000          | $10^6$    |
| 1,000,000     | 6           | 1000000    | 6000000       | $10^{12}$ |
| 1,000,000,000 | 9           | 1000000000 | 9000000000    | $10^{18}$ |

**Fig. 18.13** | Number of comparisons for common Big O notations. (Part 2 of 2.)

## 18.5 Wrap-Up

In this chapter, you learned how to search for items in arrays and how to sort arrays so that their elements are arranged in order. We discussed linear search and binary search, and selection sort, insertion sort and merge sort. You learned that linear search can operate on any set of data, but that binary search requires the data to be sorted first. You also learned that the simplest searching and sorting algorithms can exhibit poor performance. We introduced Big O notation—a measure of the efficiency of algorithms—and used it to compare the efficiency of the algorithms we discussed. In the next chapter, you’ll learn about dynamic data structures that can grow or shrink at execution time.

## Summary

### Section 18.1 Introduction

- Searching involves determining if a search key is present in the data and, if so, finding its location.
- Sorting involves arranging data in order.

### Section 18.2.1 Linear Search

- The linear search algorithm searches each element in an array sequentially until it finds the element that matches the search key. If the search key is not in the array, the algorithm tests each element in the array, and when the end of the array is reached, informs the user that the search key is not present, usually by means of a sentinel value.
- One way to describe the efficiency of an algorithm is with Big O notation ( $O$ ), which indicates how hard an algorithm may have to work to solve a problem.
- In searching and sorting algorithms, Big O is dependent on how many elements are in the data.
- An  $O(n)$  algorithm is referred to as having a linear runtime.
- Big O is designed to highlight dominant factors and ignore terms that become unimportant with high  $n$  values. Big O notation is concerned with the growth rate of algorithm runtimes, so constants are ignored.
- The linear search algorithm runs in  $O(n)$  time.

- The worst case in linear search is that every element must be checked to determine whether the search item exists. This occurs if the search key is the last element in the array or is not present.

### **Section 18.2.2 Binary Search**

- The binary search algorithm is more efficient than the linear search algorithm, but it requires that the array be sorted.
- The first iteration of binary search tests the middle array element. If this is the search key, the algorithm returns its location. If the search key is less than the middle element, the search continues with the first half of the array. If the search key is greater than the middle element, the search continues with the second half of the array. Each iteration of binary search tests the middle value of the remaining array and, if the element is not found, eliminates half of the remaining elements.
- Binary search is a more efficient searching algorithm than linear search because with each comparison it eliminates from consideration half of the elements in the array.
- Binary search runs in  $O(\log n)$  time, because each step removes half of the remaining elements.

### **Section 18.3.1 Selection Sort**

- The selection sort is a simple, but inefficient, sorting algorithm.
- The first iteration of the selection sort selects the smallest element in the array and swaps it with the first element. The second iteration selects the second-smallest element (which is the smallest remaining element) and swaps it with the second element. Selection sort continues until the largest element is in the last position. After the  $i$ th iteration of selection sort, the smallest  $i$  elements of the whole array are sorted into the first  $i$  positions.
- The selection sort algorithm runs in  $O(n^2)$  time.

### **Section 18.3.2 Insertion Sort**

- The first iteration of insertion sort takes the second element in the array and, if it's less than the first, swaps them. The second iteration looks at the third element and inserts it in the correct position with respect to the first two. After the  $i$ th iteration of insertion sort, the first  $i$  elements in the original array are sorted.
- The insertion sort algorithm runs in  $O(n^2)$  time.

### **Section 18.3.3 Merge Sort**

- Merge sort is a sorting algorithm that is faster, but more complex to implement, than selection sort and insertion sort.
- The merge sort algorithm sorts an array by splitting it into two equal-sized subarrays, sorting each recursively and merging them into one larger array.
- Merge sort's base case is an array with one element. A one-element array is already sorted.
- Merge sort performs the merge by looking at the first element in each array, which is also the smallest. Merge sort takes the smallest of these and places it in the first element of the larger array. If there are still elements in the subarray, merge sort looks at the second element in that subarray (which is now the smallest element remaining) and compares it to the first element in the other subarray. Merge sort continues this process until the larger array is filled.
- In the worst case, the first call to merge sort has to make  $O(n)$  comparisons to fill the  $n$  slots in the final array.
- The merging portion of the merge sort algorithm is performed on two subarrays, each of approximately size  $n/2$ . Creating each of these subarrays requires  $n/2 - 1$  comparisons for each subarray, or  $O(n)$  comparisons total. This pattern continues as each level works on twice as many arrays, but each is half the size of the previous array. Similar to binary search, this halving results in  $\log n$  levels for a total efficiency of  $O(n \log n)$ .

## Terminology

|                          |                                         |
|--------------------------|-----------------------------------------|
| Big O notation           | $O(n)$                                  |
| binary search            | $O(n^2)$                                |
| constant runtime         | search key                              |
| efficiency of algorithms | quadratic runtime                       |
| insertion sort           | search key                              |
| linear runtime           | searching                               |
| linear search            | selection sort                          |
| logarithmic runtime      | sort key                                |
| merge sort               | Sort method of class <code>Array</code> |
| $O(1)$                   | sorting                                 |
| $O(\log n)$              | swapping values                         |
| $O(n \log n)$            |                                         |

## Self-Review Exercises

**18.1** Fill in the blanks in each of the following statements:

- a) A selection sort app would take approximately \_\_\_\_\_ times as long to run on a 128-element array as on a 32-element array.
- b) The efficiency of merge sort is \_\_\_\_\_.

**18.2** What key aspect of both the binary search and the merge sort accounts for the logarithmic portion of their respective Big Os?

**18.3** In what sense is the insertion sort superior to the merge sort? In what sense is the merge sort superior to the insertion sort?

**18.4** In the text, we say that after the merge sort splits the array into two subarrays, it then sorts these two subarrays and merges them. Why might someone be puzzled by our statement that “it then sorts these two subarrays”?

## Answers to Self-Review Exercises

**18.1** a) 16, because an  $O(n^2)$  algorithm takes 16 times as long to sort four times as much information. b)  $O(n \log n)$ .

**18.2** Both of these algorithms incorporate “halving”—somehow reducing something by half. The binary search eliminates from consideration one half of the array after each comparison. The merge sort splits the array in half each time it’s called.

**18.3** The insertion sort is easier to understand and to program than the merge sort. The merge sort is far more efficient ( $O(n \log n)$ ) than the insertion sort ( $O(n^2)$ ).

**18.4** In a sense, it does not really sort these two subarrays. It simply keeps splitting the original array in half until it provides a one-element subarray, which is, of course, sorted. It then builds up the original two subarrays by merging these one-element arrays to form larger subarrays, which are then merged until the whole array has been sorted.

## Exercises

**18.5** (*Bubble Sort*) Implement the bubble sort—another simple, yet inefficient, sorting technique. It’s called bubble sort or sinking sort because smaller values gradually “bubble” their way to the top of the array (i.e., toward the first element) like air bubbles rising in water, while the larger values sink to the bottom (end) of the array. The technique uses *nested loops* to make several passes through the array. Each pass compares successive overlapping pairs of elements (i.e., elements 0 and 1, 1 and 2, 2 and 3,

etc.). If a pair is in increasing order (or the values are equal), the bubble sort leaves the values as they are. If a pair is in decreasing order, the bubble sort swaps their values in the array.

The first pass compares the first two elements of the array and swaps them if necessary. It then compares the second and third elements. The end of this pass compares the last two elements in the array and swaps them if necessary. After one pass, the largest element will be in the last position. After two passes, the largest two elements will be in the last two positions. Explain why bubble sort is an  $O(n^2)$  algorithm.

**18.6 (Enhanced Bubble Sort)** Make the following simple modifications to improve the performance of the bubble sort you developed in Exercise 18.5:

- After the first pass, the largest number is guaranteed to be in the highest-numbered element of the array (for an array being sorted in ascending order); after the second pass, the two highest numbers are “in place”; and so on. Instead of making nine comparisons on every pass of a 10-element array, modify the bubble sort to make eight comparisons on the second pass, seven on the third pass and so on.
- The data in the array may already be in the proper order or near-proper order, so why make nine passes of a 10-element array if fewer will suffice? Modify the sort to check at the end of each pass whether any swaps have been made. If none have been made, the data must already be in the proper order, so the app should terminate. If swaps have been made, at least one more pass is needed.

**18.7 (Bucket Sort)** A bucket sort begins with a one-dimensional array of positive integers to be sorted and a two-dimensional array of integers with rows indexed from 0 to 9 and columns indexed from 0 to  $n - 1$ , where  $n$  is the number of values to be sorted. Each row of the two-dimensional array is referred to as a *bucket*. Write a class named `BucketSort` containing a method called `Sort` that operates as follows:

- Place each value of the one-dimensional array into a row of the bucket array, based on the value’s “ones” (rightmost) digit. For example, 97 is placed in row 7, 3 is placed in row 3 and 100 is placed in row 0. This procedure is called a *distribution pass*.
- Loop through the bucket array row by row, and copy the values back to the original array. This procedure is called a *gathering pass*. The new order of the preceding values in the one-dimensional array is 100, 3 and 97.
- Repeat this process for each subsequent digit position (tens, hundreds, thousands, etc.).

On the second (tens digit) pass, 100 is placed in row 0, 3 is placed in row 0 (because 3 has no tens digit) and 97 is placed in row 9. After the gathering pass, the order of the values in the one-dimensional array is 100, 3 and 97. On the third (hundreds digit) pass, 100 is placed in row 1, 3 is placed in row 0 and 97 is placed in row 0 (after the 3). After the last gathering pass, the original array is in sorted order.

The two-dimensional array of buckets is 10 times the length of the integer array being sorted. This sorting technique provides better performance than a bubble sort, but requires much more memory—the bubble sort requires space for only one additional element of data. This comparison is an example of the space/time trade-off: The bucket sort uses more memory than the bubble sort, but performs better. This version of the bucket sort requires copying all the data back to the original array on each pass. Another possibility is to create a second two-dimensional bucket array and repeatedly swap the data between the two bucket arrays.

**18.8 (Recursive Linear Search)** Modify Fig. 18.2 to use recursive method `RecursiveLinearSearch` to perform a linear search of the array. The method should receive the search key and starting index as arguments. If the search key is found, return its index in the array; otherwise, return `-1`. Each call to the recursive method should check one index in the array.

**18.9 (Recursive Binary Search)** Modify Fig. 18.4 to use recursive method `RecursiveBinarySearch` to perform a binary search of the array. The method should receive the search key, starting

index and ending index as arguments. If the search key is found, return its index in the array. If the search key is not found, return -1.

**18.10 (Quicksort)** The recursive sorting technique called quicksort uses the following basic algorithm for a one-dimensional array of values:

- Partitioning Step:* Take the first element of the unsorted array and determine its final location in the sorted array (i.e., all values to the left of the element in the array are less than the element, and all values to the right of the element in the array are greater than the element—we show how to do this below). We now have one element in its proper location and two unsorted subarrays.
- Recursive Step:* Perform *Step a* on each unsorted subarray.

Each time *Step a* is performed on a subarray, another element is placed in its final location in the sorted array, and two unsorted subarrays are created. When a subarray consists of one element, that element is in its final location (because a one-element array is already sorted).

The basic algorithm seems simple enough, but how do we determine the final position of the first element of each subarray? As an example, consider the following set of values (the element in bold is the partitioning element—it will be placed in its final location in the sorted array):

37 2 6 4 89 8 10 12 68 45

- Starting from the rightmost element of the array, compare each element with 37 until an element less than 37 is found, then swap 37 and that element. The first element less than 37 is 12, so 37 and 12 are swapped. The new array is

12 2 6 4 89 8 10 **37** 68 45

- Element 12 is in italics to indicate that it was just swapped with 37.
- Starting from the left of the array, but beginning with the element after 12, compare each element with 37 until an element greater than 37 is found—then swap 37 and that element. The first element greater than 37 is 89, so 37 and 89 are swapped. The new array is

12 2 6 4 **37** 8 10 89 68 45

- Starting from the right, but beginning with the element before 89, compare each element with 37 until an element less than 37 is found—then swap 37 and that element. The first element less than 37 is 10, so 37 and 10 are swapped. The new array is

12 2 6 4 10 8 **37** 89 68 45

- Starting from the left, but beginning with the element after 10, compare each element with 37 until an element greater than 37 is found—then swap 37 and that element. There are no more elements greater than 37, so when we compare 37 with itself, we know that 37 has been placed in its final location of the sorted array. Every value to the left of 37 is smaller than it, and every value to the right of 37 is larger than it.

Once the partition has been applied on the previous array, there are two unsorted subarrays. The subarray with values less than 37 contains 12, 2, 6, 4, 10 and 8. The subarray with values greater than 37 contains 89, 68 and 45. The sort continues recursively, with both subarrays being partitioned in the same manner as the original array.

Based on the preceding discussion, write recursive method `QuickSortHelper` to sort a one-dimensional integer array. The method should receive as arguments a starting index and an ending index in the original array being sorted.

# 19

## Data Structures

*Much that I bound,  
I could not free;  
Much that I freed  
returned to me.*

—Lee Wilson Dodd

*There is always room at the top.*

—Daniel Webster

*I think that I shall never see  
A poem lovely as a tree.*

—Joyce Kilmer

### Objectives

In this chapter you'll:

- Form linked data structures using references, self-referential classes and recursion.
- Learn how boxing and unboxing enable simple-type values to be used where **objects** are expected in a program.
- Create and manipulate dynamic data structures, such as linked lists, queues, stacks and binary trees.
- Learn various important applications of linked data structures.
- Create reusable data structures with classes, inheritance and composition.



# Outline

|                                                              |                                                         |
|--------------------------------------------------------------|---------------------------------------------------------|
| <b>19.1</b> Introduction                                     | <b>19.6</b> Queues                                      |
| <b>19.2</b> Simple-Type <b>structs</b> , Boxing and Unboxing | <b>19.7</b> Trees                                       |
| <b>19.3</b> Self-Referential Classes                         | 19.7.1 Binary Search Tree of Integer Values             |
| <b>19.4</b> Linked Lists                                     | 19.7.2 Binary Search Tree of <b>IComparable</b> Objects |
| <b>19.5</b> Stacks                                           | <b>19.8</b> Wrap-Up                                     |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 19.1 Introduction

This chapter continues our four-chapter treatment of algorithms and data structures. Most of the data structures that we have studied thus far have had fixed sizes, such as one- and two-dimensional arrays. Previously, we also introduced the dynamically resizable `List<T>` collection (Chapter 9). This chapter enhances our discussion of **dynamic data structures** that grow and shrink at execution time. *Linked lists* are collections of data items “lined up in a row” or “chained together”—users can make insertions and deletions anywhere in a linked list. *Stacks* are important in compilers and operating systems; insertions and deletions are made at only one end—its **top**. *Queues* represent waiting lines; insertions are made at the back (also referred to as the **tail**) of a queue, and deletions are made from the front (also referred to as the **head**) of a queue. **Binary trees** facilitate high-speed searching and sorting of data, efficient elimination of duplicate data items, representation of file-system directories and compilation of expressions into machine language. These data structures have many other interesting applications as well.

We’ll discuss each of these major types of data structures and implement programs that create and manipulate them. We use classes, inheritance and composition to create and package these data structures for reusability and maintainability. In Chapter 20, we introduce *generics*, which allow you to declare data structures that can be automatically adapted to contain data of any type. In Chapter 21, we discuss C#’s predefined *collection classes* that implement various data structures.

The chapter examples are practical programs that will be useful in more advanced courses and in industrial applications. The programs focus on reference manipulation. The exercises offer a rich collection of useful applications.

## 19.2 Simple-Type **structs**, Boxing and Unboxing

The data structures we discuss in this chapter store object references. However, as you’ll soon see, we’re able to store both simple- and reference-type values in these data structures. This section discusses the mechanisms that enable simple-type values to be manipulated as objects.

### *Simple-Type **structs***

Each simple type (see Appendix B, Simple Types) has a corresponding **struct** in namespace `System` that defines the simple type. These structs are called `Boolean`, `Byte`, `SByte`, `Char`, `Decimal`, `Double`, `Single`, `Int16`, `UInt16`, `Int32`, `UInt32`, `Int64` and `UInt64`. Types declared with keyword **struct** are *value types*.

Simple types are actually *aliases* for their corresponding *structs*, so a variable of a simple type can be declared using either the keyword for that simple type or the *struct* name—e.g., `int` and `Int32` are interchangeable. The methods related to a simple type are located in the corresponding *struct* (e.g., method `Parse`, which converts a `string` to an `int` value, is located in *struct Int32*). Refer to the documentation for the corresponding *struct* type to see the methods available for manipulating values of that type.

### ***Boxing and Unboxing Conversions***

Simple types and other *structs* inherit from class `ValueType` in namespace `System`. Class `ValueType` inherits from class `object`. Thus, any simple-type value can be assigned to an `object` variable; this is referred to as a **boxing conversion** and enables simple types to be used anywhere objects are expected. In a boxing conversion, the simple-type value is copied into an `object` so that the simple-type value can be manipulated as an `object`. Boxing conversions can be performed either *explicitly* or *implicitly* as shown in the following statements:

```
int i = 5; // create an int value
object object1 = ( object ) i; // explicitly box the int value
object object2 = i; // implicitly box the int value
```

After executing the preceding code, both `object1` and `object2` refer to two different `objects` that contain a copy of the integer value in `int` variable `i`.

An **unboxing conversion** can be used to explicitly convert an `object` reference to a simple value, as shown in the following statement:

```
int int1 = ( int ) object1; // explicitly unbox the int value
```

Explicitly attempting to unbox an `object` reference that does not refer to the correct simple value type causes an `InvalidOperationException`.

In Chapters 20 and 21, we discuss C#’s *generics* and *generic collections* where you’ll see that you can create data structures of specific value types so that do not need boxing and unboxing conversions.

## **19.3 Self-Referential Classes**

A **self-referential class** contains a reference member that refers to an object of the same class type. For example, the class declaration in Fig. 19.1 defines the shell of a self-referential class named `Node`. This type has two properties—`int Data` and `Node` reference `Next`. `Next` references an object of type `Node`, an object of the same type as the one being declared here—hence, the term “self-referential class.” `Next` is referred to as a **link** (i.e., `Next` can be used to “tie” an object of type `Node` to another object of the same type).

---

```
1 // Fig. 19.1: Fig19_01.cs
2 // Self-referential Node class declaration.
3 class Node
4 {
5     public int Data { get; set; } // store integer data
6     public Node Next { get; set; } // store reference to next Node
7 }
```

---

**Fig. 19.1** | Self-referential `Node` class declaration. (Part 1 of 2.)

---

```

8     public Node( int dataValue )
9     {
10         Data = dataValue;
11     } // end constructor
12 } // end class node

```

---

**Fig. 19.1** | Self-referential Node class declaration. (Part 2 of 2.)

Self-referential objects can be linked together to form useful data structures, such as lists, queues, stacks and trees. Figure 19.2 illustrates two self-referential objects *linked together* to form a linked list. A backslash (representing a `null` reference) is placed in the link member of the second self-referential object to indicate that the link does not refer to another object. The backslash is for illustration purposes; it does *not* correspond to the backslash character in C#. A `null` link normally indicates the *end* of a data structure.



### Common Programming Error 19.1

*Not setting the link in the last node of a list to null is a logic error.*



**Fig. 19.2** | Self-referential class objects linked together.

Creating and maintaining dynamic data structures requires **dynamic memory allocation**—a program’s ability to obtain more memory space at execution time to hold new nodes and to release space no longer needed. As you learned in Section 10.8, C# programs do not *explicitly* release dynamically allocated memory—rather, the CLR performs automatic *garbage collection*.

The `new` operator is essential to dynamic memory allocation. Operator `new` takes as an operand the type of the object being dynamically allocated and returns a reference to an object of that type. For example, the statement

```
Node nodeToAdd = new Node( 10 );
```

allocates the appropriate amount of memory to store a `Node`, initializes it and stores a reference to this object in `nodeToAdd`. If no memory is available, `new` throws an `OutOfMemoryException`. The constructor argument `10` specifies the `Node` object’s data.

The following sections discuss lists, stacks, queues and trees. These data structures are created and maintained with dynamic memory allocation and self-referential classes.

## 19.4 Linked Lists

A **linked list** is a *linear collection* (i.e., a sequence) of self-referential class objects, called **nodes**, connected by reference links—hence, the term “linked” list. A program accesses a

linked list via a reference to the first node of the list. Each subsequent node is accessed via the link-reference member stored in the previous node. By convention, the link reference in the *last* node of a list is set to `null` to mark the end of the list. Data is stored in a linked list dynamically—that is, each node is created as necessary. A node can contain data of any type, including references to objects of other classes. Stacks and queues are also linear data structures—in fact, they may be viewed as constrained versions of linked lists. Trees are nonlinear data structures.

Lists of data can be stored in arrays, but linked lists provide several advantages. A linked list is appropriate when the number of data elements to be represented in the data structure is unpredictable. Unlike a linked list, the size of a conventional C# array cannot be altered, because the array size is *fixed* at creation time. Conventional arrays can become full, but linked lists become full only when the system has insufficient memory to satisfy dynamic memory allocation requests.



### Performance Tip 19.1

*An array can be declared to contain more elements than the number of items expected, possibly wasting memory. Linked lists provide better memory utilization in these situations, because they can grow and shrink at execution time.*

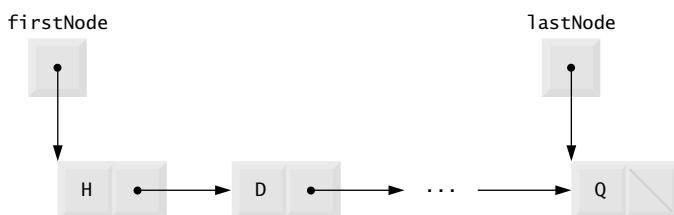
Programmers can maintain linked lists in sorted order simply by inserting each new element at the proper point in the list (locating the proper insertion point does take time). They do not need to move existing list elements.



### Performance Tip 19.2

*The elements of an array are stored contiguously in memory to allow immediate access to any array element—the address of any element can be calculated directly from its index. Linked lists do not afford such immediate access to their elements—an element can be accessed only by traversing the list from the front.*

Normally linked-list nodes are *not* stored contiguously in memory. Rather, the nodes are logically contiguous. Figure 19.3 illustrates a linked list with several nodes.



**Fig. 19.3** | Linked list graphical representation.



### Performance Tip 19.3

*Using linked data structures and dynamic memory allocation (instead of arrays) for data structures that grow and shrink at execution time can save memory. Keep in mind, however, that reference links occupy space, and dynamic memory allocation incurs the overhead of method calls.*

### **Linked-List Implementation**

Figures 19.4–19.5 use an object of our List class to manipulate a list of miscellaneous object types. Class ListTest's Main method (Fig. 19.5) creates a list of objects, inserts objects at the beginning of the list using List method InsertAtFront, inserts objects at the end of the list using List method InsertAtBack, deletes objects from the front of the list using List method RemoveFromFront and deletes objects from the end of the list using List method RemoveFromBack. After each insert and delete operation, the program invokes List method Display to output the current list contents. If an attempt is made to remove an item from an empty list, an EmptyListException occurs. A detailed discussion of the program follows.



#### **Performance Tip 19.4**

*Insertion and deletion in a sorted array can be time consuming—all the elements following the inserted or deleted element must be shifted appropriately.*

The program consists of four classes—ListNode (Fig. 19.4, lines 8–30), List (lines 33–147), EmptyListException (lines 150–172) and ListTest (Fig. 19.5). The classes in Fig. 19.4 create a linked-list library (defined in namespace LinkedListLibrary) that can be reused throughout this chapter. You should place the code of Fig. 19.4 in its own class library project, as we described in Section 15.13.

---

```

1 // Fig. 19.4: LinkedListLibrary.cs
2 // ListNode, List and EmptyListException class declarations.
3 using System;
4
5 namespace LinkedListLibrary
6 {
7     // class to represent one node in a list
8     class ListNode
9     {
10         // automatic read-only property Data
11         public object Data { get; private set; }
12
13         // automatic property Next
14         public ListNode Next { get; set; }
15
16         // constructor to create ListNode that refers to dataValue
17         // and is last node in list
18         public ListNode( object dataValue )
19             : this( dataValue, null )
20         {
21             } // end default constructor
22
23         // constructor to create ListNode that refers to dataValue
24         // and refers to next ListNode in List
25         public ListNode( object dataValue, ListNode nextNode )
26         {
27             Data = dataValue;
28             Next = nextNode;
29         } // end constructor
30     } // end class ListNode

```

---

**Fig. 19.4 |** ListNode, List and EmptyListException class declarations. (Part 1 of 4.)

```
31 // class List declaration
32 public class List
33 {
34     private ListNode firstNode;
35     private ListNode lastNode;
36     private string name; // string like "list" to display
37
38     // construct empty List with specified name
39     public List( string listName )
40     {
41         name = listName;
42         firstNode = lastNode = null;
43     } // end constructor
44
45     // construct empty List with "list" as its name
46     public List()
47     : this( "list" )
48     {
49     } // end default constructor
50
51     // Insert object at front of List. If List is empty,
52     // firstNode and lastNode will refer to same object.
53     // Otherwise, firstNode refers to new node.
54     public void InsertAtFront( object insertItem )
55     {
56         if ( IsEmpty() )
57             firstNode = lastNode = new ListNode( insertItem );
58         else
59             firstNode = new ListNode( insertItem, firstNode );
60     } // end method InsertAtFront
61
62     // Insert object at end of List. If List is empty,
63     // firstNode and lastNode will refer to same object.
64     // Otherwise, lastNode's Next property refers to new node.
65     public void InsertAtBack( object insertItem )
66     {
67         if ( IsEmpty() )
68             firstNode = lastNode = new ListNode( insertItem );
69         else
70             lastNode = lastNode.Next = new ListNode( insertItem );
71     } // end method InsertAtBack
72
73     // remove first node from List
74     public object RemoveFromFront()
75     {
76         if ( IsEmpty() )
77             throw new EmptyListException( name );
78
79         object removeItem = firstNode.Data; // retrieve data
80
81 }
```

---

Fig. 19.4 | ListNode, List and EmptyListException class declarations. (Part 2 of 4.)

```

82         // reset firstNode and lastNode references
83         if ( firstNode == lastNode )
84             firstNode = lastNode = null;
85         else
86             firstNode = firstNode.Next;
87
88         return removeItem; // return removed data
89     } // end method RemoveFromFront
90
91     // remove last node from List
92     public object RemoveFromBack()
93     {
94         if ( IsEmpty() )
95             throw new EmptyListException( name );
96
97         object removeItem = lastNode.Data; // retrieve data
98
99         // reset firstNode and lastNode references
100        if ( firstNode == lastNode )
101            firstNode = lastNode = null;
102        else
103        {
104            ListNode current = firstNode;
105
106            // loop while current.Next is not lastNode
107            while ( current.Next != lastNode )
108                current = current.Next; // move to next node
109
110            // current is new lastNode
111            lastNode = current;
112            current.Next = null;
113        } // end else
114
115        return removeItem; // return removed data
116    } // end method RemoveFromBack
117
118    // return true if List is empty
119    public bool IsEmpty()
120    {
121        return firstNode == null;
122    } // end method IsEmpty
123
124    // output List contents
125    public void Display()
126    {
127        if ( IsEmpty() )
128        {
129            Console.WriteLine( "Empty " + name );
130        } // end if
131        else
132        {
133            Console.Write( "The " + name + " is: " );

```

**Fig. 19.4** | ListNode, List and EmptyListException class declarations. (Part 3 of 4.)

```
134         ListNode current = firstNode;
135
136         // output current node data while not at end of list
137         while ( current != null )
138         {
139             Console.WriteLine( current.Data + " " );
140             current = current.Next;
141         } // end while
142
143         Console.WriteLine( "\n" );
144     } // end else
145 } // end method Display
146 } // end class List
147
148 // class EmptyListException declaration
149 public class EmptyListException : Exception
150 {
151     // parameterless constructor
152     public EmptyListException()
153         : base( "The list is empty" )
154     {
155         // empty constructor
156     } // end EmptyListException constructor
157
158     // one-parameter constructor
159     public EmptyListException( string name )
160         : base( "The " + name + " is empty" )
161     {
162         // empty constructor
163     } // end EmptyListException constructor
164
165     // two-parameter constructor
166     public EmptyListException( string exception, Exception inner )
167         : base( exception, inner )
168     {
169         // empty constructor
170     } // end EmptyListException constructor
171 } // end class EmptyListException
172 } // end namespace LinkedListLibrary
```

---

**Fig. 19.4 |** ListNode, List and EmptyListException class declarations. (Part 4 of 4.)

### Class *ListNode*

Encapsulated in each *List* object is a linked list of *ListNode* objects. Class *ListNode* (Fig. 19.4, lines 8–30) contains two properties—*Data* and *Next*. *Data* can refer to any object. [Note: Typically, a data structure will contain data of only *one* type, or data of any type derived from one base type.] In this example, we use data of various types derived from *object* to demonstrate that our *List* class can store data of any type. *Next* stores a reference to the next *ListNode* object in the linked list. The *ListNode* constructors (lines 18–21 and 25–29) enable us to initialize a *ListNode* that will be placed at the end of a *List* or before a specific *ListNode* in a *List*, respectively.

**Class List**

Class `List` (lines 33–147) contains private instance variables `firstNode` (a reference to the first `ListNode` in a `List`) and `lastNode` (a reference to the last `ListNode` in a `List`). The constructors (lines 40–44 and 47–50) initialize both references to `null` and enable us to specify the `List`'s name for output purposes. `InsertAtFront` (lines 55–61), `InsertAtBack` (lines 66–72), `RemoveFromFront` (lines 75–89) and `RemoveFromBack` (lines 92–116) are the primary methods of class `List`. Method `IsEmpty` (lines 119–122) is a **predicate method** that determines whether the list is empty (i.e., the reference to the first node of the list is `null`). Predicate methods typically *test a condition* and *do not modify* the object on which they're called. If the list is empty, method `IsEmpty` returns `true`; otherwise, it returns `false`. Method `Display` (lines 125–146) displays the list's contents. A detailed discussion of class `List`'s methods follows Fig. 19.5.

**Class EmptyListException**

Class `EmptyListException` (lines 150–172) defines an exception class that we use to indicate illegal operations on an empty `List`.

**Class ListTest**

Class `ListTest` (Fig. 19.5) uses the linked-list library to create and manipulate a linked list. [Note: In the project containing Fig. 19.5, you must add a reference to the class library containing the classes in Fig. 19.4. If you use our existing example, you may need to update this reference.] Line 11 creates a new `List` object and assigns it to variable `list`. Lines 14–17 create data to add to the list. Lines 20–27 use `List` insertion methods to insert these values and use `List` method `Display` to output the contents of `list` after each insertion. The values of the simple-type variables are implicitly boxed in lines 20, 22 and 24 where object references are expected. The code inside the `try` block (lines 33–50) removes objects via `List` deletion methods, outputs each removed object and outputs `list` after every deletion. If there's an attempt to remove an object from an *empty* list, the catch at lines 51–54 catches the `EmptyListException` and displays an error message.

---

```

1 // Fig. 19.5: ListTest.cs
2 // Testing class List.
3 using System;
4 using LinkedListLibrary;
5
6 // class to test List class functionality
7 class ListTest
8 {
9     public static void Main( string[] args )
10    {
11        List list = new List(); // create List container
12
13        // create data to store in List
14        bool aBoolean = true;
15        char aCharacter = '$';
16        int anInteger = 34567;
17        string aString = "hello";
18

```

---

**Fig. 19.5** | Testing class `List`. (Part 1 of 3.)

```
19     // use List insert methods
20     list.InsertAtFront( aBoolean );
21     list.Display();
22     list.InsertAtFront( aCharacter );
23     list.Display();
24     list.InsertAtBack( anInteger );
25     list.Display();
26     list.InsertAtBack( aString );
27     list.Display();
28
29     // use List remove methods
30     object removedObject;
31
32     // remove data from list and display after each removal
33     try
34     {
35         removedObject = list.RemoveFromFront();
36         Console.WriteLine( removedObject + " removed" );
37         list.Display();
38
39         removedObject = list.RemoveFromFront();
40         Console.WriteLine( removedObject + " removed" );
41         list.Display();
42
43         removedObject = list.RemoveFromBack();
44         Console.WriteLine( removedObject + " removed" );
45         list.Display();
46
47         removedObject = list.RemoveFromBack();
48         Console.WriteLine( removedObject + " removed" );
49         list.Display();
50     } // end try
51     catch ( EmptyListException emptyListException )
52     {
53         Console.Error.WriteLine( "\n" + emptyListException );
54     } // end catch
55 } // end Main
56 } // end class ListTest
```

```
The list is: True
The list is: $ True
The list is: $ True 34567
The list is: $ True 34567 hello
$ removed
The list is: True 34567 hello
True removed
The list is: 34567 hello
```

Fig. 19.5 | Testing class List. (Part 2 of 3.)

```

hello removed
The list is: 34567

34567 removed
Empty list

```

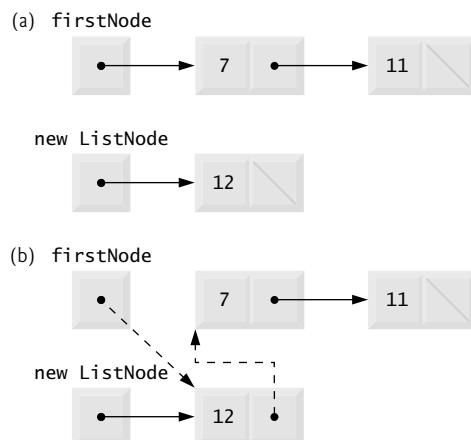
**Fig. 19.5** | Testing class List. (Part 3 of 3.)

### Method InsertAtFront

Over the next several pages, we discuss each of the methods of class List in detail. Method `InsertAtFront` (Fig. 19.4, lines 55–61) places a new node at the front of the list. The method consists of three steps:

1. Call `IsEmpty` to determine whether the list is empty (line 57).
2. If the list is empty, set both `firstNode` and `lastNode` to refer to a new `ListNode` initialized with `insertItem` (line 58). The `ListNode` constructor at lines 18–21 calls the `ListNode` constructor at lines 25–29, which sets property `Data` to refer to the object passed as the first argument and sets the `Next` property's reference to `null`.
3. If the list is not empty, the new node is “linked” into the list by setting `firstNode` to refer to a new `ListNode` object initialized with `insertItem` and `firstNode` (line 60). When the `ListNode` constructor (lines 25–29) executes, it sets property `Data` to refer to the object passed as the first argument and performs the insertion by setting the `Next` reference to the `ListNode` passed as the second argument.

In Fig. 19.6, part (a) shows a list and a new node during the `InsertAtFront` operation before the new node is linked into the list. The dashed lines and arrows in part (b) illustrate *Step 3* of the `InsertAtFront` operation, which enables the node containing 12 to become the new list front.



**Fig. 19.6** | `InsertAtFront` operation.



### Performance Tip 19.5

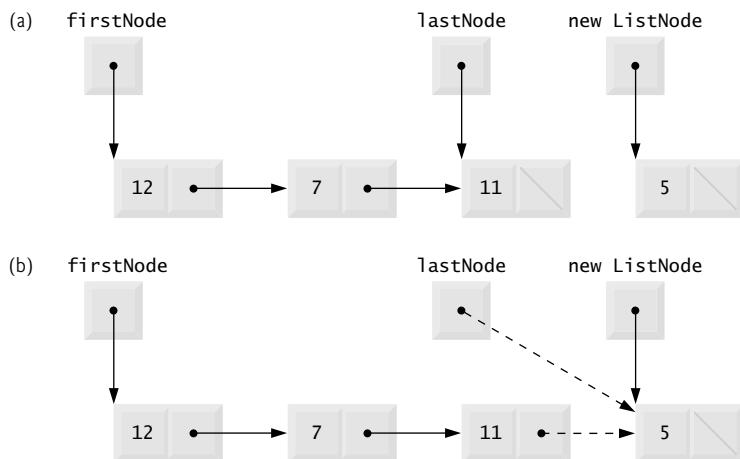
After locating the insertion point for a new item in a sorted linked list, inserting an element in the list is fast—only two references have to be modified. All existing nodes remain at their current locations in memory.

#### **Method InsertAtBack**

Method `InsertAtBack` (Fig. 19.4, lines 66–72) places a new node at the back of the list. The method consists of three steps:

1. Call `IsEmpty` to determine whether the list is empty (line 68).
2. If the list is empty, set both `firstNode` and `lastNode` to refer to a new `ListNode` initialized with `insertItem` (lines 68–69). The `ListNode` constructor at lines 18–21 calls the `ListNode` constructor at lines 25–29, which sets property `Data` to refer to the object passed as the first argument and sets the `Next` reference to `null`.
3. If the list is not empty, link the new node into the list by setting `lastNode` and `lastNode.Next` to refer to a new `ListNode` object initialized with `insertItem` (line 71). When the `ListNode` constructor (lines 18–21) executes, it calls the constructor at lines 25–29, which sets property `Data` to refer to the object passed as an argument and sets the `Next` reference to `null`.

In Fig. 19.7, part (a) shows a list and a new node during the `InsertAtBack` operation before the new node has been linked into the list. The dashed lines and arrows in part (b) illustrate Step 3 of method `InsertAtBack`, which enables a new node to be added to the end of a list that is not empty.



**Fig. 19.7** | `InsertAtBack` operation.

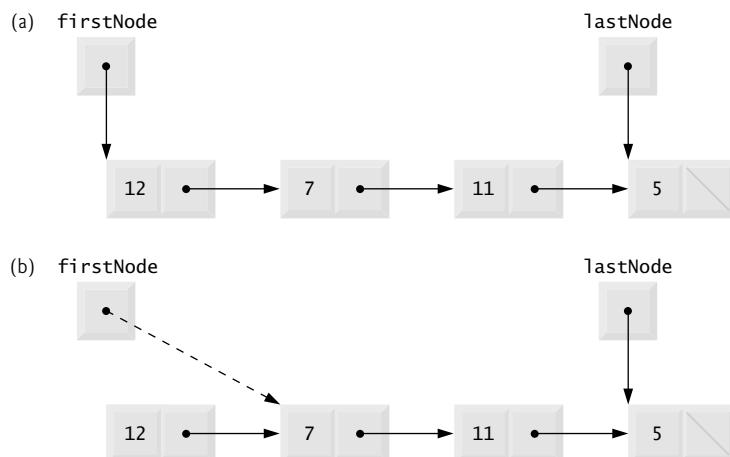
#### **Method RemoveFromFront**

Method `RemoveFromFront` (Fig. 19.4, lines 75–89) removes the front node of the list and returns a reference to the removed data. The method throws an `EmptyListException` (line 78) if the programmer tries to remove a node from an empty list. Otherwise, the method

returns a reference to the removed data. After determining that a `List` is not empty, the method consists of four steps to remove the first node:

1. Assign `firstNode.Data` (the data being removed from the list) to variable `removeItem` (line 80).
2. If the objects to which `firstNode` and `lastNode` refer are the *same* object, the list has only one element, so the method sets `firstNode` and `lastNode` to `null` (line 84) to remove the node from the list (leaving the list empty).
3. If the list has more than one node, the method leaves reference `lastNode` as is and assigns `firstNode.Next` to `firstNode` (line 86). Thus, `firstNode` references the node that was previously the second node in the `List`.
4. Return the `removeItem` reference (line 88).

In Fig. 19.8, part (a) illustrates a list before a removal operation. The dashed lines and arrows in part (b) show the reference manipulations.



**Fig. 19.8** | RemoveFromFront operation.

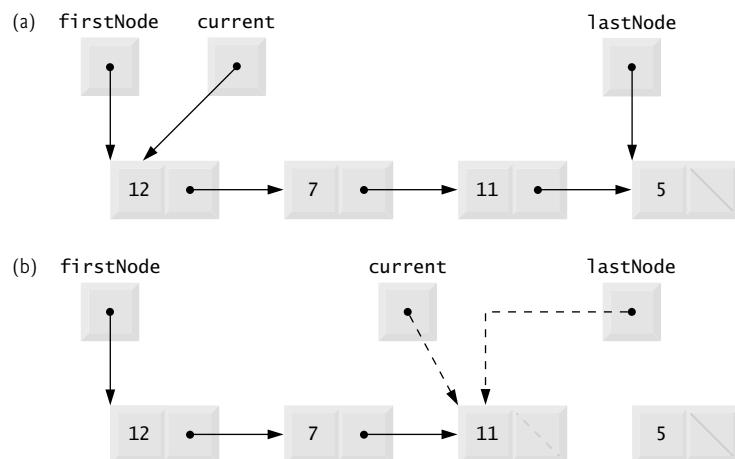
### Method RemoveFromBack

Method `RemoveFromBack` (Fig. 19.4, lines 92–116) removes the last node of a list and returns a reference to the removed data. The method throws an `EmptyListException` (line 95) if the program attempts to remove a node from an empty list. The method consists of several steps:

1. Assign `lastNode.Data` (the data being removed from the list) to variable `removeItem` (line 97).
2. If `firstNode` and `lastNode` refer to the *same* object (line 100), the list has only one element, so the method sets `firstNode` and `lastNode` to `null` (line 101) to remove that node from the list (leaving the list empty).
3. If the list has more than one node, create `ListNode` variable `current` and assign it `firstNode` (line 104).

4. Now “walk the list” with `current` until it references the node before the last node. The `while` loop (lines 107–108) assigns `current.Next` to `current` as long as `current.Next` is not equal to `lastNode`.
5. After locating the second-to-last node, assign `current` to `lastNode` (line 111) to update which node is last in the list.
6. Set `current.Next` to `null` (line 112) to remove the last node from the list and terminate the list at the current node.
7. Return the `removeItem` reference (line 115).

In Fig. 19.9, part (a) illustrates a list before a removal operation. The dashed lines and arrows in part (b) show the reference manipulations.



**Fig. 19.9** | RemoveFromBack operation.

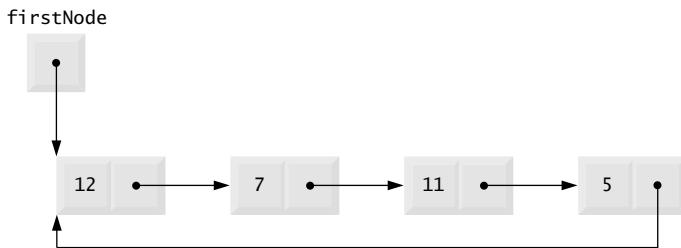
### Method Display

Method `Display` (Fig. 19.4, lines 125–146) first determines whether the list is empty (line 127). If so, `Display` displays a string consisting of the string "Empty " and the list's name, then returns control to the calling method. Otherwise, `Display` outputs the data in the list. The method writes a string consisting of the string "The ", the list's name and the string " is: ". Then line 135 creates `ListNode` variable `current` and initializes it with `firstNode`. While `current` is not `null`, there are more items in the list. Therefore, the method displays `current.Data` (line 140), then assigns `current.Next` to `current` (line 141) to move to the next node in the list.

### Linear and Circular Singly Linked and Doubly Linked Lists

The kind of linked list we have been discussing is a **singly linked list**—it begins with a reference to the first node, and each node contains a reference to the next node “in sequence.” This list terminates with a node whose reference member has the value `null`. A singly linked list may be traversed in *only* one direction.

A **circular, singly linked list** (Fig. 19.10) begins with a reference to the first node, and each node contains a reference to the next node. The “last node” does not contain a `null`

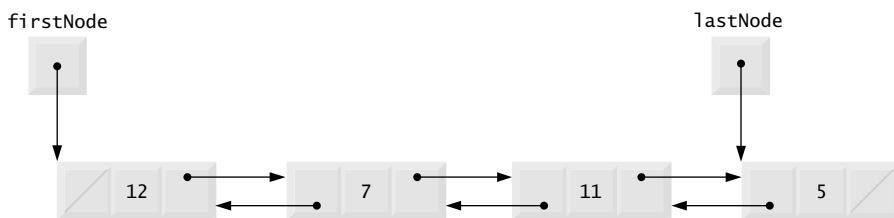


**Fig. 19.10** | Circular, singly linked list.

reference; rather, the reference in the last node points back to the first node, thus closing the “circle.”

A **doubly linked list** (Fig. 19.11) allows traversals both forward and backward. Such a list is often implemented with two “start references”—one that refers to the *first* element of the list to allow *front-to-back traversal* of the list and one that refers to the *last* element to allow *back-to-front traversal*. Each node has both a forward reference to the next node in the list and a backward reference to the previous node. If your list contains an alphabetized telephone directory, for example, a search for someone whose name begins with a letter near the front of the alphabet might begin from the front of the list. A search for someone whose name begins with a letter near the end of the alphabet might begin from the back.

In a **circular, doubly linked list** (Fig. 19.12), the forward reference of the last node refers to the first node, and the backward reference of the first node refers to the last node, thus closing the “circle.”



**Fig. 19.11** | Doubly linked list.



**Fig. 19.12** | Circular, doubly linked list.

## 19.5 Stacks

A **stack** may be viewed as a constrained version of a linked list—it receives new nodes and releases nodes only at the top. For this reason, a stack is referred to as a **last-in, first-out (LIFO)** data structure.

The primary operations to manipulate a stack are **push** and **pop**. Operation **push** adds a new node to the top of the stack. Operation **pop** removes a node from the top of the stack and returns the data item from the popped node.

Stacks have many interesting applications. For example, when a program calls a method, the called method must know how to return to its caller, so the return address is pushed onto the method-call stack. If a series of method calls occurs, the successive return values are pushed onto the stack in last-in, first-out order so that each method can return to its caller. Stacks support recursive method calls in the same manner that they do conventional nonrecursive method calls.

The `System.Collections` namespace contains class `Stack` for implementing and manipulating stacks that can grow and shrink during program execution.

In our next example, we take advantage of the close relationship between lists and stacks to implement a stack class by reusing a list class. We demonstrate two different forms of reusability. First, we implement the stack class by inheriting from class `List` of Fig. 19.4. Then we implement an identically performing stack class through composition by including a `List` object as a `private` member of a stack class.

### *Stack Class That Inherits from List*

The code in Fig. 19.13 creates a stack class by inheriting from class `List` of Fig. 19.4 (line 8 of Fig. 19.13). We want the stack to have methods `Push`, `Pop`, `IsEmpty` and `Display`. Essentially, these are the methods `InsertAtFront`, `RemoveFromFront`, `IsEmpty` and `Display` of class `List`. Of course, class `List` contains other methods (such as `InsertAtBack` and `RemoveFromBack`) that we would rather not make accessible through the `public` interface of the stack. It's important to remember though that all methods in the `public` interface of class `List` are also `public` methods of the derived class `StackInheritance` (Fig. 19.13).

---

```

1 // Fig. 19.13: StackInheritanceLibrary.cs
2 // Implementing a stack by inheriting from class List.
3 using LinkedListLibrary;
4
5 namespace StackInheritanceLibrary
6 {
7     // class StackInheritance inherits class List's capabilities
8     public class StackInheritance : List
9     {
10         // pass name "stack" to List constructor
11         public StackInheritance()
12             : base( "stack" )
13         {
14         } // end constructor
15 }
```

---

**Fig. 19.13** | Implementing a stack by inheriting from class `List`. (Part 1 of 2.)

---

```

16     // place dataValue at top of stack by inserting
17     // dataValue at front of linked list
18     public void Push( object dataValue )
19     {
20         InsertAtFront( dataValue );
21     } // end method Push
22
23     // remove item from top of stack by removing
24     // item at front of linked list
25     public object Pop()
26     {
27         return RemoveFromFront();
28     } // end method Pop
29 } // end class StackInheritance
30 } // end namespace StackInheritanceLibrary

```

---

**Fig. 19.13** | Implementing a stack by inheriting from class *List*. (Part 2 of 2.)

The implementation of each *StackInheritance* method calls the appropriate *List* method—method *Push* calls *InsertAtFront*, method *Pop* calls *RemoveFromFront*. Class *StackInheritance* does not define methods *IsEmpty* and *Display*, because *StackInheritance* inherits these methods from class *List* into *StackInheritance*'s public interface. Class *StackInheritance* uses namespace *LinkedListLibrary* (Fig. 19.4); thus, the class library that defines *StackInheritance* must have a reference to the *LinkedListLibrary* class library.

*StackInheritanceTest*'s *Main* method (Fig. 19.14) uses class *StackInheritance* to create a stack of objects called *stack* (line 12). Lines 15–18 define four values that will be pushed onto the stack and popped off it. The program pushes onto the stack (lines 21, 23, 25 and 27) a *bool* containing *true*, a *char* containing '\$', an *int* containing 34567 and a *string* containing "hello". An infinite *while* loop (lines 33–38) pops the elements from the stack. When the stack is empty, method *Pop* throws an *EmptyListException*, and the program displays the exception's stack trace, which shows the program-execution stack at the time the exception occurred. The program uses method *Display* (inherited by *StackInheritance* from class *List*) to output the contents of the stack after each operation. Class *StackInheritanceTest* uses namespace *LinkedListLibrary* (Fig. 19.4) and namespace *StackInheritanceLibrary* (Fig. 19.13); thus, the solution for class *StackInheritanceTest* must have references to both class libraries.

---

```

1 // Fig. 19.14: StackInheritanceTest.cs
2 // Testing class StackInheritance.
3 using System;
4 using StackInheritanceLibrary;
5 using LinkedListLibrary;
6
7 // demonstrate functionality of class StackInheritance
8 class StackInheritanceTest
9 {

```

---

**Fig. 19.14** | Testing class *StackInheritance*. (Part 1 of 3.)

```
10  public static void Main( string[] args )
11  {
12      StackInheritance stack = new StackInheritance();
13
14      // create objects to store in the stack
15      bool aBoolean = true;
16      char aCharacter = '$';
17      int anInteger = 34567;
18      string aString = "hello";
19
20      // use method Push to add items to stack
21      stack.Push( aBoolean );
22      stack.Display();
23      stack.Push( aCharacter );
24      stack.Display();
25      stack.Push( anInteger );
26      stack.Display();
27      stack.Push( aString );
28      stack.Display();
29
30      // remove items from stack
31      try
32      {
33          while ( true )
34          {
35              object removedObject = stack.Pop();
36              Console.WriteLine( removedObject + " popped" );
37              stack.Display();
38          } // end while
39      } // end try
40      catch ( EmptyListException emptyListException )
41      {
42          // if exception occurs, write stack trace
43          Console.Error.WriteLine( emptyListException.StackTrace );
44      } // end catch
45  } // end Main
46 } // end class StackInheritanceTest
```

```
The stack is: True
The stack is: $ True
The stack is: 34567 $ True
The stack is: hello 34567 $ True

hello popped
The stack is: 34567 $ True

34567 popped
The stack is: $ True

$ popped
The stack is: True
```

**Fig. 19.14** | Testing class StackInheritance. (Part 2 of 3.)

```

True popped
Empty stack
at LinkedListLibrary.List.RemoveFromFront()
  in C:\examples\ch21\Fig21_04\LinkedListLibrary\
  LinkedListLibrary\LinkedListLibrary.cs:line 78
at StackInheritanceLibrary.StackInheritance.Pop()
  in C:\examples\ch21\Fig21_13\StackInheritanceLibrary\
  StackInheritanceLibrary\StackInheritance.cs:line 27
at StackInheritanceTest.Main(String[] args)
  in C:\examples\ch21\Fig21_14\StackInheritanceTest\
  StackInheritanceTest\StackInheritanceTest.cs:line 35

```

**Fig. 19.14** | Testing class StackInheritance. (Part 3 of 3.)

### *Stack Class That Contains a Reference to a List*

Another way to implement a stack class is by *reusing* a list class through *composition*. The class in Fig. 19.15 uses a *private* object of class *List* (line 10) in the declaration of class *StackComposition*. Composition enables us to *hide* the methods of class *List* that should not be in our stack's *public* interface by providing *public* interface methods only to the required *List* methods. This class implements each stack method by *delegating* its work to an appropriate *List* method. *StackComposition*'s methods call *List* methods *InsertAtFront*, *RemoveFromFront*, *IsEmpty* and *Display*. In this example, we do not show class *StackCompositionTest*, because the only difference in this example is that we change the name of the stack class from *StackInheritance* to *StackComposition*.

---

```

1 // Fig. 19.15: StackCompositionLibrary.cs
2 // StackComposition declaration with composed List object.
3 using LinkedListLibrary;
4
5 namespace StackCompositionLibrary
6 {
7     // class StackComposition encapsulates List's capabilities
8     public class StackComposition
9     {
10         private List stack;
11
12         // construct empty stack
13         public StackComposition()
14         {
15             stack = new List( "stack" );
16         } // end constructor
17
18         // add object to stack
19         public void Push( object dataValue )
20         {
21             stack.InsertAtFront( dataValue );
22         } // end method Push
23     }

```

**Fig. 19.15** | StackComposition class encapsulates functionality of class List. (Part 1 of 2.)

```
24      // remove object from stack
25  public object Pop()
26  {
27      return stack.RemoveFromFront();
28  } // end method Pop
29
30  // determine whether stack is empty
31  public bool IsEmpty()
32  {
33      return stack.IsEmpty();
34  } // end method IsEmpty
35
36  // output stack contents
37  public void Display()
38  {
39      stack.Display();
40  } // end method Display
41 } // end class StackComposition
42 } // end namespace StackCompositionLibrary
```

**Fig. 19.15** | StackComposition class encapsulates functionality of class List. (Part 2 of 2.)

## 19.6 Queues

Another commonly used data structure is the *queue*. A queue is similar to a checkout line in a supermarket—the cashier services the person at the beginning of the line first. Other customers enter the line only at the end and wait for service. Queue nodes are removed only from the *head* (or *front*) of the queue and are inserted only at the *tail* (or *end*). For this reason, a queue is a **first-in, first-out (FIFO)** data structure. The insert and remove operations are known as **enqueue** and **dequeue**.

Queues have many uses in computer systems. Computers with only a single processor can service only one app at a time. Each app requiring processor time is placed in a queue. The app at the front of the queue is the next to receive service. Each app gradually advances to the front as the apps before it receive service.

Queues are also used to support **print spooling**. For example, a single printer might be shared by all users of a network. Many users can send print jobs to the printer, even when the printer is already busy. These print jobs are placed in a queue until the printer becomes available. A program called a **spooler** manages the queue to ensure that as each print job completes, the next one is sent to the printer.

Information packets also wait in queues in computer networks. Each time a packet arrives at a network node, it must be routed to the next node along the path to the packet's final destination. The routing node routes one packet at a time, so additional packets are enqueued until the router can route them.

A file server in a computer network handles file-access requests from many clients throughout the network. Servers have a limited capacity to service requests from clients. When that capacity is exceeded, client requests wait in queues.

### Queue Class That Inherits from List

The code in Fig. 19.16 creates a queue class by inheriting from a list class. We want the QueueInheritance class (Fig. 19.16) to have methods Enqueue, Dequeue, IsEmpty and

Display. Essentially, these are the methods `InsertAtBack`, `RemoveFromFront`, `IsEmpty` and `Display` of class `List`. Of course, the `List` class contains other methods (such as `InsertAtFront` and `RemoveFromBack`) that we would rather not make accessible through the `public` interface to the queue class. Remember that all methods in the `public` interface of the `List` class are also `public` methods of the derived class `QueueInheritance`.

The implementation of each `QueueInheritance` method calls the appropriate `List` method—method `Enqueue` calls `InsertAtBack` and method `Dequeue` calls `RemoveFromFront`. Calls to `IsEmpty` and `Display` invoke the base-class versions that were inherited from class `List` into `QueueInheritance`'s `public` interface. Class `QueueInheritance` uses namespace `LinkedListLibrary` (Fig. 19.4); thus, the class library for `QueueInheritance` must have a reference to the `LinkedListLibrary` class library.

---

```

1 // Fig. 19.16: QueueInheritanceLibrary.cs
2 // Implementing a queue by inheriting from class List.
3 using LinkedListLibrary;
4
5 namespace QueueInheritanceLibrary
6 {
7     // class QueueInheritance inherits List's capabilities
8     public class QueueInheritance : List
9     {
10         // pass name "queue" to List constructor
11         public QueueInheritance()
12             : base( "queue" )
13         {
14         } // end constructor
15
16         // place dataValue at end of queue by inserting
17         // dataValue at end of linked list
18         public void Enqueue( object dataValue )
19         {
20             InsertAtBack( dataValue );
21         } // end method Enqueue
22
23         // remove item from front of queue by removing
24         // item at front of linked list
25         public object Dequeue()
26         {
27             return RemoveFromFront();
28         } // end method Dequeue
29     } // end class QueueInheritance
30 } // end namespace QueueInheritanceLibrary

```

---

**Fig. 19.16** | Implementing a queue by inheriting from class `List`.

Class `QueueInheritanceTest`'s `Main` method (Fig. 19.17) creates a `QueueInheritance` object called `queue`. Lines 15–18 define four values that will be enqueued and dequeued. The program enqueues (lines 21, 23, 25 and 27) a `bool` containing `true`, a `char` containing `'$'`, an `int` containing 34567 and a `string` containing `"hello"`. Class `QueueInheritanceTest` uses namespace `LinkedListLibrary` and namespace `QueueIn-`

heritanceLibrary; thus, the solution for class StackInheritanceTest must have references to both class libraries.

```
1 // Fig. 19.17: QueueTest.cs
2 // Testing class QueueInheritance.
3 using System;
4 using QueueInheritanceLibrary;
5 using LinkedListLibrary;
6
7 // demonstrate functionality of class QueueInheritance
8 class QueueTest
9 {
10     public static void Main( string[] args )
11    {
12        QueueInheritance queue = new QueueInheritance();
13
14        // create objects to store in the queue
15        bool aBoolean = true;
16        char aCharacter = '$';
17        int anInteger = 34567;
18        string aString = "hello";
19
20        // use method Enqueue to add items to queue
21        queue.Enqueue( aBoolean );
22        queue.Display();
23        queue.Enqueue( aCharacter );
24        queue.Display();
25        queue.Enqueue( anInteger );
26        queue.Display();
27        queue.Enqueue( aString );
28        queue.Display();
29
30        // use method Dequeue to remove items from queue
31        object removedObject = null;
32
33        // remove items from queue
34        try
35        {
36            while ( true )
37            {
38                removedObject = queue.Dequeue();
39                Console.WriteLine( removedObject + " dequeued" );
40                queue.Display();
41            } // end while
42        } // end try
43        catch ( EmptyListException emptyListException )
44        {
45            // if exception occurs, write stack trace
46            Console.Error.WriteLine( emptyListException.StackTrace );
47        } // end catch
48    } // end Main
49 } // end class QueueTest
```

Fig. 19.17 | Testing class QueueInheritance. (Part 1 of 2.)

```

The queue is: True
The queue is: True $
The queue is: True $ 34567
The queue is: True $ 34567 hello
True dequeued
The queue is: $ 34567 hello
$ dequeued
The queue is: 34567 hello
34567 dequeued
The queue is: hello
hello dequeued
Empty queue
  at LinkedListLibrary.List.RemoveFromFront()
    in C:\examples\ch21\Fig21_04\LinkedListLibrary\
      LinkedListLibrary\LinkedListLibrary.cs:line 78
  at QueueInheritanceLibrary.QueueInheritance.Dequeue()
    in C:\examples\ch21\Fig21_16\QueueInheritanceLibrary\
      QueueInheritanceLibrary\QueueInheritance.cs:line 28
  at QueueTest.Main(String[] args)
    in C:\examples\ch21\Fig21_17\QueueTest\
      QueueTest\QueueTest.cs:line 38

```

**Fig. 19.17** | Testing class QueueInheritance. (Part 2 of 2.)

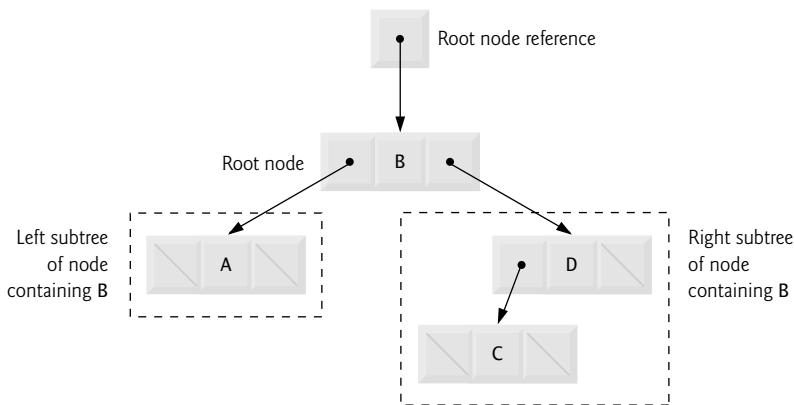
An infinite while loop (lines 36–41) dequeues the elements from the queue in FIFO order. When there are no objects left to dequeue, method Dequeue throws an `EmptyListException`, and the program displays the exception's stack trace, which shows the program-execution stack at the time the exception occurred. The program uses method `Display` (inherited from class `List`) to output the contents of the queue after each operation.

## 19.7 Trees

Linked lists, stacks and queues are **linear data structures** (i.e., **sequences**). A **tree** is a non-linear, two-dimensional data structure with special properties. Tree nodes contain two or more links.

### *Basic Terminology*

With binary trees (Fig. 19.18), each tree node contains two links (none, one or both of which may be `null`). The **root node** is the first node in a tree. Each link in the root node refers to a **child**. The **left child** is the first node in the **left subtree**, and the **right child** is the first node in the **right subtree**. The children of a specific node are called **siblings**. A node with no children is called a **leaf node**. Computer scientists normally draw trees from the root node down—the opposite of the way most trees grow in nature.



**Fig. 19.18** | Binary-tree graphical representation.

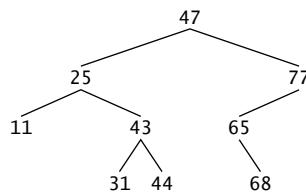


### Common Programming Error 19.2

*Not setting to null the links in leaf nodes of a tree is a common logic error.*

#### Binary Search Trees

In our binary-tree example, we create a special binary tree called a **binary search tree**. A binary search tree (with no duplicate node values) has the characteristic that the values in any left subtree are less than the value in the subtree's **parent node**, and the values in any right subtree are greater than the value in the subtree's parent node. Figure 19.19 illustrates a binary search tree with 9 integer values. The shape of the binary search tree that corresponds to a set of data can depend on the order in which the values are inserted into the tree.



**Fig. 19.19** | Binary search tree containing 9 values.

#### 19.7.1 Binary Search Tree of Integer Values

The app of Figs. 19.20 and 19.21 creates a binary search tree of integers and *traverses* it (i.e., walks through all its nodes) in three ways—using recursive **inorder**, **preorder** and **postorder** traversals. The program generates 10 random numbers and inserts each into the tree. Figure 19.20 defines class **Tree** in namespace **BinaryTreeLibrary** for reuse purposes. Figure 19.21 defines class **TreeTest** to demonstrate class **Tree**'s functionality. Method **Main** of class **TreeTest** instantiates an empty **Tree** object, then randomly generates 10 in-

tegers and inserts each value in the binary tree by calling Tree method `InsertNode`. The program then performs *preorder*, *inorder* and *postorder* traversals of the tree. We'll discuss these traversals shortly.

```

1 // Fig. 19.20: BinaryTreeNodeLibrary.cs
2 // Declaration of class TreeNode and class Tree.
3 using System;
4
5 namespace BinaryTreeNodeLibrary
6 {
7     // class TreeNode declaration
8     class TreeNode
9     {
10         // automatic property LeftNode
11         public TreeNode LeftNode { get; set; }
12
13         // automatic property Data
14         public int Data { get; set; }
15
16         // automatic property RightNode
17         public TreeNode RightNode { get; set; }
18
19         // initialize Data and make this a leaf node
20         public TreeNode( int nodeData )
21         {
22             Data = nodeData;
23             LeftNode = RightNode = null; // node has no children
24         } // end constructor
25
26         // insert TreeNode into Tree that contains nodes;
27         // ignore duplicate values
28         public void Insert( int insertValue )
29         {
30             if ( insertValue < Data ) // insert in left subtree
31             {
32                 // insert new TreeNode
33                 if ( LeftNode == null )
34                     LeftNode = new TreeNode( insertValue );
35                 else // continue traversing left subtree
36                     LeftNode.Insert( insertValue );
37             } // end if
38             else if ( insertValue > Data ) // insert in right subtree
39             {
40                 // insert new TreeNode
41                 if ( RightNode == null )
42                     RightNode = new TreeNode( insertValue );
43                 else // continue traversing right subtree
44                     RightNode.Insert( insertValue );
45             } // end else if
46         } // end method Insert
47     } // end class TreeNode
48 }
```

**Fig. 19.20** | Declaration of class `TreeNode` and class `Tree`. (Part I of 3.)

```
49 // class Tree declaration
50 public class Tree
51 {
52     private TreeNode root;
53
54     // construct an empty Tree of integers
55     public Tree()
56     {
57         root = null;
58     } // end constructor
59
60     // Insert a new node in the binary search tree.
61     // If the root node is null, create the root node here.
62     // Otherwise, call the insert method of class TreeNode.
63     public void InsertNode( int insertValue )
64     {
65         if ( root == null )
66             root = new TreeNode( insertValue );
67         else
68             root.Insert( insertValue );
69     } // end method InsertNode
70
71     // begin preorder traversal
72     public void PreorderTraversal()
73     {
74         PreorderHelper( root );
75     } // end method PreorderTraversal
76
77     // recursive method to perform preorder traversal
78     private void PreorderHelper( TreeNode node )
79     {
80         if ( node != null )
81         {
82             // output node Data
83             Console.WriteLine( node.Data + " " );
84
85             // traverse left subtree
86             PreorderHelper( node.LeftNode );
87
88             // traverse right subtree
89             PreorderHelper( node.RightNode );
90         } // end if
91     } // end method PreorderHelper
92
93     // begin inorder traversal
94     public void InorderTraversal()
95     {
96         InorderHelper( root );
97     } // end method InorderTraversal
98
99     // recursive method to perform inorder traversal
100    private void InorderHelper( TreeNode node )
101    {
```

---

**Fig. 19.20** | Declaration of class TreeNode and class Tree. (Part 2 of 3.)

---

```

102         if ( node != null )
103     {
104         // traverse left subtree
105         InorderHelper( node.LeftNode );
106
107         // output node data
108         Console.Write( node.Data + " " );
109
110         // traverse right subtree
111         InorderHelper( node.RightNode );
112     } // end if
113 } // end method InorderHelper
114
115 // begin postorder traversal
116 public void PostorderTraversal()
117 {
118     PostorderHelper( root );
119 } // end method PostorderTraversal
120
121 // recursive method to perform postorder traversal
122 private void PostorderHelper( TreeNode node )
123 {
124     if ( node != null )
125     {
126         // traverse left subtree
127         PostorderHelper( node.LeftNode );
128
129         // traverse right subtree
130         PostorderHelper( node.RightNode );
131
132         // output node Data
133         Console.Write( node.Data + " " );
134     } // end if
135 } // end method PostorderHelper
136 } // end class Tree
137 } // end namespace BinaryTreeLibrary

```

---

**Fig. 19.20** | Declaration of class `TreeNode` and class `Tree`. (Part 3 of 3.)

---

```

1 // Fig. 19.21: TreeTest.cs
2 // Testing class Tree with a binary tree.
3 using System;
4 using BinaryTreeLibrary;
5
6 // class TreeTest declaration
7 public class TreeTest
8 {
9     // test class Tree
10    public static void Main( string[] args )
11    {
12        Tree tree = new Tree();
13        int insertValue;

```

---

**Fig. 19.21** | Testing class `Tree` with a binary tree. (Part 1 of 2.)

```

14     Console.WriteLine( "Inserting values: " );
15     Random random = new Random();
16
17     // insert 10 random integers from 0-99 in tree
18     for ( int i = 1; i <= 10; i++ )
19     {
20         insertValue = random.Next( 100 );
21         Console.Write( insertValue + " " );
22
23         tree.InsertNode( insertValue );
24     } // end for
25
26
27     // perform preorder traversal of tree
28     Console.WriteLine( "\n\nPreorder traversal" );
29     tree.PreorderTraversal();
30
31     // perform inorder traversal of tree
32     Console.WriteLine( "\n\nInorder traversal" );
33     tree.InorderTraversal();
34
35     // perform postorder traversal of tree
36     Console.WriteLine( "\n\nPostorder traversal" );
37     tree.PostorderTraversal();
38     Console.WriteLine();
39 } // end Main
40 } // end class TreeTest

```

```

Inserting values:
39 69 94 47 50 72 55 41 97 73

Preorder traversal
39 69 47 41 50 55 94 72 73 97

Inorder traversal
39 41 47 50 55 69 72 73 94 97

Postorder traversal
41 55 50 47 73 72 97 94 69 39

```

**Fig. 19.21** | Testing class Tree with a binary tree. (Part 2 of 2.)

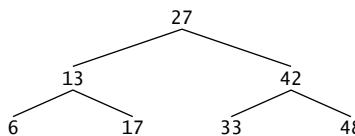
Class `TreeNode` (lines 8–47 of Fig. 19.20) is a self-referential class containing three properties—`LeftNode` and `RightNode` of type `TreeNode` and `Data` of type `int`. Initially, every `TreeNode` is a leaf node, so the constructor (lines 20–24) initializes references `LeftNode` and `RightNode` to `null`. We discuss `TreeNode` method `Insert` (lines 28–46) shortly.

Class `Tree` (lines 50–136) manipulates objects of class `TreeNode`. Class `Tree` has as private data `root` (line 52)—a reference to the root node of the tree. The class contains public method `InsertNode` (lines 63–69) to insert a new node in the tree and public methods `PreorderTraversal` (lines 72–75), `InorderTraversal` (lines 94–97) and `PostorderTraversal` (lines 116–119) to begin traversals of the tree. Each of these methods calls a separate *recursive utility method* to perform the traversal operations on the internal representation of the tree. The `Tree` constructor (lines 55–58) initializes `root` to `null` to indicate that the tree initially is empty.

Tree method `InsertNode` (lines 63–69) first determines whether the tree is empty. If so, line 66 allocates a new `TreeNode`, initializes the node with the integer being inserted in the tree and assigns the new node to `root`. If the tree is not empty, `InsertNode` calls `TreeNode` method `Insert` (lines 28–46), which recursively determines the location for the new node in the tree and inserts the node at that location. *A node can be inserted only as a leaf node in a binary search tree.*

The `TreeNode` method `Insert` compares the value to insert with the data value in the root node. If the insert value is less than the root-node data, the program determines whether the left subtree is empty (line 33). If so, line 34 allocates a new `TreeNode`, initializes it with the integer being inserted and assigns the new node to reference `LeftNode`. Otherwise, line 36 recursively calls `Insert` for the left subtree to insert the value into the left subtree. If the insert value is greater than the root-node data, the program determines whether the right subtree is empty (line 41). If so, line 42 allocates a new `TreeNode`, initializes it with the integer being inserted and assigns the new node to reference `RightNode`. Otherwise, line 44 recursively calls `Insert` for the right subtree to insert the value in the right subtree. If the insert value matches an existing node value, the insert value is *ignored*.

Methods `InorderTraversal`, `PreorderTraversal` and `PostorderTraversal` call helper methods `InorderHelper` (lines 100–113), `PreorderHelper` (lines 78–91) and `PostorderHelper` (lines 122–135), respectively, to traverse the tree and display the node values. The purpose of the helper methods in class `Tree` is to allow the programmer to start a traversal without needing to obtain a reference to the root node first, then call the recursive method with that reference. Methods `InorderTraversal`, `PreorderTraversal` and `PostorderTraversal` simply take private variable `root` and pass it to the appropriate helper method to initiate a traversal of the tree. For the following discussion, we use the binary search tree shown in Fig. 19.22.



**Fig. 19.22** | Binary search tree.

### Inorder Traversal Algorithm

Method `InorderHelper` (lines 100–113) defines the steps for an *inorder traversal*. Those steps are as follows:

1. If the argument is `null`, do not process the tree.
2. Traverse the left subtree with a call to `InorderHelper` (line 105).
3. Process the value in the node (line 108).
4. Traverse the right subtree with a call to `InorderHelper` (line 111).

The inorder traversal does not process the value in a node until the values in that node's left subtree are processed. The inorder traversal of the tree in Fig. 19.22 is

6 13 17 27 33 42 48

The inorder traversal of a binary search tree displays the node values in ascending order. The process of creating a binary search tree actually sorts the data (when coupled with an inorder traversal)—thus, this process is called the **binary-tree sort**.

### *Preorder Traversal Algorithm*

Method `PreorderHelper` (lines 78–91) defines the steps for a *preorder traversal*. Those steps are as follows:

1. If the argument is `null`, do not process the tree.
2. Process the value in the node (line 83).
3. Traverse the left subtree with a call to `PreorderHelper` (line 86).
4. Traverse the right subtree with a call to `PreorderHelper` (line 89).

The preorder traversal processes the value in each node as the node is visited. After processing the value in a given node, the preorder traversal processes the values in the left subtree, then the values in the right subtree. The preorder traversal of the tree in Fig. 19.22 is

```
27 13 6 17 42 33 48
```

### *Postorder Traversal Algorithm*

Method `PostorderHelper` (lines 122–135) defines the steps for a *postorder traversal*. Those steps are as follows:

1. If the argument is `null`, do not process the tree.
2. Traverse the left subtree with a call to `PostorderHelper` (line 127).
3. Traverse the right subtree with a call to `PostorderHelper` (line 130).
4. Process the value in the node (line 133).

The postorder traversal processes the value in each node after the values of all that node's children are processed. The postorder traversal of the tree in Fig. 19.22 is

```
6 17 13 33 48 42 27
```

### *Duplicate Elimination*

A binary search tree facilitates **duplicate elimination**. While building a tree, the insertion operation recognizes attempts to insert a duplicate value, because a duplicate follows the same “go left” or “go right” decisions on each comparison as the original value did. Thus, the insertion operation eventually compares the duplicate with a node containing the same value. At this point, the insertion operation might simply discard the duplicate value.

Searching a binary tree for a value that matches a key value is fast, especially for **tightly packed** binary trees. In a tightly packed binary tree, each level contains about twice as many elements as the previous level. Figure 19.22 is a tightly packed binary tree. A tightly packed binary search tree with  $n$  elements has a minimum of  $\log_2 n$  levels. For such a tree, at most  $\log_2 n$  comparisons are required either to find a match or to determine that no match exists. Searching a (tightly packed) 1000-element binary search tree requires at most 10 comparisons, because  $2^{10} > 1000$ . Searching a (tightly packed) 1,000,000-element binary search tree requires at most 20 comparisons, because  $2^{20} > 1,000,000$ .

### *Overview of the Binary-Tree Exercises*

The chapter exercises present algorithms for other binary-tree operations, such as performing a **level-order traversal of a binary tree**. The level-order traversal of a binary tree visits the nodes of the tree row by row, starting at the root-node level. On each level of the tree, a level-order traversal visits the nodes from left to right.

### 19.7.2 Binary Search Tree of **IComparable** Objects

The binary-tree example in Section 19.7.1 works nicely when all the data is of type `int`. Suppose that you want to manipulate a binary tree of `doubles`. You could rewrite the `TreeNode` and `Tree` classes with different names and customize the classes to manipulate `doubles`. Similarly, for each data type you could create customized versions of classes `TreeNode` and `Tree`. This proliferates code, and can become difficult to manage and maintain.

Ideally, we'd like to define the binary tree's functionality once and *reuse* it for *many* types. Languages like C# provide capabilities that enable all objects to be manipulated in a uniform manner. Using such capabilities enables us to design a more flexible data structure. C# provides these capabilities with *generics* (Chapter 20).

In our next example, we take advantage of C#'s polymorphic capabilities by implementing `TreeNode` and `Tree` classes that manipulate objects of *any* type that implements interface **IComparable** (namespace `System`). It is imperative that we be able to compare objects stored in a binary search tree, so we can determine the path to the insertion point of a new node. Classes that implement **IComparable** define method **CompareTo**, which compares the object that invokes the method with the object that the method receives as an argument. The method returns an `int` value less than zero if the calling object is less than the argument object, zero if the objects are equal and a positive value if the calling object is greater than the argument object. Also, both the calling and argument objects must be of the *same* data type; otherwise, the method throws an `ArgumentException`.

Figures 19.23–19.24 enhance the program of Section 19.7.1 to manipulate **IComparable** objects. One restriction on the new versions of classes `TreeNode` and `Tree` is that each `Tree` object can contain objects of only one type (e.g., all `strings` or all `doubles`). If a program attempts to insert multiple types in the same `Tree` object, `ArgumentExceptions` will occur. We modified only five lines of code in class `TreeNode` (lines 14, 20, 28, 30 and 38 of Fig. 19.23) and one line of code in class `Tree` (line 63) to enable processing of **IComparable** objects. Except for lines 30 and 38, all other changes simply replaced `int` with **IComparable**. Lines 30 and 38 previously used the `<` and `>` operators to compare the value being inserted with the value in a given node. These lines now compare **IComparable** objects via the interface's **CompareTo** method, then test the method's return value to determine whether it's less than zero (the calling object is less than the argument object) or greater than zero (the calling object is greater than the argument object), respectively. [Note: If this class were written using generics, the type of data, `int` or **IComparable**, could be replaced at compile time by any other type that implements the necessary operators and methods.]

---

```

1 // Fig. 19.23: BinaryTreeLibrary2.cs
2 // Declaration of class TreeNode and class Tree.
3 using System;

```

---

**Fig. 19.23** | Declaration of class `TreeNode` and class `Tree`. (Part 1 of 4.)

```
4  namespace BinaryTreeLibrary2
5  {
6      // class TreeNode declaration
7      class TreeNode
8      {
9          // automatic property LeftNode
10         public TreeNode LeftNode { get; set; }
11
12         // automatic property Data
13         public IComparable Data { get; set; }
14
15         // automatic property RightNode
16         public TreeNode RightNode { get; set; }
17
18         // initialize Data and make this a leaf node
19         public TreeNode( IComparable nodeData )
20         {
21             Data = nodeData;
22             LeftNode = RightNode = null; // node has no children
23         } // end constructor
24
25
26         // insert TreeNode into Tree that contains nodes;
27         // ignore duplicate values
28         public void Insert( IComparable insertValue )
29         {
30             if ( insertValue.CompareTo(Data) < 0 ) // insert in left subtree
31             {
32                 // insert new TreeNode
33                 if ( LeftNode == null )
34                     LeftNode = new TreeNode( insertValue );
35                 else // continue traversing left subtree
36                     LeftNode.Insert( insertValue );
37             } // end if
38             else if ( insertValue.CompareTo( Data ) > 0 ) // insert in right
39             {
40                 // insert new TreeNode
41                 if ( RightNode == null )
42                     RightNode = new TreeNode( insertValue );
43                 else // continue traversing right subtree
44                     RightNode.Insert( insertValue );
45             } // end else if
46         } // end method Insert
47     } // end class TreeNode
48
49     // class Tree declaration
50     public class Tree
51     {
52         private TreeNode root;
53
54         // construct an empty Tree of IComparable objects
55         public Tree()
56         {
```

---

**Fig. 19.23** | Declaration of class `TreeNode` and class `Tree`. (Part 2 of 4.)

```

57         root = null;
58     } // end constructor
59
60     // Insert a new node in the binary search tree.
61     // If the root node is null, create the root node here.
62     // Otherwise, call the insert method of class TreeNode.
63     public void InsertNode( IComparable insertValue )
64     {
65         if ( root == null )
66             root = new TreeNode( insertValue );
67         else
68             root.Insert( insertValue );
69     } // end method InsertNode
70
71     // begin preorder traversal
72     public void PreorderTraversal()
73     {
74         PreorderHelper( root );
75     } // end method PreorderTraversal
76
77     // recursive method to perform preorder traversal
78     private void PreorderHelper( TreeNode node )
79     {
80         if ( node != null )
81         {
82             // output node Data
83             Console.Write( node.Data + " " );
84
85             // traverse left subtree
86             PreorderHelper( node.LeftNode );
87
88             // traverse right subtree
89             PreorderHelper( node.RightNode );
90         } // end if
91     } // end method PreorderHelper
92
93     // begin inorder traversal
94     public void InorderTraversal()
95     {
96         InorderHelper( root );
97     } // end method InorderTraversal
98
99     // recursive method to perform inorder traversal
100    private void InorderHelper( TreeNode node )
101    {
102        if ( node != null )
103        {
104            // traverse left subtree
105            InorderHelper( node.LeftNode );
106
107            // output node data
108            Console.Write( node.Data + " " );
109

```

**Fig. 19.23** | Declaration of class TreeNode and class Tree. (Part 3 of 4.)

```
110          // traverse right subtree
111          InorderHelper( node.RightNode );
112      } // end if
113  } // end method InorderHelper
114
115  // begin postorder traversal
116  public void PostorderTraversal()
117  {
118      PostorderHelper( root );
119  } // end method PostorderTraversal
120
121  // recursive method to perform postorder traversal
122  private void PostorderHelper( TreeNode node )
123  {
124      if ( node != null )
125      {
126          // traverse left subtree
127          PostorderHelper( node.LeftNode );
128
129          // traverse right subtree
130          PostorderHelper( node.RightNode );
131
132          // output node Data
133          Console.Write( node.Data + " " );
134      } // end if
135  } // end method PostorderHelper
136 } // end class Tree
137 } // end namespace BinaryTreeLibrary
```

---

**Fig. 19.23** | Declaration of class `TreeNode` and class `Tree`. (Part 4 of 4.)

Class `TreeTest` (Fig. 19.24) creates three `Tree` objects to store `int`, `double` and `string` values, all of which the .NET Framework defines as `IComparable` types. The program populates the trees with the values in arrays `intArray` (line 12), `doubleArray` (line 13) and `stringArray` (lines 14–15), respectively.

```
1 // Fig. 19.24: TreeTest.cs
2 // Testing class Tree with IComparable objects.
3 using System;
4 using BinaryTreeLibrary2;
5
6 // class TreeTest declaration
7 public class TreeTest
8 {
9     // test class Tree
10    public static void Main( string[] args )
11    {
12        int[] intArray = { 8, 2, 4, 3, 1, 7, 5, 6 };
13        double[] doubleArray = { 8.8, 2.2, 4.4, 3.3, 1.1, 7.7, 5.5, 6.6 };
14        string[] stringArray = { "eight", "two", "four",
15                                "three", "one", "seven", "five", "six" };
```

---

**Fig. 19.24** | Testing class `Tree` with `IComparable` objects. (Part 1 of 3.)

```

16    // create int Tree
17    Tree intTree = new Tree();
18    PopulateTree( intArray, intTree, "intTree" );
19    TraverseTree( intTree, "intTree" );
20
21    // create double Tree
22    Tree doubleTree = new Tree();
23    PopulateTree( doubleArray, doubleTree, "doubleTree" );
24    TraverseTree( doubleTree, "doubleTree" );
25
26    // create string Tree
27    Tree stringTree = new Tree();
28    PopulateTree( stringArray, stringTree, "stringTree" );
29    TraverseTree( stringTree, "stringTree" );
30 } // end Main
31
32 // populate Tree with array elements
33 private static void PopulateTree( Array array, Tree tree, string name )
34 {
35     Console.WriteLine( "\n\n\nInserting into " + name + ":" );
36
37     foreach ( IComparable data in array )
38     {
39         Console.Write( data + " " );
40         tree.InsertNode( data );
41     } // end foreach
42 } // end method PopulateTree
43
44 // perform traversals
45 private static void TraverseTree( Tree tree, string treeType )
46 {
47     // perform preorder traversal of tree
48     Console.WriteLine( "\n\nPreorder traversal of " + treeType );
49     tree.PreorderTraversal();
50
51     // perform inorder traversal of tree
52     Console.WriteLine( "\n\nInorder traversal of " + treeType );
53     tree.InorderTraversal();
54
55     // perform postorder traversal of tree
56     Console.WriteLine( "\n\nPostorder traversal of " + treeType );
57     tree.PostorderTraversal();
58 } // end method TraverseTree
59 } // end class TreeTest
60 } // end class TreeTest

```

Inserting into intTree:  
8 2 4 3 1 7 5 6

Preorder traversal of intTree  
8 2 1 4 3 7 5 6

Inorder traversal of intTree  
1 2 3 4 5 6 7 8

**Fig. 19.24** | Testing class Tree with IComparable objects. (Part 2 of 3.)

```

Postorder traversal of intTree
1 3 6 5 7 4 2 8

Inserting into doubleTree:
8.8 2.2 4.4 3.3 1.1 7.7 5.5 6.6

Preorder traversal of doubleTree
8.8 2.2 1.1 4.4 3.3 7.7 5.5 6.6

Inorder traversal of doubleTree
1.1 2.2 3.3 4.4 5.5 6.6 7.7 8.8

Postorder traversal of doubleTree
1.1 3.3 6.6 5.5 7.7 4.4 2.2 8.8

Inserting into stringTree:
eight two four three one seven five six

Preorder traversal of stringTree
eight two four five three one seven six

Inorder traversal of stringTree
eight five four one seven six three two

Postorder traversal of stringTree
five six seven one three four two eight

```

**Fig. 19.24** | Testing class Tree with IComparable objects. (Part 3 of 3.)

Method `PopulateTree` (lines 34–43) receives as arguments an `Array` containing the initializer values for the `Tree`, a `Tree` in which the array elements will be placed and a `string` representing the `Tree` name, then inserts each `Array` element into the `Tree`. Method `TraverseTree` (lines 46–59) receives as arguments a `Tree` and a `string` representing the `Tree` name, then outputs the preorder, inorder and postorder traversals of the `Tree`. The inorder traversal of each `Tree` outputs the data in *sorted order* regardless of the data type stored in the `Tree`. Our polymorphic implementation of class `Tree` invokes the appropriate data type's `CompareTo` method to determine the path to each value's insertion point by using the standard binary-search-tree insertion rules. Also, notice that the `Tree` of `strings` appears in alphabetical order.

## 19.8 Wrap-Up

In this chapter, you learned that simple types are value-type `structs` but can still be used anywhere `objects` are expected in a program due to boxing and unboxing conversions. You learned that linked lists are collections of data items that are “linked together in a chain.” You also learned that a program can perform insertions and deletions anywhere in a linked list (though our implementation performed insertions and deletions only at the ends of the list). We demonstrated that the stack and queue data structures are constrained versions of lists. For stacks, you saw that insertions and deletions are made only at the top—so stacks are known as last-in, first out (LIFO) data structures. For queues, which

represent waiting lines, you saw that insertions are made at the tail and deletions are made from the head—so queues are known as first-in, first out (FIFO) data structures. We also presented the binary tree data structure. You saw a binary search tree that facilitated high-speed searching and sorting of data and efficient duplicate elimination. In the next chapter, we introduce *generics*, which allow you to declare a family of classes and methods that implement the same functionality on *any* type.

---

## Summary

### Section 19.1 Introduction

- Dynamic data structures can grow and shrink at execution time.

### Section 19.2 Simple-Type **structs**, **Boxing** and **Unboxing**

- All simple-type names are aliases for corresponding **structs** in namespace **System**.
- Each simple type **struct** declares methods for manipulating the corresponding simple-type values.
- Each **struct** that represents a simple type inherits from class **ValueType** in namespace **System**.
- A **boxing** conversion creates an object that contains a copy of a simple-type value.
- An **unboxing** conversion retrieves a simple-type value from an object.

### Section 19.3 Self-Referential Classes

- A self-referential class contains a data member that refers to an object of the same class type. Self-referential objects can be linked to form data structures, such as lists, queues, stacks and trees.
- Creating and maintaining dynamic data structures requires dynamic memory allocation—a program’s ability to obtain more memory at execution time (to hold new nodes) and to release memory no longer needed.
- Operator **new** takes as an operand the type of the object being dynamically allocated, calls the appropriate constructor to initialize the object and returns a reference to the new object. If no memory is available, **new** throws an **OutOfMemoryException**.

### Section 19.4 Linked Lists

- A linked list is a linear collection (i.e., a sequence) of self-referential class objects called nodes, connected by reference links.
- A node can contain properties of any type, including references to objects of other classes.
- A linked list is accessed via a reference to the first node of the list. Each subsequent node is accessed via the link-reference member stored in the previous node.
- By convention, the link reference in the last node of a list is set to **null** to mark the end of the list.
- A circular, singly linked list begins with a reference to the first node, and each node contains a reference to the next node. The “last node” does not contain a null reference; rather, the reference in the last node points back to the first node, thus closing the “circle.”
- A doubly linked list allows traversals both forward and backward. Such a list is often implemented with two “start references”—one that refers to the first element of the list to allow front-to-back traversal of the list and one that refers to the last element to allow back-to-front traversal. Each node has both a forward reference to the next node in the list and a backward reference to the previous node.

- In a circular, doubly linked list, the forward reference of the last node refers to the first node, and the backward reference of the first node refers to the last node, thus closing the “circle.”

### **Section 19.5 Stacks**

- Stacks are important in compilers and operating systems.
- A stack is a constrained version of a linked list—new nodes can be added to and removed from a stack only at the top. A stack is referred to as a last-in, first-out (LIFO) data structure.
- The primary stack operations are push and pop. Operation push adds a new node to the top of the stack. Operation pop removes a node from the top of the stack and returns the data object from the popped node.

### **Section 19.6 Queues**

- Queues represent waiting lines. Insertions occur at the back (also referred to as the tail) of a queue, and deletions occur from the front (also referred to as the head) of a queue.
- A queue is similar to a checkout line in a supermarket: The first person in line is served first; other customers enter the line at the end and wait to be served.
- Queue nodes are removed only from the head of the queue and are inserted only at the tail of the queue. For this reason, a queue is referred to as a first-in, first-out (FIFO) data structure.
- The insert and remove operations for a queue are known as enqueue and dequeue.

### **Section 19.7 Trees**

- Binary trees facilitate high-speed searching and sorting of data.
- Tree nodes contain two or more links.
- A binary tree is a tree whose nodes all contain two links (each of which can be null). The root node is the first node in a tree.
- Each link in the root node refers to a child. The left child is the root node of the left subtree, and the right child is the root node of the right subtree.
- The children of a node are called siblings. A node with no children is called a leaf node.
- A binary search tree (with no duplicate node values) has the characteristic that the values in any left subtree are less than the value in that subtree’s parent node, and the values in any right subtree are greater than the value in that subtree’s parent node.
- A node can be inserted only as a leaf node in a binary search tree.
- In a preorder traversal, the value in each node is processed as the node is visited. After the value in a given node is processed, the values in the left subtree are processed, then the values in the right subtree are processed.
- In a postorder traversal, the value in each node is processed after the node’s left and right subtrees are processed.
- In an inorder traversal, the value in each node is processed after the node’s left subtree is processed and before the node’s right subtree is processed.
- The inorder traversal of a binary search tree processes the node values in ascending order. The process of creating a binary search tree actually sorts the data (when coupled with an inorder traversal)—thus, this process is called the binary-tree sort.
- The binary search tree facilitates duplicate elimination. As the tree is created, attempts to insert a duplicate value are recognized because a duplicate follows the same “go left” or “go right” decisions on each comparison that the original value did. Thus, the duplicate eventually is compared with a node containing the same value. The duplicate value may simply be discarded at this point.

## Terminology

|                                           |                            |
|-------------------------------------------|----------------------------|
| ArgumentException                         | linked list                |
| binary search tree                        | node                       |
| binary tree                               | OutOfMemoryException       |
| binary-tree sort                          | parent node                |
| boxing conversion                         | pop on a stack             |
| child node                                | postorder traversal        |
| circular, doubly linked list              | predicate method           |
| circular, singly linked list              | preorder traversal         |
| collection                                | print spooling             |
| CompareTo method of interface IComparable | push on a stack            |
| data structures                           | queue                      |
| dequeue                                   | right child node           |
| doubly linked list                        | right subtree              |
| duplicate elimination                     | root node                  |
| dynamic data structures                   | searching                  |
| enqueue                                   | self-referential class     |
| first-in, first-out (FIFO) data structure | sibling node               |
| head of a queue                           | simple type                |
| IComparable interface                     | singly linked list         |
| inorder traversal                         | sorting                    |
| InvalidCastException                      | spooler                    |
| last-in, first-out (LIFO) data structure  | stack                      |
| leaf node                                 | struct                     |
| left child node                           | tail of a queue            |
| left subtree                              | top of a stack             |
| level-order traversal of a binary tree    | tightly packed binary tree |
| linear data structure                     | unboxing conversion        |
| link                                      | ValueType class            |

## Self-Review Exercises

**19.1** State whether each of the following is *true* or *false*. If *false*, explain why.

- a) In a queue, the first item to be added is the last item to be removed.
- b) Trees can have no more than two child nodes per node.
- c) A tree node with no children is called a leaf node.
- d) Linked-list nodes are stored contiguously in memory.
- e) The primary operations of the stack data structure are enqueue and dequeue.
- f) Lists, stacks and queues are linear data structures.

**19.2** Fill in the blanks in each of the following statements:

- a) A(n) \_\_\_\_\_ class is used to define nodes that form dynamic data structures, which can grow and shrink at execution time.
- b) Operator \_\_\_\_\_ allocates memory dynamically; this operator returns a reference to the allocated memory.
- c) A(n) \_\_\_\_\_ is a constrained version of a linked list in which nodes can be inserted and deleted only from the start of the list; this data structure returns node values in last-in, first-out order.
- d) A queue is a(n) \_\_\_\_\_ data structure, because the first nodes inserted are the first nodes removed.

- e) A(n) \_\_\_\_\_ is a constrained version of a linked list in which nodes can be inserted only at the end of the list and deleted only from the start of the list.
- f) A(n) \_\_\_\_\_ is a nonlinear, two-dimensional data structure that contains nodes with two or more links.
- g) The nodes of a(n) \_\_\_\_\_ tree contain two link members.
- h) The tree-traversal algorithm that processes the node then processes all the nodes to its left followed by all the nodes to its right is called \_\_\_\_\_.

## Answers to Self-Review Exercises

**19.1** a) False. A queue is a first-in, first-out data structure—the first item added is the first item removed. b) False. In general, trees may have as many child nodes per node as is necessary. Only binary trees are restricted to no more than two child nodes per node. c) True. d) False. Linked-list nodes are logically contiguous, but they need not be stored in a physically contiguous memory space. e) False. Those are the primary operations of a queue. The primary operations of a stack are push and pop. f) True.

**19.2** a) self-referential. b) new. c) stack. d) first-in, first-out (FIFO). e) queue. f) tree. g) binary. h) preorder.

## Exercises

**19.3** (*Merging Ordered-List Objects*) Write a program that merges two ordered-list objects of integers into a single ordered-list object of integers. Method `Merge` of class `ListMerge` should receive references to each of the list objects to be merged and should return a reference to the merged-list object.

**19.4** (*Reversing a Line of Text with a Stack*) Write a program that inputs a line of text and uses a stack object to display the line reversed.

**19.5** (*Palindromes*) Write a program that uses a stack to determine whether a string is a palindrome (i.e., the string is spelled identically backward and forward). The program should ignore capitalization, spaces and punctuation.

**19.6** (*Evaluating Expressions with a Stack*) Stacks are used by compilers to evaluate expressions and generate machine-language code. In this and the next exercise, we investigate how compilers evaluate arithmetic expressions consisting only of constants, operators and parentheses.

Humans generally write expressions like  $3 + 4$  and  $7 / 9$ , in which the operator (+ or / here) is written between its operands—this is called *infix notation*. Computers “prefer” *postfix notation*, in which the operator is written to the right of its two operands. The preceding infix expressions would appear in postfix notation as  $3\ 4 +$  and  $7\ 9 /$ , respectively.

To evaluate a complex infix expression, a compiler would first convert the expression to postfix notation, then evaluate the postfix version of the expression. Each of these algorithms requires only a single left-to-right pass of the expression. Each algorithm uses a stack object in support of its operation, and in each algorithm the stack is used for a different purpose. Here, you’ll implement the infix-to-postfix conversion algorithm. In the next exercise, you’ll implement the postfix-expression evaluation algorithm.

Write class `InfixToPostfixConverter` to convert an ordinary infix arithmetic expression (assume a valid expression is entered), with single-digit integers, such as

$(6 + 2) * 5 - 8 / 4$

to a postfix expression. The postfix version of the preceding infix expression is

$6\ 2\ +\ 5\ *\ 8\ 4\ / -$

The program should read the expression into `StringBuilder infix`, then use class `StackInheritance` (implemented in Fig. 19.13) to help create the postfix expression in `StringBuilder postfix`. The algorithm for creating a postfix expression is as follows:

- Push a left parenthesis '(' on the stack.
- Append a right parenthesis ')' to the end of `infix`.
- While the stack is not empty, read `infix` from left to right and do the following:
  - If the current character in `infix` is a digit, append it to `postfix`.
  - If the current character in `infix` is a left parenthesis, push it onto the stack.
  - If the current character in `infix` is an operator:
    - Pop operators (if there are any) at the top of the stack while they have equal or higher precedence than the current operator, and append the popped operators to `postfix`.
    - Push the current character in `infix` onto the stack.
  - If the current character in `infix` is a right parenthesis:
    - Pop operators from the top of the stack and append them to `postfix` until a left parenthesis is at the top of the stack.
    - Pop (and discard) the left parenthesis from the stack.

The following arithmetic operations are allowed in an expression:

- + addition
- subtraction
- \* multiplication
- / division
- ^ exponentiation
- % modulus

Some of the methods you may want to provide in your program follow:

- Method `ConvertToPostfix`, which converts the infix expression to postfix notation.
- Method `IsOperator`, which determines whether `c` is an operator.
- Method `Precedence`, which determines whether the precedence of `operator1` (from the infix expression) is less than, equal to or greater than the precedence of `operator2` (from the stack). The method returns `true` if `operator1` has lower precedence than or equal precedence to `operator2`. Otherwise, `false` is returned.

**19.7** (*Evaluating a Postfix Expression with a Stack*) Write class `PostfixEvaluator`, which evaluates a postfix expression (assume it is valid) such as

6 2 + 5 \* 8 4 / -

The program should read a postfix expression consisting of digits and operators into a `StringBuilder`. Using the stack class from Exercise 19.6, the program should scan the expression and evaluate it. The algorithm (for single-digit numbers) is as follows:

- Append a right parenthesis ')' to the end of the postfix expression. When the right-parenthesis character is encountered, no further processing is necessary.
- When the right-parenthesis character has not been encountered, read the expression from left to right.

If the current character is a digit, do the following:

Push its integer value on the stack (the integer value of a digit character is its value in the computer's character set minus the value of '0' in Unicode).

Otherwise, if the current character is an *operator*:

Pop the two top elements of the stack into variables `x` and `y`.

Calculate  $y \text{ operator } x$ .

Push the result of the calculation onto the stack.

- When the right parenthesis is encountered in the expression, pop the top value of the stack. This is the result of the postfix expression.

[Note: In Part b above (based on the sample expression at the beginning of this exercise), if the operator is '/', the top of the stack is 4 and the next element in the stack is 8, then pop 4 into x, pop 8 into y, evaluate  $8 / 4$  and push the result, 2, back on the stack. This note also applies to operator '-'.] The arithmetic operations allowed in an expression are:

- + addition
- subtraction
- \* multiplication
- / division
- <sup>^</sup> exponentiation
- % modulus

You may want to provide the following methods:

- a) Method `EvaluatePostfixExpression`, which evaluates the postfix expression.
- b) Method `Calculate`, which evaluates the expression `op1 operator op2`.

**19.8 (Level-Order Binary Tree-Traversal)** The program of Fig. 19.21 illustrated three recursive methods of traversing a binary tree—inorder, preorder, and postorder traversals. This exercise presents the *level-order traversal* of a binary tree, in which the node values are displayed level by level, starting at the root-node level. The nodes on each level are displayed from left to right. The level-order traversal is not a recursive algorithm. It uses a queue object to control the output of the nodes. The algorithm is as follows:

- a) Insert the root node in the queue.
- b) While there are nodes left in the queue, do the following:
  - Get the next node in the queue.
  - Display the node's value.
  - If the reference to the left child of the node is not `null`:
    - Insert the left child node in the queue.
  - If the reference to the right child of the node is not `null`:
    - Insert the right child node in the queue.

Write method `LevelOrderTraversal` to perform a level-order traversal of a binary-tree object. Modify the program of Fig. 19.21 to use this method. [Note: You also will need to use the queue-processing methods of Fig. 19.16 in this program.]

# 20

## Generics



*...our special individuality, as distinguished from our generic humanity.*

—Oliver Wendell Holmes, Sr.

*Every man of genius sees the world at a different angle from his fellows.*

—Havelock Ellis

*Born under one law, to another bound.*

—Lord Brooke

### Objectives

In this chapter you'll:

- Create generic methods that perform identical tasks on arguments of different types.
- Create a generic `Stack` class that can be used to store objects of most types.
- Understand how to overload generic methods with nongeneric methods or with other generic methods.
- Understand the kinds of constraints that can be applied to a type parameter.
- Apply multiple constraints to a type parameter.

|                                            |                                         |
|--------------------------------------------|-----------------------------------------|
| <b>20.1</b> Introduction                   | <b>20.5</b> Overloading Generic Methods |
| <b>20.2</b> Motivation for Generic Methods | <b>20.6</b> Generic Classes             |
| <b>20.3</b> Generic-Method Implementation  | <b>20.7</b> Wrap-Up                     |
| <b>20.4</b> Type Constraints               |                                         |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 20.1 Introduction

In Chapter 19, we presented data structures that stored and manipulated object references. This chapter continues our multi-chapter discussion on data structures. You could store any object in our data structures. One inconvenient aspect of storing object references occurs when retrieving them from a collection. An app normally needs to process specific types of objects. As a result, the object references obtained from a collection typically need to be *downcast* to an appropriate type to allow the app to process the objects correctly. In addition, data of value types (e.g., `int` and `double`) must be *boxed* to be manipulated with object references, which increases the overhead of processing such data. Most importantly, processing all data as type object limits the C# compiler's ability to perform type checking.

Though we can easily create data structures that manipulate any type of data as objects (as we did in Chapter 19), it would be nice if we could detect type mismatches at compile time—this is known as **compile-time type safety**. For example, if a `Stack` should store only `int` values, attempting to push a `string` onto that `Stack` should cause a compile-time error. Similarly, a `Sort` method should be able to compare elements that are all guaranteed to have the same type. If we create type-specific versions of class `Stack` class and method `Sort`, the C# compiler would certainly be able to ensure compile-time type safety. However, this would require that we create many copies of the same basic code.

This chapter discusses **generics**, which provide the means to create the general models mentioned above. **Generic methods** enable you to specify, with a *single method declaration, a set of related methods*. **Generic classes** enable you to specify, with a *single class declaration, a set of related classes*. Similarly, **generic interfaces** enable you to specify, with a *single interface declaration, a set of related interfaces*. Generics provide *compile-time type safety*. [Note: You can also implement generic `structs` and `delegates`.] So far in this book, we've used the generic types `List` (Chapter 9) and `Dictionary` (Chapter 17).

We can write a generic method for sorting an array of objects, then invoke the generic method separately with an `int` array, a `double` array, a `string` array and so on, to sort each different type of array. The compiler performs **type checking** to ensure that the array passed to the sorting method contains only elements of the correct type. We can write a single generic `Stack` class that manipulates a stack of objects, then instantiate `Stack` objects for a stack of `ints`, a stack of `doubles`, a stack of `strings` and so on. The compiler performs *type checking* to ensure that the `Stack` stores *only* elements of the correct type.

This chapter presents examples of generic methods and generic classes. It also considers the relationships between generics and other C# features, such as overloading. Chapter 21, Collections, discusses the .NET Framework's generic and nongeneric collections classes. A *collection* is a data structure that maintains a group of related objects or

values. The .NET Framework collection classes use generics to allow you to specify the exact types of object that a particular collection will store.

## 20.2 Motivation for Generic Methods

Overloaded methods are often used to perform similar operations on different types of data. To understand the motivation for generic methods, let's begin with an example (Fig. 20.1) that contains three overloaded `DisplayArray` methods (lines 23–29, lines 32–38 and lines 41–47). These methods display the elements of an `int` array, a `double` array and a `char` array, respectively. Soon, we'll reimplement this program more concisely and elegantly using a single generic method.

---

```

1 // Fig. 20.1: OverloadedMethods.cs
2 // Using overloaded methods to display arrays of different types.
3 using System;
4
5 class OverloadedMethods
6 {
7     static void Main( string[] args )
8     {
9         // create arrays of int, double and char
10        int[] intArray = { 1, 2, 3, 4, 5, 6 };
11        double[] doubleArray = { 1.1, 2.2, 3.3, 4.4, 5.5, 6.6, 7.7 };
12        char[] charArray = { 'H', 'E', 'L', 'L', 'O' };
13
14        Console.WriteLine( "Array intArray contains:" );
15        DisplayArray( intArray ); // pass an int array argument
16        Console.WriteLine( "Array doubleArray contains:" );
17        DisplayArray( doubleArray ); // pass a double array argument
18        Console.WriteLine( "Array charArray contains:" );
19        DisplayArray( charArray ); // pass a char array argument
20    } // end Main
21
22    // output int array
23    private static void DisplayArray( int[] inputArray )
24    {
25        foreach ( int element in inputArray )
26            Console.Write( element + " " );
27
28        Console.WriteLine( "\n" );
29    } // end method DisplayArray
30
31    // output double array
32    private static void DisplayArray( double[] inputArray )
33    {
34        foreach ( double element in inputArray )
35            Console.Write( element + " " );
36
37        Console.WriteLine( "\n" );
38    } // end method DisplayArray

```

---

**Fig. 20.1** | Using overloaded methods to display arrays of different types. (Part 1 of 2.)

```

39     // output char array
40     private static void DisplayArray( char[] inputArray )
41     {
42         foreach ( char element in inputArray )
43             Console.WriteLine( element + " " );
44
45             Console.WriteLine( "\n" );
46     } // end method DisplayArray
47 } // end class OverloadedMethods

```

Array intArray contains:  
1 2 3 4 5 6

Array doubleArray contains:  
1.1 2.2 3.3 4.4 5.5 6.6 7.7

Array charArray contains:  
H E L L O

**Fig. 20.1** | Using overloaded methods to display arrays of different types. (Part 2 of 2.)

The program begins by declaring and initializing three arrays—six-element **int** array **intArray** (line 10), seven-element **double** array **doubleArray** (line 11) and five-element **char** array **charArray** (line 12). Then, lines 14–19 output the arrays.

When the compiler encounters a method call, it attempts to locate a method declaration that has the *same* method name and parameters that *match* the argument types in the method call. In this example, each **DisplayArray** call exactly matches one of the **DisplayArray** method declarations. For example, line 15 calls **DisplayArray** with **intArray** as its argument. At compile time, the compiler determines argument **intArray**'s type (i.e., **int**[]), attempts to locate a method named **DisplayArray** that specifies a single **int**[] parameter (which it finds at lines 23–29) and sets up a call to that method. Similarly, when the compiler encounters the **DisplayArray** call at line 17, it determines argument **doubleArray**'s type (i.e., **double**[]), then attempts to locate a method named **DisplayArray** that specifies a single **double**[] parameter (which it finds at lines 32–38) and sets up a call to that method. Finally, when the compiler encounters the **DisplayArray** call at line 19, it determines argument **charArray**'s type (i.e., **char**[]), then attempts to locate a method named **DisplayArray** that specifies a single **char**[] parameter (which it finds at lines 41–47) and sets up a call to that method.

Study each **DisplayArray** method. Note that the array element type (**int**, **double** or **char**) appears in two locations in each method—the method header (lines 23, 32 and 41) and the **foreach** statement header (lines 25, 34 and 43). If we replace the element types in each method with a generic name (such as **T** for “type”) then all three methods would look like the one in Fig. 20.2. It appears that if we can replace the array element type in each of the three methods with a single “generic type parameter,” then we should be able to declare one **DisplayArray** method that can display the elements of *any* array. The method in Fig. 20.2 *will not compile*, because its syntax is not correct. We declare a generic **DisplayArray** method with the proper syntax in Fig. 20.3.

---

```

1 private static void DisplayArray( T[] inputArray )
2 {
3     foreach ( T element in inputArray )
4         Console.WriteLine( element + " " );
5
6     Console.WriteLine( "\n" );
7 } // end method DisplayArray

```

---

**Fig. 20.2** | `DisplayArray` method in which actual type names are replaced by convention with the generic name `T`. Again, this code will *not* compile.

## 20.3 Generic-Method Implementation

If the operations performed by several overloaded methods are identical for each argument type, the overloaded methods can be more compactly and conveniently coded using a generic method. You can write a single generic-method declaration that can be called at different times with arguments of different types. Based on the types of the arguments passed to the generic method, the compiler handles each method call appropriately.

Figure 20.3 reimplements the app of Fig. 20.1 using a generic `DisplayArray` method (lines 24–30). Note that the `DisplayArray` method calls in lines 16, 18 and 20 are identical to those of Fig. 20.1, the outputs of the two apps are identical and the code in Fig. 20.3 is 17 lines *shorter* than that in Fig. 20.1. As illustrated in Fig. 20.3, generics enable us to create and test our code once, then *reuse* it for many different types of data. This demonstrates the expressive power of generics.

---

```

1 // Fig. 20.3: GenericMethod.cs
2 // Using overloaded methods to display arrays of different types.
3 using System;
4 using System.Collections.Generic;
5
6 class GenericMethod
7 {
8     public static void Main( string[] args )
9     {
10        // create arrays of int, double and char
11        int[] intArray = { 1, 2, 3, 4, 5, 6 };
12        double[] doubleArray = { 1.1, 2.2, 3.3, 4.4, 5.5, 6.6, 7.7 };
13        char[] charArray = { 'H', 'E', 'L', 'L', 'O' };
14
15        Console.WriteLine( "Array intArray contains:" );
16        DisplayArray( intArray ); // pass an int array argument
17        Console.WriteLine( "Array doubleArray contains:" );
18        DisplayArray( doubleArray ); // pass a double array argument
19        Console.WriteLine( "Array charArray contains:" );
20        DisplayArray( charArray ); // pass a char array argument
21    } // end Main
22

```

---

**Fig. 20.3** | Using a generic method to display arrays of different types. (Part 1 of 2.)

```

23  // output array of all types
24  private static void DisplayArray< T >( T[] inputArray )
25  {
26      foreach ( T element in inputArray )
27          Console.WriteLine( element + " " );
28
29      Console.WriteLine( "\n" );
30  } // end method DisplayArray
31 } // end class GenericMethod

```

Array intArray contains:  
1 2 3 4 5 6

Array doubleArray contains:  
1.1 2.2 3.3 4.4 5.5 6.6 7.7

Array charArray contains:  
H E L L O

**Fig. 20.3** | Using a generic method to display arrays of different types. (Part 2 of 2.)

Line 24 begins method `DisplayArray`'s declaration. All generic method declarations have a **type-parameter list** delimited by angle brackets (`<T>` in this example) that follows the method's name. Each type-parameter list contains one or more **type parameters**, separated by commas. A type parameter is an identifier that's used in place of actual type names. The type parameters can be used to declare the return type, the parameter types and the local variable types in a generic method declaration; the type parameters act as placeholders for **type arguments** that represent the types of data that will be passed to the generic method.

A generic method's body is declared like that of any other method. Note that the type-parameter names throughout the method declaration must match those declared in the type-parameter list. For example, line 26 declares `element` in the `foreach` statement as type `T`, which matches the type parameter (`T`) declared in line 24. Also, a type parameter can be declared *only once* in the type-parameter list but can appear *more than once* in the method's parameter list. Type-parameter names need *not* be unique among different generic methods.



### Common Programming Error 20.1

*If you forget to include the type-parameter list when declaring a generic method, the compiler will not recognize the type-parameter names when they're encountered in the method. This results in compilation errors.*

Method `DisplayArray`'s type-parameter list (line 24) declares type parameter `T` as the placeholder for the array-element type that `DisplayArray` will output. Note that `T` appears in the parameter list as the array-element type (line 24). The `foreach` statement header (line 26) also uses `T` as the `element` type. These are the same two locations where the overloaded `DisplayArray` methods of Fig. 20.1 specified `int`, `double` or `char` as the element type. The remainder of `DisplayArray` is identical to the version presented in Fig. 20.1.



### Good Programming Practice 20.1

*It's recommended that type parameters be specified as individual capital letters. Typically, a type parameter that represents the type of an element in an array (or other collection) is named E for "element" or T for "type."*

As in Fig. 20.1, the program of Fig. 20.3 begins by declaring and initializing six-element int array `intArray` (line 11), seven-element double array `doubleArray` (line 12) and five-element char array `charArray` (line 13). Then each array is output by calling `DisplayArray` (lines 16, 18 and 20)—once with argument `intArray`, once with argument `doubleArray` and once with argument `charArray`.

When the compiler encounters a method call such as line 16, it analyzes the set of methods (both nongeneric and generic) that might match the method call, looking for a method that best matches the call. If there are no matching methods, or if there's more than one best match, the compiler generates an error. If you have any uncertainty on which of your methods will be called, the complete details of method-call resolution can be found in Section 14.5.5.1 of the ECMA C# Language Specification

[www.ecma-international.org/publications/standards/Ecma-334.htm](http://www.ecma-international.org/publications/standards/Ecma-334.htm)

or Section 7.5.3 of the Microsoft C# Language Specification 4

[bit.ly/CSharp4Spec](http://bit.ly/CSharp4Spec)

In the case of line 16, the compiler determines that the best match occurs if the type parameter `T` in lines 24 and 26 of method `DisplayArray`'s declaration is replaced with the type of the elements in the method call's argument `intArray` (i.e., `int`). Then, the compiler sets up a call to `DisplayArray` with `int` as the **type argument** for the type parameter `T`. This is known as the **type-inferencing** process. The same process is repeated for the calls to method `DisplayArray` in lines 18 and 20.



### Common Programming Error 20.2

*If the compiler cannot find a single nongeneric or generic method declaration that's a best match for a method call, or if there are multiple best matches, a compilation error occurs.*

You can also use **explicit type arguments** to indicate the exact type that should be used to call a generic function. For example, line 16 could be written as

```
DisplayArray< int >( intArray ); // pass an int array argument
```

The preceding method call explicitly provides the type argument (`int`) that should be used to replace type parameter `T` in lines 24 and 26 of the `DisplayArray` method's declaration.

For each variable declared with a type parameter, the compiler also determines whether the operations performed on such a variable are allowed for all types that the type parameter can assume. The only operation performed on the array elements in this example is to output the `string` representation of the elements. Line 27 performs an *implicit* boxing conversion for every value-type array element and an *implicit* `ToString` call on every array element. Since all objects have a `ToString` method, the compiler is satisfied that line 27 performs a valid operation for any array element.

By declaring `DisplayArray` as a generic method in Fig. 20.3, we eliminated the need for the overloaded methods of Fig. 20.1, saving 17 lines of code and creating a *reusable*

method that can output the string representations of the elements in *any* one-dimensional array, not just arrays of `int`, `double` or `char` elements.

## 20.4 Type Constraints

In this section, we present a generic `Maximum` method that determines and returns the largest of its three arguments (all of the same type). The generic method in this example uses the type parameter to declare *both* the method's return type *and* its parameters. Normally, when comparing values to determine which one is greater, you would use the `>` operator. However, this operator is not overloaded for use with every type that's built into the Framework Class Library or that might be defined by extending those types. Generic code is restricted to performing operations that are guaranteed to work for every possible type. Thus, an expression like `variable1 < variable2` is not allowed unless the compiler can ensure that the operator `<` is provided for every type that will ever be used in the generic code. Similarly, you cannot call a method on a generic-type variable unless the compiler can ensure that all types that will ever be used in the generic code support that method.

### `IComparable<T>` Interface

It's possible to compare two objects of the *same* type if that type implements the generic interface `IComparable<T>` (of namespace `System`). A benefit of implementing interface `IComparable<T>` is that `IComparable<T>` objects can be used with the *sorting* and *searching* methods of classes in the `System.Collections.Generic` namespace—we discuss those methods in Chapter 21. The structures in the Framework Class Library that correspond to the simple types *all* implement this interface. For example, the structure for simple type `double` is `Double` and the structure for simple type `int` is `Int32`—both `Double` and `Int32` implement the `IComparable<T>` interface. Types that implement `IComparable<T>` must declare a `CompareTo` method for comparing objects. For example, if we have two `ints`, `int1` and `int2`, they can be compared with the expression:

```
int1.CompareTo( int2 )
```

Method `CompareTo` must return 0 if the objects are equal, a negative integer if `int1` is less than `int2` or a positive integer if `int1` is greater than `int2`. It's the responsibility of the programmer who declares a type that implements `IComparable<T>` to define method `CompareTo` such that it compares the contents of two objects of that type and returns the appropriate result.

### Specifying Type Constraints

Even though `IComparable` objects can be compared, they cannot be used with generic code by default, because *not* all types implement interface `IComparable<T>`. However, we can restrict the types that can be used with a generic method or class to ensure that they meet certain requirements. This feature—known as a **type constraint**—restricts the type of the argument supplied to a particular type parameter. Figure 20.4 declares method `Maximum` (lines 20–34) with a type constraint that requires each of the method's arguments to be of type `IComparable<T>`. This restriction is important, because *not* all objects can be compared. However, all `IComparable<T>` objects are guaranteed to have a `CompareTo` method that can be used in method `Maximum` to determine the largest of its three arguments.

```

1 // Fig. 20.4: MaximumTest.cs
2 // Generic method Maximum returns the largest of three objects.
3 using System;
4
5 class MaximumTest
6 {
7     public static void Main( string[] args )
8     {
9         Console.WriteLine( "Maximum of {0}, {1} and {2} is {3}\n",
10             3, 4, 5, Maximum( 3, 4, 5 ) );
11         Console.WriteLine( "Maximum of {0}, {1} and {2} is {3}\n",
12             6.6, 8.8, 7.7, Maximum( 6.6, 8.8, 7.7 ) );
13         Console.WriteLine( "Maximum of {0}, {1} and {2} is {3}\n",
14             "pear", "apple", "orange",
15             Maximum( "pear", "apple", "orange" ) );
16     } // end Main
17
18     // generic function determines the
19     // largest of the IComparable objects
20     private static T Maximum< T >( T x, T y, T z )
21     where T : IComparable< T >
22     {
23         T max = x; // assume x is initially the largest
24
25         // compare y with max
26         if ( y.CompareTo( max ) > 0 )
27             max = y; // y is the largest so far
28
29         // compare z with max
30         if ( z.CompareTo( max ) > 0 )
31             max = z; // z is the largest
32
33         return max; // return largest object
34     } // end method Maximum
35 } // end class MaximumTest

```

```

Maximum of 3, 4 and 5 is 5
Maximum of 6.6, 8.8 and 7.7 is 8.8
Maximum of pear, apple and orange is pear

```

**Fig. 20.4** | Generic method Maximum returns the largest of three objects.

Generic method `Maximum` uses type parameter `T` as the return type of the method (line 20), as the type of method parameters `x`, `y` and `z` (line 20), and as the type of local variable `max` (line 23). Generic method `Maximum`'s `where` clause (after the parameter list in line 21) specifies the type constraint for type parameter `T`. In this case, the clause `where T : IComparable<T>` indicates that this method requires the type argument to implement interface `IComparable<T>`. If no type constraint is specified, the default type constraint is `object`.

C# provides several kinds of type constraints. A **class constraint** indicates that the type argument must be an object of a specific base class or one of its subclasses. An **interface constraint** indicates that the type argument's class must implement a specific interface. The type

constraint in line 21 is an interface constraint, because `IComparable<T>` is an interface. You can specify that the type argument must be a reference type or a value type by using the **reference-type constraint (`class`)** or the **value-type constraint (`struct`)**, respectively. Finally, you can specify a **constructor constraint—`new()`**—to indicate that the generic code can use operator `new` to create new objects of the type represented by the type parameter. If a type parameter is specified with a constructor constraint, the type argument's class must provide a `public` parameterless or default constructor to ensure that objects of the class can be created without passing constructor arguments; otherwise, a compilation error occurs.

It's possible to apply **multiple constraints** to a type parameter. To do so, simply provide a comma-separated list of constraints in the `where` clause. If you have a class constraint, reference-type constraint or value-type constraint, it must be listed first—only one of these types of constraints can be used for each type parameter. Interface constraints (if any) are listed next. The constructor constraint is listed last (if there is one).

### *Analyzing the Code*

Method `Maximum` assumes that its first argument (`x`) is the largest and assigns it to local variable `max` (line 23). Next, the `if` statement at lines 26–27 determines whether `y` is greater than `max`. The condition invokes `y`'s `CompareTo` method with the expression `y.CompareTo(max)`. If `y` is greater than `max`, then `y` is assigned to variable `max` (line 27). Similarly, the statement at lines 30–31 determines whether `z` is greater than `max`. If so, line 31 assigns `z` to `max`. Then, line 33 returns `max` to the caller.

In `Main` (lines 7–16), line 10 calls `Maximum` with the integers 3, 4 and 5. Generic method `Maximum` is a match for this call, but its arguments must implement interface `IComparable<T>` to ensure that they can be compared. Type `int` is a synonym for `struct Int32`, which implements interface `IComparable<int>`. Thus, `ints` (and other simple types) are valid arguments to method `Maximum`.

Line 12 passes three `double` arguments to `Maximum`. Again, this is allowed because `double` is a synonym for the `Double struct`, which implements `IComparable<double>`. Line 15 passes `Maximum` three `strings`, which are also `IComparable<string>` objects. We intentionally placed the largest value in a different position in each method call (lines 10, 12 and 15) to show that the generic method always finds the maximum value, regardless of its position in the argument list and regardless of the inferred type argument.

## 20.5 Overloading Generic Methods

A generic method may be **overloaded**. Each overloaded method must have a unique signature (as discussed in Chapter 7). A class can provide two or more generic methods with the *same* name but *different* method parameters. For example, we could provide a second version of generic method `DisplayArray` (Fig. 20.3) with the additional parameters `lowIndex` and `highIndex` that specify the portion of the array to output (see Exercise 20.8).

A generic method can be overloaded by nongeneric methods with the same method name. When the compiler encounters a method call, it searches for the method declaration that best matches the method name and the argument types specified in the call. For example, generic method `DisplayArray` of Fig. 20.3 could be overloaded with a version specific to `strings` that outputs the `strings` in tabular format (see Exercise 20.9). If the compiler cannot match a method call to either a nongeneric method or a generic method, or if there's ambiguity due to multiple possible matches, the compiler generates an error.

## 20.6 Generic Classes

The concept of a data structure (e.g., a stack) that contains data elements can be understood independently of the element type it manipulates. A generic class provides a means for describing a class in a type-independent manner. We can then instantiate type-specific versions of the generic class. This capability is an opportunity for software reusability.

With a generic class, you can use a simple, concise notation to indicate the actual type(s) that should be used in place of the class's type parameter(s). At compilation time, the compiler ensures your code's type safety, and the runtime system replaces type parameters with type arguments to enable your client code to interact with the generic class.

One generic Stack class, for example, could be the basis for creating many Stack classes (e.g., "Stack of double," "Stack of int," "Stack of char," "Stack of Employee"). Figure 20.5 presents a generic Stack class declaration. This class should not be confused with the class Stack from namespace `System.Collections.Generics`. A generic class declaration is similar to a nongeneric class declaration, except that the class name is followed by a type-parameter list (line 5) and, optionally, one or more constraints on its type parameter. Type parameter `T` represents the element type the Stack will manipulate. As with generic methods, the type-parameter list of a generic class can have one or more type parameters separated by commas. (You'll create a generic class with two type parameters in Exercise 20.11.) Type parameter `T` is used throughout the Stack class declaration (Fig. 20.5) to represent the element type. Class Stack declares variable `elements` as an array of type `T` (line 8). This array (created at line 21) will store the Stack's elements. [Note: This example implements a Stack as an array. As you've seen in Chapter 19, Stacks also are commonly implemented as constrained versions of linked lists.]

---

```

1 // Fig. 20.5: Stack.cs
2 // Generic class Stack.
3 using System;
4
5 class Stack< T >
6 {
7     private int top; // location of the top element
8     private T[] elements; // array that stores stack elements
9
10    // parameterless constructor creates a stack of the default size
11    public Stack()
12        : this( 10 ) // default stack size
13    {
14        // empty constructor; calls constructor at line 18 to perform init
15    } // end stack constructor
16
17    // constructor creates a stack of the specified number of elements
18    public Stack( int stackSize )
19    {
20        if ( stackSize > 0 ) // validate stackSize
21            elements = new T[ stackSize ]; // create stackSize elements
22        else
23            throw new ArgumentException( "Stack size must be positive." );

```

**Fig. 20.5** | Generic class Stack. (Part I of 2.)

```
24      top = -1; // stack initially empty
25  } // end stack constructor
26
27
28  // push element onto the stack; if unsuccessful,
29  // throw FullStackException
30  public void Push( T pushValue )
31  {
32      if ( top == elements.Length - 1 ) // stack is full
33          throw new FullStackException( string.Format(
34              "Stack is full, cannot push {0}", pushValue ) );
35
36      ++top; // increment top
37      elements[ top ] = pushValue; // place pushValue on stack
38  } // end method Push
39
40  // return the top element if not empty,
41  // else throw EmptyStackException
42  public T Pop()
43  {
44      if ( top == -1 ) // stack is empty
45          throw new EmptyStackException( "Stack is empty, cannot pop" );
46
47      --top; // decrement top
48      return elements[ top + 1 ]; // return top value
49  } // end method Pop
50 } // end class Stack
```

---

**Fig. 20.5** | Generic class Stack. (Part 2 of 2.)

### Stack Constructors

Class Stack has two constructors. The parameterless constructor (lines 11–15) passes the default stack size (10) to the one-argument constructor, using the syntax `this` (line 12) to invoke another constructor in the same class. The one-argument constructor (lines 18–26) validates the `stackSize` argument and creates an array of the specified `stackSize` (if it's greater than 0) or throws an exception, otherwise.

### Stack Method Push

Method `Push` (lines 30–38) first determines whether an attempt is being made to push an element onto a full Stack. If so, lines 33–34 throw a `FullStackException` (declared in Fig. 20.6). If the Stack is not full, line 36 increments the `top` counter to indicate the new top position, and line 37 places the argument in that location of array `elements`.

### Stack Method Pop

Method `Pop` (lines 42–49) first determines whether an attempt is being made to pop an element from an empty Stack. If so, line 45 throws an `EmptyStackException` (declared in Fig. 20.7). Otherwise, line 47 decrements the `top` counter to indicate the new top position, and line 48 returns the original top element of the Stack.

Classes `FullStackException` (Fig. 20.6) and `EmptyStackException` (Fig. 20.7) each provide a parameterless constructor, a one-argument constructor of exception classes (as discussed in Section 13.8) and a two-argument constructor for creating a new exception

using an existing one. The parameterless constructor sets the default error message while the other two constructors set custom error messages.

---

```

1 // Fig. 20.6: FullStackException.cs
2 // FullStackException indicates a stack is full.
3 using System;
4
5 class FullStackException : Exception
6 {
7     // parameterless constructor
8     public FullStackException() : base( "Stack is full" )
9     {
10         // empty constructor
11     } // end FullStackException constructor
12
13     // one-parameter constructor
14     public FullStackException( string exception ) : base( exception )
15     {
16         // empty constructor
17     } // end FullStackException constructor
18
19     // two-parameter constructor
20     public FullStackException( string exception, Exception inner )
21         : base( exception, inner )
22     {
23         // empty constructor
24     } // end FullStackException constructor
25 } // end class FullStackException

```

---

**Fig. 20.6** | FullStackException indicates a stack is full.

---

```

1 // Fig. 20.7: EmptyStackException.cs
2 // EmptyStackException indicates a stack is empty.
3 using System;
4
5 class EmptyStackException : Exception
6 {
7     // parameterless constructor
8     public EmptyStackException() : base( "Stack is empty" )
9     {
10         // empty constructor
11     } // end EmptyStackException constructor
12
13     // one-parameter constructor
14     public EmptyStackException( string exception ) : base( exception )
15     {
16         // empty constructor
17     } // end EmptyStackException constructor
18

```

---

**Fig. 20.7** | EmptyStackException indicates a stack is empty. (Part 1 of 2.)

---

```

19 // two-parameter constructor
20 public EmptyStackException( string exception, Exception inner )
21     : base( exception, inner )
22 {
23     // empty constructor
24 } // end EmptyStackException constructor
25 } // end class EmptyStackException

```

---

**Fig. 20.7 |** `EmptyStackException` indicates a stack is empty. (Part 2 of 2.)

As with generic methods, when a generic class is compiled, the compiler performs type checking on the class's type parameters to ensure that they can be used with the code in the generic class. The constraints determine the operations that can be performed on the type parameters. The runtime system replaces the type parameters with the actual types at runtime. For class `Stack` (Fig. 20.5), no type constraint is specified, so the default type constraint, `object`, is used. The scope of a generic class's type parameter is the entire class.

Now, let's consider an app (Fig. 20.8) that uses the `Stack` generic class. Lines 13–14 declare variables of type `Stack<double>` (pronounced "Stack of double") and `Stack<int>` (pronounced "Stack of int"). The types `double` and `int` are the `Stack`'s type arguments. The compiler replaces the type parameters in the generic class so that the compiler can perform type checking. Method `Main` instantiates objects `doubleStack` of size 5 (line 18) and `intStack` of size 10 (line 19), then calls methods `TestPushDouble` (lines 28–48), `TestPopDouble` (lines 51–73), `TestPushInt` (lines 76–96) and `TestPopInt` (lines 99–121) to manipulate the two Stacks in this example.

---

```

1 // Fig. 20.8: StackTest.cs
2 // Testing generic class Stack.
3 using System;
4
5 class StackTest
6 {
7     // create arrays of doubles and ints
8     private static double[] doubleElements =
9         new double[]{ 1.1, 2.2, 3.3, 4.4, 5.5, 6.6 };
10    private static int[] intElements =
11        new int[]{ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 };
12
13    private static Stack< double > doubleStack; // stack stores doubles
14    private static Stack< int > intStack; // stack stores int objects
15
16    public static void Main( string[] args )
17    {
18        doubleStack = new Stack< double >( 5 ); // stack of doubles
19        intStack = new Stack< int >( 10 ); // stack of ints
20
21        TestPushDouble(); // push doubles onto doubleStack
22        TestPopDouble(); // pop doubles from doubleStack
23        TestPushInt(); // push ints onto intStack
24        TestPopInt(); // pop ints from intStack
25    } // end Main

```

---

**Fig. 20.8 |** Testing generic class `Stack`. (Part 1 of 4.)

```
26 // test Push method with doubleStack
27 private static void TestPushDouble()
28 {
29     // push elements onto stack
30     try
31     {
32         Console.WriteLine( "\nPushing elements onto doubleStack" );
33
34         // push elements onto stack
35         foreach ( var element in doubleElements )
36         {
37             Console.Write( "{0:F1} ", element );
38             doubleStack.Push( element ); // push onto doubleStack
39         } // end foreach
40     } // end try
41     catch ( FullStackException exception )
42     {
43         Console.Error.WriteLine();
44         Console.Error.WriteLine( "Message: " + exception.Message );
45         Console.Error.WriteLine( exception.StackTrace );
46     } // end catch
47 } // end method TestPushDouble
48
49 // test Pop method with doubleStack
50 private static void TestPopDouble()
51 {
52     // pop elements from stack
53     try
54     {
55         Console.WriteLine( "\nPopping elements from doubleStack" );
56
57         double popValue; // store element removed from stack
58
59         // remove all elements from stack
60         while ( true )
61         {
62             popValue = doubleStack.Pop(); // pop from doubleStack
63             Console.Write( "{0:F1} ", popValue );
64         } // end while
65     } // end try
66     catch ( EmptyStackException exception )
67     {
68         Console.Error.WriteLine();
69         Console.Error.WriteLine( "Message: " + exception.Message );
70         Console.Error.WriteLine( exception.StackTrace );
71     } // end catch
72 } // end method TestPopDouble
73
74 // test Push method with intStack
75 private static void TestPushInt()
76 {
77 }
```

**Fig. 20.8** | Testing generic class Stack. (Part 2 of 4.)

```

78     // push elements onto stack
79     try
80     {
81         Console.WriteLine( "\nPushing elements onto intStack" );
82
83         // push elements onto stack
84         foreach ( var element in intElements )
85         {
86             Console.Write( "{0} ", element );
87             intStack.Push( element ); // push onto intStack
88         } // end foreach
89     } // end try
90     catch ( FullStackException exception )
91     {
92         Console.Error.WriteLine();
93         Console.Error.WriteLine( "Message: " + exception.Message );
94         Console.Error.WriteLine( exception.StackTrace );
95     } // end catch
96 } // end method TestPushInt
97
98 // test Pop method with intStack
99 private static void TestPopInt()
100 {
101     // pop elements from stack
102     try
103     {
104         Console.WriteLine( "\nPopping elements from intStack" );
105
106         int popValue; // store element removed from stack
107
108         // remove all elements from stack
109         while ( true )
110         {
111             popValue = intStack.Pop(); // pop from intStack
112             Console.Write( "{0} ", popValue );
113         } // end while
114     } // end try
115     catch ( EmptyStackException exception )
116     {
117         Console.Error.WriteLine();
118         Console.Error.WriteLine( "Message: " + exception.Message );
119         Console.Error.WriteLine( exception.StackTrace );
120     } // end catch
121 } // end method TestPopInt
122 } // end class StackTest

```

```

Pushing elements onto doubleStack
1.1 2.2 3.3 4.4 5.5 6.6
Message: Stack is full, cannot push 6.6
    at Stack`1.Push(T pushValue) in
        c:\examples\ch22\Fig22_05_08\Stack\Stack.cs:line 36
    at StackTest.TestPushDouble() in
        c:\examples\ch22\Fig22_05_08\Stack\StackTest.cs:line 39

```

**Fig. 20.8** | Testing generic class Stack. (Part 3 of 4.)

```

Popping elements from doubleStack
5.5 4.4 3.3 2.2 1.1
Message: Stack is empty, cannot pop
  at Stack`1.Pop() in
    c:\examples\ch22\Fig22_05_08\Stack\Stack\Stack.cs:line 47
  at StackTest.TestPopDouble() in
    c:\examples\ch22\Fig22_05_08\Stack\Stack\StackTest.cs:line 63

Pushing elements onto intStack
1 2 3 4 5 6 7 8 9 10 11
Message: Stack is full, cannot push 11
  at Stack`1.Push(T pushValue) in
    c:\examples\ch22\Fig22_05_08\Stack\Stack\Stack.cs:line 36
  at StackTest.TestPushInt() in
    c:\examples\ch22\Fig22_05_08\Stack\Stack\StackTest.cs:line 87

Popping elements from intStack
10 9 8 7 6 5 4 3 2 1
Message: Stack is empty, cannot pop
  at Stack`1.Pop() in
    c:\examples\ch22\Fig22_05_08\Stack\Stack\Stack.cs:line 47
  at StackTest.TestPopInt() in
    c:\examples\ch22\Fig22_05_08\Stack\Stack\StackTest.cs:line 111

```

**Fig. 20.8** | Testing generic class Stack. (Part 4 of 4.)

#### **Method TestPushDouble**

Method `TestPushDouble` (lines 28–48) invokes method `Push` to place the `double` values 1.1, 2.2, 3.3, 4.4 and 5.5 stored in array `doubleElements` onto `doubleStack`. The `foreach` statement terminates when the test program attempts to `Push` a sixth value onto `doubleStack` (which is full, because `doubleStack` can store only five elements). In this case, the method throws a `FullStackException` (Fig. 20.6) to indicate that the Stack is full. Lines 42–47 catch this exception and display the message and stack-trace information. The stack trace indicates the exception that occurred and shows that `Stack` method `Push` generated the exception at line 36 of the file `Stack.cs` (Fig. 20.5). The trace also shows that method `Push` was called by `StackTest` method `TestPushDouble` at line 39 of `StackTest.cs`. This information enables you to determine the methods that were on the method-call stack at the time that the exception occurred. Because the program catches the exception, the C# runtime environment considers the exception to have been handled, and the program can continue executing.

#### **Method TestPopDouble**

Method `TestPopDouble` (lines 51–73) invokes `Stack` method `Pop` in an infinite while loop to remove all the values from the stack. Note in the output that the values are popped off in *last-in, first-out order*—this, of course, is the defining characteristic of stacks. The while loop (lines 61–65) continues until the stack is empty. An `EmptyStackException` occurs when an attempt is made to `Pop` from the empty stack. This causes the program to proceed to the catch block (lines 67–72) and handle the exception, so the program can continue executing. When the test program attempts to `Pop` a sixth value, the `doubleStack` is empty, so method `Pop` throws an `EmptyStackException`.

### **Methods TestPushInt and TestPopInt**

Method TestPushInt (lines 76–96) invokes Stack method Push to place values onto intStack until it's full. Method TestPopInt (lines 99–121) invokes Stack method Pop to remove values from intStack until it's empty. Again, values pop in last-in, first-out order.

### *Creating Generic Methods to Test Class Stack< T >*

Note that the code in methods TestPushDouble and TestPushInt is almost identical for pushing values onto a Stack<double> or a Stack<int>, respectively. Similarly the code in methods TestPopDouble and TestPopInt is almost identical for popping values from a Stack<double> or a Stack<int>, respectively. This presents another opportunity to use generic methods. Figure 20.9 declares generic method TestPush (lines 33–54) to perform the same tasks as TestPushDouble and TestPushInt in Fig. 20.8—that is, Push values onto a Stack<T>. Similarly, generic method TestPop (lines 57–79) performs the same tasks as TestPopDouble and TestPopInt in Fig. 20.8—that is, Pop values off a Stack<T>.

---

```

1 // Fig. 20.9: StackTest.cs
2 // Testing generic class Stack.
3 using System;
4 using System.Collections.Generic;
5
6 class StackTest
7 {
8     // create arrays of doubles and ints
9     private static double[] doubleElements =
10         new double[] { 1.1, 2.2, 3.3, 4.4, 5.5, 6.6 };
11     private static int[] intElements =
12         new int[] { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 };
13
14     private static Stack< double > doubleStack; // stack stores doubles
15     private static Stack< int > intStack; // stack stores int objects
16
17     public static void Main( string[] args )
18     {
19         doubleStack = new Stack< double >( 5 ); // stack of doubles
20         intStack = new Stack< int >( 10 ); // stack of ints
21
22         // push doubles onto doubleStack
23         TestPush( "doubleStack", doubleStack, doubleElements );
24         // pop doubles from doubleStack
25         TestPop( "doubleStack", doubleStack );
26         // push ints onto intStack
27         TestPush( "intStack", intStack, intElements );
28         // pop ints from intStack
29         TestPop( "intStack", intStack );
30     } // end Main
31
32     // test Push method
33     private static void TestPush< T >( string name, Stack< T > stack,
34         IEnumerable< T > elements )
35     {

```

**Fig. 20.9** | Testing generic class Stack. (Part 1 of 3.)

```

36      // push elements onto stack
37      try
38      {
39          Console.WriteLine( "\nPushing elements onto " + name );
40
41          // push elements onto stack
42          foreach ( var element in elements )
43          {
44              Console.Write( "{0} ", element );
45              stack.Push( element ); // push onto stack
46          } // end foreach
47      } // end try
48      catch ( FullStackException exception )
49      {
50          Console.Error.WriteLine();
51          Console.Error.WriteLine( "Message: " + exception.Message );
52          Console.Error.WriteLine( exception.StackTrace );
53      } // end catch
54  } // end method TestPush
55
56  // test Pop method
57  private static void TestPop< T >( string name, Stack< T > stack )
58  {
59      // pop elements from stack
60      try
61      {
62          Console.WriteLine( "\nPopping elements from " + name );
63
64          T popValue; // store element removed from stack
65
66          // remove all elements from stack
67          while ( true )
68          {
69              popValue = stack.Pop(); // pop from stack
70              Console.Write( "{0} ", popValue );
71          } // end while
72      } // end try
73      catch ( EmptyStackException exception )
74      {
75          Console.Error.WriteLine();
76          Console.Error.WriteLine( "Message: " + exception.Message );
77          Console.Error.WriteLine( exception.StackTrace );
78      } // end catch
79  } // end TestPop
80 } // end class StackTest

```

```

Pushing elements onto doubleStack
1.1 2.2 3.3 4.4 5.5 6.6
Message: Stack is full, cannot push 6.6
at Stack`1.Push(T pushValue)
in c:\examples\ch22\Fig22_09\Stack\Stack\Stack.cs:line 36
at StackTest.TestPush[T](String name, Stack`1 stack, IEnumerable`1 elements)
in c:\examples\ch22\Fig22_09\Stack\Stack\StackTest.cs:line 45

```

**Fig. 20.9** | Testing generic class Stack. (Part 2 of 3.)

```

Popping elements from doubleStack
5.5 4.4 3.3 2.2 1.1
Message: Stack is empty, cannot pop
    at Stack`1.Pop() in c:\examples\ch22\Fig22_09\Stack\Stack\Stack.cs:line 47
    at StackTest.TestPop[T](String name, Stack`1 stack) in
        c:\examples\ch22\Fig22_09\Stack\Stack\StackTest.cs:line 69

Pushing elements onto intStack
1 2 3 4 5 6 7 8 9 10 11
Message: Stack is full, cannot push 11
    at Stack`1.Push(T pushValue) in
        c:\examples\ch22\Fig22_09\Stack\Stack\Stack.cs:line 36
    at StackTest.TestPush[T](String name, Stack`1 stack, IEnumerable`1 elements)
        in c:\examples\ch22\Fig22_09\Stack\Stack\StackTest.cs:line 45

Popping elements from intStack
10 9 8 7 6 5 4 3 2 1
Message: Stack is empty, cannot pop
    at Stack`1.Pop() in c:\examples\ch22\Fig22_09\Stack\Stack\Stack.cs:line 47
    at StackTest.TestPop[T](String name, Stack`1 stack) in
        c:\examples\ch22\Fig22_09\Stack\Stack\StackTest.cs:line 69

```

**Fig. 20.9** | Testing generic class Stack. (Part 3 of 3.)

Method `Main` (Fig. 20.9, lines 17–30) creates the `Stack<double>` (line 19) and `Stack<int>` (line 20) objects. Lines 23–29 invoke generic methods `TestPush` and `TestPop` to test the `Stack` objects.

Generic method `TestPush` (lines 33–54) uses type parameter `T` (specified at line 33) to represent the data type stored in the `Stack`. The generic method takes three arguments—a `string` that represents the name of the `Stack` object for output purposes, an object of type `Stack<T>` and an `IEnumerable<T>` that contains the elements that will be Pushed onto `Stack<T>`. Note that the compiler enforces consistency between the type of the `Stack` and the elements that will be pushed onto the `Stack` when `Push` is invoked, which is the type argument of the generic method call. Generic method `TestPop` (lines 57–79) takes two arguments—a `string` that represents the name of the `Stack` object for output purposes and an object of type `Stack<T>`.

## 20.7 Wrap-Up

This chapter introduced generics. We discussed how generics ensure compile-time type safety by checking for type mismatches at compile time. You learned that the compiler will allow generic code to compile only if all operations performed on the type parameters in the generic code are supported for all types that could be used with the generic code. You also learned how to declare generic methods and classes using type parameters. We demonstrated how to use a type constraint to specify the requirements for a type parameter—a key component of compile-time type safety. We discussed several kinds of type constraints, including reference-type constraints, value-type constraints, class constraints, interface constraints and constructor constraints. We also discussed how to implement multiple type constraints for a type parameter. Finally, we showed how generics improve

code reuse. In the next chapter, we demonstrate the .NET Framework Class Library's collection classes, interfaces and algorithms. Collection classes are pre-built data structures that you can reuse in your apps, saving you time.

---

## Summary

### *Section 20.1 Introduction*

- Generic methods enable you to specify, with a single method declaration, a set of related methods.
- Generic classes enable you to specify, with a single class declaration, a set of related classes.
- Generic interfaces enable you to specify, with a single interface declaration, a set of related interfaces.
- Generics provide compile-time type safety.

### *Section 20.2 Motivation for Generic Methods*

- Overloaded methods are often used to perform similar operations on different types of data.
- When the compiler encounters a method call, it attempts to locate a method declaration that has the same method name and parameters that match the argument types in the method call.

### *Section 20.3 Generic-Method Implementation*

- If the operations performed by several overloaded methods are identical for each argument type, the overloaded methods can be more compactly and conveniently coded using a generic method.
- You can write a single generic-method declaration that can be called at different times with arguments of different types. Based on the types of the arguments passed to the generic method, the compiler handles each method call appropriately.
- All generic-method declarations have a type-parameter list delimited by angle brackets that follows the method's name. Each type-parameter list contains one or more type parameters, separated by commas.
- A type parameter is used in place of actual type names. The type parameters can be used to declare the return type, parameter types and local variable types in a generic-method declaration; the type parameters act as placeholders for type arguments that represent the types of data that will be passed to the generic method.
- A generic method's body is declared like that of any other method. The type-parameter names throughout the method declaration must match those declared in the type-parameter list.
- A type parameter can be declared only once in the type-parameter list but can appear more than once in the method's parameter list. Type-parameter names need not be unique among different generic methods.
- When the compiler encounters a method call, it analyzes the set of methods (both nongeneric and generic) that might match the method call, looking for a method that best matches the call. If there are no matching methods, or if there's more than one best match, the compiler generates an error.
- You can use explicit type arguments to indicate the exact type that should be used to call a generic function. For example, the method call `DisplayArray<int>( intArray );` explicitly provides the type argument (`int`) that should be used to replace type parameter `T` in the `DisplayArray` method's declaration.
- For each variable declared with a type parameter, the compiler also determines whether the operations performed on such a variable are allowed for all types that the type parameter can assume.

### **Section 20.4 Type Constraints**

- Generic code is restricted to performing operations that are guaranteed to work for every possible type. Thus, an expression like `variable1 < variable2` is not allowed unless the compiler can ensure that the operator `<` is provided for every type that will ever be used in the generic code. Similarly, you cannot call a method on a generic-type variable unless the compiler can ensure that all types that will ever be used in the generic code support that method.
- It's possible to compare two objects of the same type if that type implements the generic interface `IComparable<T>` (of namespace `System`), which declares method `CompareTo`.
- `IComparable<T>` objects can be used with the sorting and searching methods of classes in the `System.Collections.Generic` namespace.
- Simple types all implement interface `IComparable<T>`.
- It's the responsibility of the programmer who declares a type that implements `IComparable<T>` to declare method `CompareTo` such that it compares the contents of two objects of that type and returns the appropriate result.
- You can restrict the types that can be used with a generic method or class to ensure that they meet certain requirements. This feature—known as a type constraint—restricts the type of the argument supplied to a particular type parameter. For example, the clause `where T : IComparable<T>` indicates that the type arguments must implement interface `IComparable<T>`. If no type constraint is specified, the default type constraint is `object`.
- A class constraint indicates that the type argument must be an object of a specific base class or one of its subclasses.
- An interface constraint indicates that the type argument's class must implement a specific interface.
- You can specify that the type argument must be a reference type or a value type by using the reference-type constraint (`class`) or the value-type constraint (`struct`), respectively.
- You can specify a constructor constraint—`new()`—to indicate that the generic code can use operator `new` to create new objects of the type represented by the type parameter. If a type parameter is specified with a constructor constraint, the type argument's class must provide a public parameterless or default constructor to ensure that objects of the class can be created without passing constructor arguments; otherwise, a compilation error occurs.
- It's possible to apply multiple constraints to a type parameter by providing a comma-separated list of constraints in the `where` clause.
- If you have a class constraint, reference-type constraint or value-type constraint, it must be listed first—only one of these types of constraints can be used for each type parameter. Interface constraints (if any) are listed next. The constructor constraint is listed last (if there is one).

### **Section 20.5 Overloading Generic Methods**

- A generic method may be overloaded. All methods must contain a unique signature.
- A generic method can be overloaded by nongeneric methods with the same method name. When the compiler encounters a method call, it searches for the method declaration that most precisely matches the method name and the argument types specified in the call.

### **Section 20.6 Generic Classes**

- A generic class provides a means for describing a class in a type-independent manner.
- Once you have a generic class, you can use a simple, concise notation to indicate the actual type(s) that should be used in place of the class's type parameter(s). At compilation time, the compiler ensures the type safety of your code, and the runtime system replaces type parameters with actual arguments to enable your client code to interact with the generic class.

- A generic class declaration is similar to a nongeneric class declaration, except that the class name is followed by a type-parameter list and optional constraints on its type parameters.
- As with generic methods, the type-parameter list of a generic class can have one or more type parameters separated by commas.
- When a generic class is compiled, the compiler performs type checking on the class's type parameters to ensure that they can be used with the code in the generic class. The constraints determine the operations that can be performed on the variables declared with type parameters.

## Terminology

|                                                                 |                                             |
|-----------------------------------------------------------------|---------------------------------------------|
| class constraint                                                | multiple constraints                        |
| CompareTo method of interface <code>IComparable&lt;T&gt;</code> | <code>new()</code> (constructor) constraint |
| compile-time type safety                                        | overloading generic methods                 |
| constructor constraint ( <code>new()</code> )                   | reference-type constraint (class)           |
| default type constraint (object) of a type parameter            | scope of a type parameter                   |
| explicit type argument                                          | type argument                               |
| generic class                                                   | type checking                               |
| generic interface                                               | type constraint                             |
| generic method                                                  | type inference                              |
| generics                                                        | type parameter                              |
| <code>IComparable&lt;T&gt;</code> interface                     | type-parameter list                         |
| interface constraint                                            | value type constraint (struct)              |
|                                                                 | where clause                                |

## Self-Review Exercises

- 20.1** State whether each of the following is *true* or *false*. If *false*, explain why.
- A generic method cannot have the same method name as a nongeneric method.
  - All generic method declarations have a type-parameter list that immediately precedes the method name.
  - A generic method can be overloaded by another generic method with the same method name but a different number of type parameters.
  - A type parameter can be declared only once in the type-parameter list but can appear more than once in the method's parameter list.
  - Type-parameter names among different generic methods must be unique.
  - The scope of a generic class's type parameter is the entire class.
  - A type parameter can have at most one interface constraint, but multiple class constraints.
- 20.2** Fill in the blanks in each of the following:
- \_\_\_\_\_ enable you to specify, with a single method declaration, a set of related methods; \_\_\_\_\_ enable you to specify, with a single class declaration, a set of related classes.
  - A type-parameter list is delimited by \_\_\_\_\_.
  - The \_\_\_\_\_ of a generic method can be used to specify the types of the arguments to the method, to specify the return type of the method and to declare variables within the method.
  - The statement “`Stack<int> objectStack = new Stack<int>();`” indicates that `objectStack` stores \_\_\_\_\_.
  - In a generic class declaration, the class name is followed by a(n) \_\_\_\_\_.
  - The \_\_\_\_\_ constraint requires that the type argument must have a `public` parameterless constructor.

## Answers to Self-Review Exercises

**20.1** a) False. A generic method can be overloaded by nongeneric methods with the same or a different number of arguments. b) False. All generic method declarations have a type-parameter list that immediately follows the method's name. c) True. d) True. e) False. Type-parameter names among different generic methods need not be unique. f) True. g) False. A type parameter can have at most one class constraint, but multiple interface constraints.

**20.2** a) Generic methods, generic classes. b) angle brackets. c) type parameters. d) `ints`. e) type-parameter list. f) `new`.

## Exercises

**20.3** (*Generic Notation*) Explain the use of the following notation in a C# program:

```
public class Array<T>
```

**20.4** (*Overloading Generic Methods*) How can generic methods be overloaded?

**20.5** (*Determining which Method to Call*) The compiler performs a matching process to determine which method to call when a method is invoked. Under what circumstances does an attempt to make a match result in a compile-time error?

**20.6** (*What Does this Statement Do?*) Explain why a C# program might use the statement

```
Array< Employee > workerlist = new Array< Employee >();
```

**20.7** (*Generic Linear Search Method*) Write a generic method, `Search`, that implements the linear-search algorithm. Method `Search` should compare the search key with each element in its array parameter until the search key is found or until the end of the array is reached. If the search key is found, return its location in the array; otherwise, return -1. Write a test app that inputs and searches an `int` array and a `double` array. Provide buttons that the user can click to randomly generate `int` and `double` values. Display the generated values in a `TextBox`, so the user knows what values they can search for [Hint: Use `(T : IComparable< T >)` in the `where` clause for method `Search` so that you can use method `CompareTo` to compare the search key to the elements in the array.]

**20.8** (*Overloading a Generic Method*) Overload generic method `DisplayArray` of Fig. 20.3 so that it takes two additional `int` arguments: `lowIndex` and `highIndex`. A call to this method displays only the designated portion of the array. Validate `lowIndex` and `highIndex`. If either is out of range, or if `highIndex` is less than or equal to `lowIndex`, the overloaded `DisplayArray` method should throw an `InvalidOperationException`; otherwise, `DisplayArray` should return the number of elements displayed. Then modify `Main` to exercise both versions of `DisplayArray` on arrays `intArray`, `doubleArray` and `charArray`. Test all capabilities of both versions of `DisplayArray`.

**20.9** (*Overloading a Generic Method with a Non-Generic Method*) Overload generic method `DisplayArray` of Fig. 20.3 with a nongeneric version that displays an array of strings in neat, tabular format, as shown in the sample output that follows:

```
Array stringArray contains:
one      two      three     four
five      six      seven    eight
```

**20.10** (*Generic Method `IsEqualTo`*) Write a simple generic version of method `IsEqualTo` that compares its two arguments with the `Equals` method, and returns `true` if they're equal and `false` otherwise. Use this generic method in a program that calls `IsEqualTo` with a variety of simple types, such as `object` or `int`. What result do you get when you attempt to run this program?

**20.11 (Generic Class Pair)** Write a generic class `Pair` which has two type parameters, `F` and `S`, representing the type of the first and second element of the pair, respectively. Add properties for the first and second elements of the pair. [*Hint:* The class header should be `public class Pair<F, S>`.]

**20.12 (Generic Classes `TreeNode` and `Tree`)** Convert classes `TreeNode` and `Tree` from Fig. 19.20 into generic classes. To insert an object in a `Tree`, the object must be compared to the objects in existing `TreeNodes`. For this reason, classes `TreeNode` and `Tree` should specify `IComparable<T>` as the interface constraint of each class's type parameter. After modifying classes `TreeNode` and `Tree`, write a test app that creates three `Tree` objects—one that stores `ints`, one that stores `doubles` and one that stores `strings`. Insert 10 values into each tree. Then output the preorder, inorder and postorder traversals for each `Tree`.

**20.13 (Generic Method `TestTree`)** Modify your test program from Exercise 20.12 to use generic method `TestTree` to test the three `Tree` objects. The method should be called three times—once for each `Tree` object.

# 21

# Collections

*I think this is the most extraordinary collection of talent, of human knowledge, that has ever been gathered together at the White House—with the possible exception of when Thomas Jefferson dined alone.*

—John F. Kennedy

## Objectives

In this chapter you'll:

- Learn about the nongeneric and generic collections that are provided by the .NET Framework.
- Use class `Array`'s `static` methods to manipulate arrays.
- Use enumerators to “walk through” a collection.
- Use the `foreach` statement with the .NET collections.
- Use nongeneric collection classes `ArrayList`, `Stack`, and `Hashtable`.
- Use generic collections `SortedDictionary` and `LinkedList`.
- Be introduced to covariance and contravariance for generic types.



|                                         |
|-----------------------------------------|
| <b>21.1</b> Introduction                |
| <b>21.2</b> Collections Overview        |
| <b>21.3</b> Class Array and Enumerators |
| <b>21.4</b> Nongeneric Collections      |
| 21.4.1 Class ArrayList                  |
| 21.4.2 Class Stack                      |
| 21.4.3 Class Hashtable                  |

|                                                             |
|-------------------------------------------------------------|
| <b>21.5</b> Generic Collections                             |
| 21.5.1 Generic Class SortedDictionary                       |
| 21.5.2 Generic Class LinkedList                             |
| <b>21.6</b> Covariance and Contravariance for Generic Types |
| <b>21.7</b> Wrap-Up                                         |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 21.1 Introduction

Chapter 19 discussed how to create and manipulate data structures. The discussion was “low level,” in the sense that we painstakingly created each element of each data structure dynamically with new and modified the data structures by directly manipulating their elements and references to their elements. For the vast majority of apps, there’s no need to build such custom data structures. Instead, you can use the *prepackaged* data-structure classes provided by the .NET Framework. These classes are known as **collection classes**—they store collections of data. Each instance of one of these classes is a **collection** of items. Some examples of collections are the cards you hold in a card game, the songs stored in your computer, the real-estate records in your local registry of deeds (which map book numbers and page numbers to property owners), and the players on your favorite sports team.

Collection classes enable you to store sets of items by using *existing* data structures, without concern for how they’re implemented. This is a nice example of code reuse. Programmers can code faster and expect excellent performance, maximizing execution speed and minimizing memory consumption. In this chapter, we discuss the collection interfaces that list the capabilities of each collection type, the implementation classes and the **enumerators** that “walk through” collections.

The .NET Framework provides several namespaces dedicated to collections. Namespace **System.Collections** contains collections that store references to objects. We included these because there’s a large amount of legacy code in industry that uses these collections. Most new apps should use the collections in the **System.Collections.Generic** namespace, which contains generic classes—such as the `List<T>` and `Dictionary<K, V>` classes you learned previously—to store collections of specific types. Namespace **System.Collections.Concurrent** contains so-called thread-safe collections for use in multithreaded applications. The **System.Collections.Specialized** namespace contains several collections that support specific types, such as strings and bits. You can learn more about this namespace at [msdn.microsoft.com/en-us/library/system.collections.specialized.aspx](http://msdn.microsoft.com/en-us/library/system.collections.specialized.aspx). The collections in these namespaces provide standardized, reusable components; you do not need to write your own collection classes. These collections are written for broad reuse. They’re tuned for rapid execution and for efficient use of memory.

## 21.2 Collections Overview

All collection classes in the .NET Framework implement some combination of the collection interfaces. These interfaces declare the operations to be performed generically on various types of collections. Figure 21.1 lists some of the interfaces of the .NET Framework

collections. All the interfaces in Fig. 21.1 are declared in namespace `System.Collections` and have generic analogs in namespace `System.Collections.Generic`. Implementations of these interfaces are provided within the framework. Programmers may also provide implementations specific to their own requirements.

| Interface                | Description                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>ICollection</code> | The interface from which interfaces <code>IList</code> and <code>IDictionary</code> inherit. Contains a <code>Count</code> property to determine the size of a collection and a <code>CopyTo</code> method for copying a collection's contents into a traditional array.                                                                                                                         |
| <code>IList</code>       | An ordered collection that can be manipulated like an array. Provides an indexer for accessing elements with an <code>int</code> index. Also has methods for searching and modifying a collection, including <code>Add</code> , <code>Remove</code> , <code>Contains</code> and <code>IndexOf</code> .                                                                                           |
| <code>IDictionary</code> | A collection of values, indexed by an arbitrary “key” object. Provides an indexer for accessing elements with an <code>object</code> index and methods for modifying the collection (e.g., <code>Add</code> , <code>Remove</code> ). <code>IDictionary</code> property <code>Keys</code> contains the objects used as indices, and property <code>Values</code> contains all the stored objects. |
| <code>IEnumerable</code> | An object that can be enumerated. This interface contains exactly one method, <code>GetEnumerator</code> , which returns an <code>IEnumerator</code> object (discussed in Section 21.3). <code>ICollection</code> extends <code>IEnumerable</code> , so all collection classes implement <code>IEnumerable</code> directly or indirectly.                                                        |

**Fig. 21.1** | Some common collection interfaces.

### *Namespaces `System.Collections` and `System.Collections.Specialized`*

In earlier versions of C#, the .NET Framework primarily provided the collection classes in the `System.Collections` and `System.Collections.Specialized` namespaces. These classes stored and manipulated object references. You could store any object in a collection. One inconvenient aspect of storing object references occurs when retrieving them from a collection. An app normally needs to process specific types of objects. As a result, the object references obtained from a collection typically need to be downcast to an appropriate type to allow the app to process the objects correctly.

### *Namespace `System.Collections.Generic`*

The .NET Framework also includes the `System.Collections.Generic` namespace, which uses the generics capabilities we introduced in Chapter 20. Many of these classes are simply generic counterparts of the classes in namespace `System.Collections`. This means that you can specify the exact type that will be stored in a collection. You receive the benefits of *compile-time type checking*—the compiler ensures that you're using appropriate types with your collection and, if not, issues compile-time error messages. Also, once you specify the type stored in a collection, any item you retrieve from the collection will have the correct type. This *eliminates* the need for *explicit type casts* that can throw `InvalidCastException`s at execution time if the referenced object is not of the appropriate type. This also eliminates the overhead of explicit casting, improving efficiency. Generic collections are especially useful for storing `structs`, since they eliminate the overhead of boxing and unboxing.

This chapter demonstrates collection classes **Array**, **ArrayList**, **Stack**, **Hashtable**, generic **SortedDictionary**, and generic **LinkedList**—plus built-in array capabilities. Namespace **System.Collections** provides several other data structures, including **BitArray** (a collection of true/false values), **Queue** and **SortedList** (a collection of key–value pairs that are sorted by key and can be accessed either by key or by index). Figure 21.2 summarizes many of the collection classes. We also discuss the **IEnumerator** interface. Collection classes can create enumerators that allow programmers to walk through the collections. Although these enumerators have different implementations, they all implement the **IEnumerator** interface so that they can be processed polymorphically. As we'll soon see, the **foreach** statement is simply a convenient notation for using an enumerator. In the next section, we begin our discussion by examining enumerators and the capabilities for array manipulation. Collection classes directly or indirectly implement **ICollection** and **IEnumerable** (or their generic equivalents **ICollection<T>** and **IEnumerable<T>** for generic collections).

| Class                                        | Implements        | Description                                                                                                              |
|----------------------------------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------|
| <i>System namespace:</i>                     |                   |                                                                                                                          |
| Array                                        | IList             | The base class of all conventional arrays. See Section 21.3.                                                             |
| <i>System.Collections namespace:</i>         |                   |                                                                                                                          |
| ArrayList                                    | IList             | Mimics conventional arrays, but will grow or shrink as needed to accommodate the number of elements. See Section 21.4.1. |
| BitArray                                     | ICollection       | A memory-efficient array of bools.                                                                                       |
| Hashtable                                    | IDictionary       | An unordered collection of key–value pairs that can be accessed by key. See Section 21.4.3.                              |
| Queue                                        | ICollection       | A first-in, first-out collection. See Section 19.6.                                                                      |
| SortedList                                   | IDictionary       | A collection of key–value pairs that are sorted by key and can be accessed either by key or by index.                    |
| Stack                                        | ICollection       | A last-in, first-out collection. See Section 21.4.2.                                                                     |
| <i>System.Collections.Generic namespace:</i> |                   |                                                                                                                          |
| Dictionary<K, V>                             | IDictionary<K, V> | A generic, unordered collection of key–value pairs that can be accessed by key. See Section 17.4.                        |
| LinkedList<T>                                | ICollection<T>    | A doubly linked list. See Section 21.5.2.                                                                                |
| List<T>                                      | IList<T>          | A generic ArrayList. Section 9.4.                                                                                        |
| Queue<T>                                     | ICollection<T>    | A generic Queue.                                                                                                         |
| SortedDictionary<K, V>                       | IDictionary<K, V> | A Dictionary that sorts the data by the keys in a binary tree. See Section 21.5.1.                                       |
| SortedList<K, V>                             | IDictionary<K, V> | A generic SortedList.                                                                                                    |
| Stack<T>                                     | ICollection<T>    | A generic Stack. See Section 21.4.2.                                                                                     |

**Fig. 21.2** | Some collection classes of the .NET Framework.

## 21.3 Class Array and Enumerators

Chapter 8 presented basic array-processing capabilities. All arrays implicitly inherit from abstract base class `Array` (namespace `System`); this class defines property `Length`, which specifies the number of elements in the array. In addition, class `Array` provides static methods that provide algorithms for processing arrays. Typically, class `Array` overloads these methods—for example, `Array` method `Reverse` can reverse the order of the elements in an entire array or can reverse the elements in a specified range of elements in an array. For a complete list of class `Array`'s static methods visit:

[msdn.microsoft.com/en-us/library/system.array.aspx](http://msdn.microsoft.com/en-us/library/system.array.aspx)

Figure 21.3 demonstrates several static methods of class `Array`.

```

1 // Fig. 21.3: UsingArray.cs
2 // Array class static methods for common array manipulations.
3 using System;
4 using System.Collections;
5
6 // demonstrate algorithms of class Array
7 public class UsingArray
8 {
9     private static int[] intValues = { 1, 2, 3, 4, 5, 6 };
10    private static double[] doubleValues = { 8.4, 9.3, 0.2, 7.9, 3.4 };
11    private static int[] intValuesCopy;
12
13    // method Main demonstrates class Array's methods
14    public static void Main( string[] args )
15    {
16        intValuesCopy = new int[ intValues.Length ]; // defaults to zeroes
17
18        Console.WriteLine( "Initial array values:\n" );
19        PrintArrays(); // output initial array contents
20
21        // sort doubleValues
22        Array.Sort( doubleValues );
23
24        // copy intValues into intValuesCopy
25        Array.Copy( intValues, intValuesCopy, intValues.Length );
26
27        Console.WriteLine( "\nArray values after Sort and Copy:\n" );
28        PrintArrays(); // output array contents
29        Console.WriteLine();
30
31        // search for 5 in intValues
32        int result = Array.BinarySearch( intValues, 5 );
33        if ( result >= 0 )
34            Console.WriteLine( "5 found at element {0} in intValues",
35                result );
36        else
37            Console.WriteLine( "5 not found in intValues" );
38

```

**Fig. 21.3** | Array class used to perform common array manipulations. (Part 1 of 2.)

```
39     // search for 8763 in intValues
40     result = Array.BinarySearch( intValues, 8763 );
41     if ( result >= 0 )
42         Console.WriteLine( "8763 found at element {0} in intValues",
43             result );
44     else
45         Console.WriteLine( "8763 not found in intValues" );
46 } // end Main
47
48 // output array content with enumerators
49 private static void PrintArrays()
50 {
51     Console.Write( "doubleValues: " );
52
53     // iterate through the double array with an enumerator
54     IEnumerator enumerator = doubleValues.GetEnumerator();
55
56     while ( enumerator.MoveNext() )
57         Console.Write( enumerator.Current + " " );
58
59     Console.Write( "\nintValues: " );
60
61     // iterate through the int array with an enumerator
62     enumerator = intValues.GetEnumerator();
63
64     while ( enumerator.MoveNext() )
65         Console.Write( enumerator.Current + " " );
66
67     Console.Write( "\nintValuesCopy: " );
68
69     // iterate through the second int array with a foreach statement
70     foreach ( var element in intValuesCopy )
71         Console.Write( element + " " );
72
73     Console.WriteLine();
74 } // end method PrintArrays
75 } // end class UsingArray
```

Initial array values:

```
doubleValues: 8.4 9.3 0.2 7.9 3.4
intValues: 1 2 3 4 5 6
intValuesCopy: 0 0 0 0 0 0
```

Array values after Sort and Copy:

```
doubleValues: 0.2 3.4 7.9 8.4 9.3
intValues: 1 2 3 4 5 6
intValuesCopy: 1 2 3 4 5 6
```

```
5 found at element 4 in intValues
8763 not found in intValues
```

Fig. 21.3 | Array class used to perform common array manipulations. (Part 2 of 2.)

The `using` directives in lines 3–4 include the namespaces `System` (for classes `Array` and `Console`) and `System.Collections` (for interface `IEnumerator`, which we discuss shortly). References to the assemblies for these namespaces are *implicitly* included in every app, so we do not need to add any new references to the project file.

Our test class declares three `static` array variables (lines 9–11). The first two lines initialize `intValues` and `doubleValues` to an `int` and `double` array, respectively. `static` variable `intValuesCopy` is intended to demonstrate the `Array`'s `Copy` method, so it's left with the default value `null`—it does not yet refer to an array.

Line 16 initializes `intValuesCopy` to an `int` array with the same length as array `intValues`. Line 19 calls the `PrintArrays` method (lines 49–74) to output the initial contents of all three arrays. We discuss the `PrintArrays` method shortly. We can see from the output of Fig. 21.3 that each element of array `intValuesCopy` is initialized to the default value 0.

### **Array Method Sort**

Line 22 uses `static` `Array` method `Sort` to sort array `doubleValues`. When this method returns, the array contains its original elements sorted in *ascending* order. The elements in the array must implement the `IComparable` interface.

### **Array Method Copy**

Line 25 uses `static` `Array` method `Copy` to copy elements from array `intValues` to array `intValuesCopy`. The first argument is the array to copy (`intValues`), the second argument is the destination array (`intValuesCopy`) and the third argument is an `int` representing the number of elements to copy (in this case, `intValues.Length` specifies all elements).

### **Array Method BinarySearch**

Lines 32 and 40 invoke `static` `Array` method `BinarySearch` to perform binary searches on array `intValues`. Method `BinarySearch` receives the *sorted* array in which to search and the key for which to search. The method returns the index in the array at which it finds the key (or a negative number if the key was not found). `BinarySearch` assumes that it receives a sorted array. Its behavior on an *unsorted* array is *unpredictable*. Chapter 18 discusses binary searching in detail.

### **Array Method GetEnumerator and Interface IEnumerator**

Method `PrintArrays` (lines 49–74) uses class `Array`'s methods to loop though each array. The `GetEnumerator` method (line 54) obtains an enumerator for array `doubleValues`. Recall that `Array` implements the `IEnumerable` interface. All arrays inherit implicitly from `Array`, so both the `int[]` and `double[]` array types implement `IEnumerable` interface method `GetEnumerator`, which returns an enumerator that can *iterate* over the collection. Interface `IEnumerator` (which all enumerators implement) defines methods `MoveNext` and `Reset` and property `Current`. `MoveNext` moves the enumerator to the next element in the collection. The first call to `MoveNext` positions the enumerator at the first element of the collection. `MoveNext` returns `true` if there's at least one more element in the collection; otherwise, the method returns `false`. Method `Reset` positions the enumerator before the first element of the collection. Methods `MoveNext` and `Reset` throw an `InvalidOperationException` if the contents of the collection are modified in any way after the enumerator is created. Property `Current` returns the object at the current location in the collection.



### Common Programming Error 21.1

*If a collection is modified after an enumerator is created for that collection, the enumerator immediately becomes invalid—any methods called on the enumerator after this point throw `InvalidOperationExceptions`. For this reason, enumerators are said to be “fail fast.”*

When an enumerator is returned by the `GetEnumerator` method in line 54, it's initially positioned *before* the first element in `Array doubleValues`. Then when line 56 calls `MoveNext` in the first iteration of the `while` loop, the enumerator advances to the first element in `doubleValues`. The `while` statement in lines 56–57 loops over each element until the enumerator passes the end of `doubleValues` and `MoveNext` returns `false`. In each iteration, we use the enumerator's `Current` property to obtain and output the current array element. Lines 62–65 iterate over array `intValues`.

Notice that `PrintArrays` is called twice (lines 19 and 28), so `GetEnumerator` is called twice on `doubleValues`. The `GetEnumerator` method (lines 54 and 62) always returns an enumerator positioned *before the first element*. Also notice that the `IEnumerator` property `Current` is read-only. Enumerators *cannot* be used to *modify* the contents of collections, only to obtain the contents.

#### *Iterating Over a Collection with `foreach`*

Lines 70–71 use a `foreach` statement to iterate over the collection elements. The `foreach` statement uses an enumerator to accomplish this task. Both loop over the elements of an array one by one in consecutive order. Neither allows you to modify the elements during the iteration. This is not a coincidence. The `foreach` statement implicitly obtains an enumerator via the `GetEnumerator` method and uses the enumerator's `MoveNext` method and `Current` property to traverse the collection, just as we did explicitly in lines 54–57. For this reason, we can use the `foreach` statement to iterate over *any* collection that implements the `IEnumerable` interface—not just arrays. We demonstrate this functionality in the next section when we discuss class `ArrayList`.

#### *Array Methods `Clear`, `CreateInstance`, `IndexOf`, `LastIndexOf` and `Reverse`*

Other static `Array` methods include `Clear` (to set a range of elements to 0, `false` or `null`, as appropriate), `CreateInstance` (to create a new array of a specified type), `IndexOf` (to locate the first occurrence of an object in an array or portion of an array), `LastIndexOf` (to locate the last occurrence of an object in an array or portion of an array) and `Reverse` (to reverse the contents of an array or portion of an array).

## 21.4 Nongeneric Collections

The `System.Collections` namespace in the .NET Framework Class Library is the primary source for *nongeneric collections*. These classes provide standard implementations of many of the data structures discussed in Chapter 19 with collections that store references of type `object`. In this section, we demonstrate classes `ArrayList`, `Stack` and `Hashtable`.

### 21.4.1 Class `ArrayList`

In most programming languages, conventional arrays have a *fixed size*—they cannot be changed dynamically to conform to an app's execution-time memory requirements. In some apps, this fixed-size limitation presents a problem. You must choose between using

fixed-size arrays that are large enough to store the maximum number of elements the app may require and using dynamic data structures that can grow and shrink the amount of memory required to store data in response to the changing requirements of an app at execution time.

The .NET Framework's **ArrayList** collection class mimics the functionality of conventional arrays and provides dynamic resizing of the collection through the class's methods. At any time, an **ArrayList** contains a certain number of elements less than or equal to its **capacity**—the number of elements currently *reserved* for the **ArrayList**. An app can manipulate the capacity with **ArrayList** property **Capacity**. New apps should use the generic **List<T>** class (the generic version of **ArrayList**) introduced in Chapter 9.



### Performance Tip 21.1

*As with linked lists, inserting additional elements into an **ArrayList** whose current size is less than its capacity is a fast operation.*



### Performance Tip 21.2

*It's a slow operation to insert an element into an **ArrayList** that needs to grow larger to accommodate a new element. An **ArrayList** that's at its capacity must have its memory reallocated and the existing values copied into it.*



### Performance Tip 21.3

*If storage is at a premium, use method **TrimToSize** of class **ArrayList** to trim an **ArrayList** to its exact size. This will optimize an **ArrayList**'s memory use. Be careful—if the app needs to insert additional elements, the process will be slower, because the **ArrayList** must grow dynamically (trimming leaves no room for growth).*

**ArrayLists** store references to objects. All classes derive from class **object**, so an **ArrayList** can contain objects of any type. Figure 21.4 lists some useful methods and properties of class **ArrayList**.

| Method or property | Description                                                                                                                 |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------|
| <b>Add</b>         | Adds an object to the <b>ArrayList</b> 's end and returns an <b>int</b> specifying the index at which the object was added. |
| <b>Capacity</b>    | Property that gets and sets the number of elements for which space is currently reserved in the <b>ArrayList</b> .          |
| <b>Clear</b>       | Removes all the elements from the <b>ArrayList</b> .                                                                        |
| <b>Contains</b>    | Returns <b>true</b> if the specified <b>object</b> is in the <b>ArrayList</b> ; otherwise, returns <b>false</b> .           |
| <b>Count</b>       | Read-only property that gets the number of elements stored in the <b>ArrayList</b> .                                        |
| <b>IndexOf</b>     | Returns the index of the first occurrence of the specified <b>object</b> in the <b>ArrayList</b> .                          |
| <b>Insert</b>      | Inserts an <b>object</b> at the specified index.                                                                            |

**Fig. 21.4** | Some methods and properties of class **ArrayList**. (Part 1 of 2.)

| Method or property | Description                                                                                                                                                                  |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Remove             | Removes the first occurrence of the specified object.                                                                                                                        |
| RemoveAt           | Removes an object at the specified index.                                                                                                                                    |
| RemoveRange        | Removes a specified number of elements starting at a specified index.                                                                                                        |
| Sort               | Sorts the ArrayList—the elements must implement <code>IComparable</code> or the overloaded version of <code>Sort</code> that receives a <code>IComparer</code> must be used. |
| TrimToSize         | Sets the <code>Capacity</code> of the <code>ArrayList</code> to the number of elements the <code>ArrayList</code> currently contains ( <code>Count</code> ).                 |

**Fig. 21.4** | Some methods and properties of class `ArrayList`. (Part 2 of 2.)

Figure 21.5 demonstrates class `ArrayList` and several of its methods. Class `ArrayList` belongs to the `System.Collections` namespace (line 4). Lines 8–11 declare two arrays of strings (`colors` and `removeColors`) that we'll use to fill two `ArrayList` objects. Recall from Section 10.10 that constants must be initialized at compile time, but `readonly` variables can be initialized at execution time. Arrays are objects created at execution time, so we declare `colors` and `removeColors` with `readonly`—not `const`—to make them *unmodifiable*. When the app begins execution, we create an `ArrayList` with an *initial capacity* of one element and store it in variable `list` (line 16). The `foreach` statement in lines 19–20 adds the five elements of array `colors` to `list` via `ArrayList`'s `Add` method, so `list` *grows* to accommodate these new elements. Line 24 uses `ArrayList`'s overloaded constructor to create a new `ArrayList` initialized with the contents of array `removeColors`, then assigns it to variable `removeList`. This constructor can initialize the contents of an `ArrayList` with the elements of any `ICollection` passed to it. Many of the collection classes have such a constructor. Notice that the constructor call in line 24 performs the task of lines 19–20.

Line 27 calls method `DisplayInformation` (lines 37–54) to output the contents of the `list`. This method uses a `foreach` statement to traverse the elements of an `ArrayList`. As we discussed in Section 21.3, the `foreach` statement is a convenient shorthand for calling `ArrayList`'s `GetEnumerator` method and using an enumerator to *traverse* the elements of the collection. Also, line 40 *infers* that the iteration variable's type is `object` because class `ArrayList` is nongeneric and stores references to objects.

---

```

1 // Fig. 21.5: ArrayListTest.cs
2 // Using class ArrayList.
3 using System;
4 using System.Collections;
5
6 public class ArrayListTest
7 {
8     private static readonly string[] colors =
9         { "MAGENTA", "RED", "WHITE", "BLUE", "CYAN" };
10    private static readonly string[] removeColors =
11        { "RED", "WHITE", "BLUE" };

```

---

**Fig. 21.5** | Using class `ArrayList`. (Part 1 of 3.)

```
12 // create ArrayList, add colors to it and manipulate it
13 public static void Main( string[] args )
14 {
15     ArrayList list = new ArrayList( 1 ); // initial capacity of 1
16
17     // add the elements of the colors array to the ArrayList list
18     foreach ( var color in colors )
19         list.Add( color ); // add color to the ArrayList list
20
21     // add elements in the removeColors array to
22     // the ArrayList removeList with the ArrayList constructor
23     ArrayList removeList = new ArrayList( removeColors );
24
25
26     Console.WriteLine( "ArrayList: " );
27     DisplayInformation( list ); // output the list
28
29     // remove from ArrayList list the colors in removeList
30     RemoveColors( list, removeList );
31
32     Console.WriteLine( "\nArrayList after calling RemoveColors: " );
33     DisplayInformation( list ); // output list contents
34 } // end Main
35
36 // displays information on the contents of an array list
37 private static void DisplayInformation( ArrayList arrayList )
38 {
39     // iterate through array list with a foreach statement
40     foreach ( var element in arrayList )
41         Console.Write( "{0} ", element ); // invokes ToString
42
43     // display the size and capacity
44     Console.WriteLine( "\nSize = {0}; Capacity = {1}",
45         arrayList.Count, arrayList.Capacity );
46
47     int index = arrayList.IndexOf( "BLUE" );
48
49     if ( index != -1 )
50         Console.WriteLine( "The array list contains BLUE at index {0}.",
51             index );
52     else
53         Console.WriteLine( "The array list does not contain BLUE." );
54 } // end method DisplayInformation
55
56 // remove colors specified in secondList from firstList
57 private static void RemoveColors( ArrayList firstList,
58     ArrayList secondList )
59 {
60     // iterate through second ArrayList like an array
61     for ( int count = 0; count < secondList.Count; ++count )
62         firstList.Remove( secondList[ count ] );
63 } // end method RemoveColors
64 } // end class ArrayListTest
```

---

Fig. 21.5 | Using class ArrayList. (Part 2 of 3.)

```

ArrayList:
MAGENTA RED WHITE BLUE CYAN
Size = 5; Capacity = 8
The array list contains BLUE at index 3.

ArrayList after calling RemoveColors:
MAGENTA CYAN
Size = 2; Capacity = 8
The array list does not contain BLUE.

```

**Fig. 21.5** | Using class ArrayList. (Part 3 of 3.)

### **ArrayList Methods Count and Capacity**

We use properties **Count** and **Capacity** (line 45) to display the *current number* and the *maximum number* of elements that can be stored without allocating more memory to the **ArrayList**. The output of Fig. 21.5 indicates that the **ArrayList** has capacity 8.

### **ArrayList Methods IndexOf and Contains**

In line 47, we invoke method **IndexOf** to determine the position of the string "BLUE" in **arrayList** and store the result in local variable **index**. **IndexOf** returns -1 if the element is not found. The **if** statement in lines 49–53 checks if **index** is -1 to determine whether **arrayList** contains "BLUE". If it does, we output its index. **ArrayList** also provides method **Contains**, which simply returns true if an object is in the **ArrayList**, and false otherwise. Method **Contains** is preferred if we do not need the index of the element.



#### **Performance Tip 21.4**

*ArrayList methods IndexOf and Contains each perform a linear search, which is a costly operation for large ArrayLists. If the ArrayList is sorted, use ArrayList method BinarySearch to perform a more efficient search. Method BinarySearch returns the index of the element, or a negative number if the element is not found.*

### **ArrayList Method Remove**

After method **DisplayInformation** returns, we call method **RemoveColors** (lines 57–63) with the two **ArrayLists**. The **for** statement in lines 61–62 iterates over **ArrayList secondList**. Line 62 uses an indexer to access an **ArrayList** element—by following the **ArrayList** reference name with square brackets (**[]**) containing the desired index of the element. An **ArgumentOutOfRangeException** occurs if the specified index is not both greater than 0 and less than the number of elements currently stored in the **ArrayList** (specified by the **ArrayList**'s **Count** property).

We use the indexer to obtain each of **secondList**'s elements, then remove each one from **firstList** with the **Remove** method. This method deletes a specified item from an **ArrayList** by performing a *linear search* and removing (only) the first occurrence of the specified object. All subsequent elements *shift* toward the beginning of the **ArrayList** to fill the emptied position.

After the call to **RemoveColors**, line 33 again outputs the contents of **list**, confirming that the elements of **removeList** were, indeed, removed.

## 21.4.2 Class Stack

The Stack class implements a stack data structure and provides much of the functionality that we defined in our own implementation in Section 19.5. Refer to that section for a discussion of stack data-structure concepts. We created a test app in Fig. 19.14 to demonstrate the StackInheritance data structure that we developed. We adapt Fig. 19.14 in Fig. 21.6 to demonstrate the .NET Framework collection class Stack. New apps requiring a stack class should use the generic Stack<T> class.

```

1 // Fig. 21.6: StackTest.cs
2 // Demonstrating class Stack.
3 using System;
4 using System.Collections;
5
6 public class StackTest
7 {
8     public static void Main( string[] args )
9     {
10        Stack stack = new Stack(); // create an empty Stack
11
12        // create objects to store in the stack
13        bool aBoolean = true;
14        char aCharacter = '$';
15        int anInteger = 34567;
16        string aString = "hello";
17
18        // use method Push to add items to (the top of) the stack
19        stack.Push( aBoolean );
20        PrintStack( stack );
21        stack.Push( aCharacter );
22        PrintStack( stack );
23        stack.Push( anInteger );
24        PrintStack( stack );
25        stack.Push( aString );
26        PrintStack( stack );
27
28        // check the top element of the stack
29        Console.WriteLine( "The top element of the stack is {0}\n",
30                           stack.Peek() );
31
32        // remove items from stack
33        try
34        {
35            while ( true )
36            {
37                object removedObject = stack.Pop();
38                Console.WriteLine( removedObject + " popped" );
39                PrintStack( stack );
40            } // end while
41        } // end try
42        catch ( InvalidOperationException exception )
43        {

```

**Fig. 21.6** | Demonstrating class Stack. (Part 1 of 2.)

```

44         // if exception occurs, output stack trace
45         Console.Error.WriteLine( exception );
46     } // end catch
47 } // end Main
48
49 // display the contents of a stack
50 private static void PrintStack( Stack stack )
51 {
52     if ( stack.Count == 0 )
53         Console.WriteLine( "stack is empty\n" ); // the stack is empty
54     else
55     {
56         Console.Write( "The stack is: " );
57
58         // iterate through the stack with a foreach statement
59         foreach ( var element in stack )
60             Console.Write( "{0} ", element ); // invokes ToString
61
62         Console.WriteLine( "\n" );
63     } // end else
64 } // end method PrintStack
65 } // end class StackTest

```

```

The stack is: True
The stack is: $ True
The stack is: 34567 $ True
The stack is: hello 34567 $ True
The top element of the stack is hello
hello popped
The stack is: 34567 $ True
34567 popped
The stack is: $ True
$ popped
The stack is: True
True popped
stack is empty
System.InvalidOperationException: Stack empty.
  at System.Collections.Stack.Pop()
  at StackTest.Main(String[] args) in
    c:\examples\ch23\fig23_06\StackTest\StackTest.cs:line 37

```

**Fig. 21.6** | Demonstrating class Stack. (Part 2 of 2.)

The `using` directive in line 4 allows us to use the `Stack` class with its unqualified name from the `System.Collections` namespace. Line 10 creates a `Stack`. As one might expect, class `Stack` has methods `Push` and `Pop` to perform the basic stack operations.

#### **Stack Method Push**

Method `Push` takes an object as an argument and inserts it at the top of the `Stack`. If the number of items on the `Stack` (the `Count` property) is equal to the capacity at the time of

the Push operation, the Stack *grows* to accommodate more objects. Lines 19–26 use method Push to add four elements (a bool, a char, an int and a string) to the stack and invoke method PrintStack (lines 50–64) after each Push to output the contents of the stack. Notice that this nongeneric Stack class can store only *references* to objects, so each of the value-type items—the bool, the char and the int—is *implicitly boxed* before it's added to the Stack. (Namespace System.Collections.Generic provides a generic Stack class that has many of the same methods and properties used in Fig. 21.6. This version eliminates the overhead of boxing and unboxing simple types.)

### **Method PrintStack**

Method PrintStack (lines 50–64) uses Stack property Count (implemented to fulfill the contract of interface ICollection) to obtain the number of elements in stack. If the stack is not empty (i.e., Count is not equal to 0), we use a foreach statement to iterate over the stack and output its contents by *implicitly* invoking the ToString method of each element. The foreach statement implicitly invokes Stack's GetEnumerator method, which we could have called *explicitly* to traverse the stack via an enumerator.

### **Stack Method Peek**

Method Peek returns the value of the *top* stack element but does *not* remove the element from the Stack. We use Peek at line 30 to obtain the *top* object of the Stack, then output that object, *implicitly* invoking the object's ToString method. An InvalidOperationException occurs if the Stack is empty when the app calls Peek. We do *not* need an exception-handling block because we know the stack is *not* empty here.

### **Stack Method Pop**

Method Pop takes no arguments—it removes and returns the object currently on the Stack's top. An infinite loop (lines 35–40) pops objects off the stack and outputs them until the stack is empty. When the app calls Pop on the empty stack, an InvalidOperationException is thrown. The catch block (lines 42–46) outputs the exception, *implicitly* invoking the InvalidOperationException's ToString method to obtain its error message and stack trace.



#### **Common Programming Error 21.2**

Attempting to Peek or Pop an empty Stack (a Stack whose Count property is 0) causes an InvalidOperationException.

### **Stack Method Contains**

Although Fig. 21.6 does not demonstrate it, class Stack also has method Contains, which returns true if the Stack contains the specified object, and returns false otherwise.

### **21.4.3 Class Hashtable**

When an app creates objects of new or existing types, it needs to manage those objects efficiently. This includes sorting and retrieving objects. Sorting and retrieving information with arrays is efficient if some aspect of your data directly matches the key value and if those keys are *unique* and *tightly packed*. If you have 100 employees with nine-digit social security numbers and you want to store and retrieve employee data by using the social security number as a key, it would nominally require an array with 1,000,000,000 elements, because there are 1,000,000,000 unique nine-digit numbers. If you have an array that large, you

could get high performance storing and retrieving employee records by simply using the social security number as the array index, but it would be a huge waste of memory.

Many apps have this problem—either the keys are of the wrong type (i.e., not non-negative integers), or they’re of the right type but are sparsely spread over a large range.

### **Hashing**

What is needed is a high-speed scheme for converting keys such as social security numbers and inventory part numbers to unique array indices. Then, when an app needs to store something, the scheme could convert the key rapidly to an index and the record of information could be stored at that location in the array. Retrieval occurs the same way—once the app has a key for which it wants to retrieve the data record, the app simply applies the conversion to the key, which produces the array index where the data resides in the array and retrieves the data.

The scheme we describe here is the basis of a technique called **hashing**, in which we store data in a data structure called a **hash table**. Why the name? Because, when we convert a key into an array index, we literally *scramble* the bits, making a “hash” of the number. The number actually has no real significance beyond its usefulness in storing and retrieving this particular data record.

### **Collisions**

A glitch in the scheme occurs when there are **collisions** (i.e., two different keys “hash into” the same cell, or element, in the array). Since we cannot sort two different data records to the *same* space, we need to find an alternative home for all records beyond the first that hash to a particular array index. One scheme for doing this is to “hash again” (i.e., to reapply the hashing transformation to the key to provide a next candidate cell in the array). The hashing process is designed so that with just a few hashes, an available cell will be found.

Another scheme uses one hash to locate the first candidate cell. If the cell is occupied, successive cells are searched linearly until an available cell is found. Retrieval works the same way—the key is hashed once, the resulting cell is checked to determine whether it contains the desired data. If it does, the search is complete. If it does not, successive cells are searched linearly until the desired data is found.

The most popular solution to hash-table collisions is to have each cell of the table be a hash “bucket”—typically, a linked list of all the key–value pairs that hash to that cell. This is the solution that the .NET Framework’s **Hashtable** class implements.

### **Load Factor**

The **load factor** affects the performance of hashing schemes. The load factor is the ratio of the number of objects stored in the hash table to the total number of cells of the hash table. As this ratio gets *higher*, the chance of collisions tends to *increase*.



#### **Performance Tip 21.5**

*The load factor in a hash table is a classic example of a space/time trade-off. By increasing the load factor, we get better memory utilization, but the app runs slower due to increased hashing collisions. By decreasing the load factor, we get better speed because of reduced hashing collisions, but we get poorer memory utilization because a larger portion of the hash table remains empty.*

Computer-science students study hashing schemes in courses called “Data Structures” and “Algorithms.” Recognizing the value of hashing, the .NET Framework provides class `Hashtable` to enable programmers to easily employ hashing in apps.

This concept is profoundly important in our study of object-oriented programming. Classes *encapsulate* and *hide* complexity (i.e., implementation details) and offer user-friendly interfaces. Crafting classes to do this properly is one of the most valued skills in the field of object-oriented programming.

### *Hash Function*

A **hash function** performs a calculation that determines *where* to place data in the hash table. The hash function is applied to the key in a key–value pair of objects. Class `Hashtable` can accept any `object` as a key. For this reason, class `object` defines method `GetHashCode`, which all objects inherit. Most classes that are candidates to be used as keys in a hash table override this method to provide one that performs efficient hash-code calculations for a specific type. For example, a `string` has a hash-code calculation that’s based on the contents of the `string`.

### *Demonstrating Hashtable*

Figure 21.7 uses a `Hashtable` to count the number of occurrences of each word in a `string`. New apps should use generic class `Dictionary<K, V>` (introduced in Section 17.4) rather than `Hashtable`.

---

```

1 // Fig. 21.7: HashtableTest.cs
2 // App counts the number of occurrences of each word in a string
3 // and stores them in a hash table.
4 using System;
5 using System.Text.RegularExpressions;
6 using System.Collections;
7
8 public class HashtableTest
9 {
10     public static void Main( string[] args )
11     {
12         // create hash table based on user input
13         Hashtable table = CollectWords();
14
15         // display hash-table content
16         DisplayHashtable( table );
17     } // end Main
18
19     // create hash table from user input
20     private static Hashtable CollectWords()
21     {
22         Hashtable table = new Hashtable(); // create a new hash table
23
24         Console.WriteLine( "Enter a string: " ); // prompt for user input
25         string input = Console.ReadLine(); // get input
26

```

**Fig. 21.7** | App counts the number of occurrences of each word in a `string` and stores them in a hash table. (Part I of 2.)

```

27      // split input text into tokens
28      string[] words = Regex.Split( input, @"\s+" );
29
30      // processing input words
31      foreach ( var word in words )
32      {
33          string wordKey = word.ToLower(); // get word in lowercase
34
35          // if the hash table contains the word
36          if ( table.ContainsKey( wordKey ) )
37          {
38              table[ wordKey ] = ( ( int ) table[ wordKey ] ) + 1;
39          } // end if
40          else
41              // add new word with a count of 1 to hash table
42              table.Add( wordKey, 1 );
43      } // end foreach
44
45      return table;
46 } // end method CollectWords
47
48 // display hash-table content
49 private static void DisplayHashtable( Hashtable table )
50 {
51     Console.WriteLine( "\nHashtable contains:\n{0,-12}{1,-12}",
52                     "Key:", "Value:" );
53
54     // generate output for each key in hash table
55     // by iterating through the Keys property with a foreach statement
56     foreach ( var key in table.Keys )
57         Console.WriteLine( "{0,-12}{1,-12}", key, table[ key ] );
58
59     Console.WriteLine( "\nsize: {0}", table.Count );
60 }
61 } // end class HashtableTest

```

Enter a string:  
**As idle as a painted ship upon a painted ocean**

Hashtable contains:

| Key:    | Value: |
|---------|--------|
| ocean   | 1      |
| a       | 2      |
| as      | 2      |
| ship    | 1      |
| upon    | 1      |
| painted | 2      |
| idle    | 1      |

size: 7

**Fig. 21.7** | App counts the number of occurrences of each word in a **string** and stores them in a hash table. (Part 2 of 2.)

Lines 4–6 contain using directives for namespaces `System` (for class `Console`), `System.Text.RegularExpressions` (for class `Regex`) and `System.Collections` (for class `Hashtable`). Class `HashtableTest` declares three static methods. Method `CollectWords` (lines 20–46) inputs a string and returns a `Hashtable` in which each value stores the number of times that word appears in the string and the word is used for the key. Method `DisplayHashtable` (lines 49–60) displays the `Hashtable` passed to it in column format. The `Main` method (lines 10–17) simply invokes `CollectWords` (line 13), then passes the `Hashtable` returned by `CollectWords` to `DisplayHashtable` in line 16.

### **Method `CollectWords`**

Method `CollectWords` (lines 20–46) begins by initializing local variable `table` with a new `Hashtable` (line 22) that has a default maximum load factor of 1.0. When the `Hashtable` reaches the specified load factor, the capacity is increased *automatically*. (This implementation detail is invisible to clients of the class.) Lines 24–25 prompt the user and input a string. We use `static` method `Split` of class `Regex` (introduced in the online section of Chapter 16) in line 28 to divide the string by its whitespace characters. This creates an array of “words,” which we then store in local variable `words`.

### **Hashtable Methods `ContainsKey` and `Add`**

Lines 31–43 loop over every element of array `words`. Each word is converted to lowercase with `string` method `ToLower`, then stored in variable `wordKey` (line 33). Then line 36 calls `Hashtable` method `ContainsKey` to determine whether the word is in the hash table (and thus has occurred previously in the string). If the `Hashtable` does *not* contain an entry for the word, line 42 uses `Hashtable` method `Add` to create a new entry in the hash table, with the lowercase word as the key and an object containing 1 as the value. *Autoboxing* occurs when the app passes integer 1 to method `Add`, because the hash table stores both the key and value in references of type `object`.



### **Common Programming Error 21.3**

*Using the Add method to add a key that already exists in the hash table causes an ArgumentException.*

### **Hashtable Indexer**

If the word is already a key in the hash table, line 38 uses the `Hashtable`’s indexer to obtain and set the key’s associated value (the word count) in the hash table. We first *downcast* the value obtained by the `get` accessor from an `object` to an `int`. This *unboxes* the value so that we can increment it by 1. Then, when we use the indexer’s `set` accessor to assign the key’s associated value, the incremented value is *implicitly reboxed* so that it can be stored in the hash table.

Invoking the `get` accessor of a `Hashtable` indexer with a key that does *not* exist in the hash table obtains a `null` reference. Using the `set` accessor with a key that does not exist in the hash table creates a new entry, as if you had used the `Add` method.

### **Method `DisplayHashtable`**

Line 45 returns the hash table to the `Main` method, which then passes it to method `DisplayHashtable` (lines 49–60), which displays all the entries. This method uses read-only property `Keys` (line 56) to get an `ICollection` that contains all the keys. Because `ICollection`

lection extends `IEnumerable`, we can use this collection in the `foreach` statement in lines 56–57 to iterate over the keys of the hash table. This loop accesses and outputs each key and its value in the hash table using the iteration variable and `table`'s get accessor. Each key and its value is displayed in a field width of -12. The *negative field width* indicates that the output is *left justified*. A hash table is not sorted, so the key–value pairs are not displayed in any particular order. Line 59 uses `Hashtable` property `Count` to get the number of key–value pairs in the `Hashtable`.

### **DictionaryEntry and IDictionary**

Lines 56–57 could have also used the `foreach` statement with the `Hashtable` object itself, instead of using the `Keys` property. If you use a `foreach` statement with a `Hashtable` object, the iteration variable will be of type `DictionaryEntry`. The enumerator of a `Hashtable` (or any other class that implements `IDictionary`) uses the `DictionaryEntry` structure to store key–value pairs. This structure provides properties `Key` and `Value` for retrieving the key and value of the current element. If you do not need the keys, class `Hashtable` also provides a read-only `Values` property that gets an `ICollection` of all the values stored in the `Hashtable`. We can use this property to iterate through the values stored in the `Hashtable` without regard for where they're stored.

### **Problems with Nongeneric Collections**

In the word-counting app of Fig. 21.7, our `Hashtable` stores its keys and data as object references, even though we store only `string` keys and `int` values by convention. This results in some awkward code. For example, line 38 was forced to *unbox and box* the `int` data stored in the `Hashtable` every time it incremented the count for a particular key. This is inefficient. A similar problem occurs in line 56—the iteration variable of the `foreach` statement is an object reference. If we need to use any of its `string`-specific methods, we need an *explicit downcast*.

This can cause subtle bugs. Suppose we decide to improve the readability of Fig. 21.7 by using the indexer's `set` accessor instead of the `Add` method to add a key–value pair in line 42, but accidentally type:

```
table[ wordKey ] = wordKey; // initialize to 1
```

This statement will create a new entry with a `string` key and `string` value instead of an `int` value of 1. Although the app will compile correctly, this is clearly incorrect. If a word appears twice, line 38 will try to downcast this `string` to an `int`, causing an `InvalidOperationException` at execution time. The error that appears at execution time will indicate that the problem is at line 38, where the exception occurred, *not* at line 42. This makes the error more difficult to find and debug, especially in large apps where the exception may occur in a different file—and even in a different assembly.

## **21.5 Generic Collections**

The `System.Collections.Generic` namespace contains generic classes that allow us to create collections of specific types. As you saw in Fig. 21.2, many of the classes are simply generic versions of nongeneric collections. A couple of classes implement new data structures. Here, we demonstrate generic collections `SortedDictionary` and `LinkedList`.

### 21.5.1 Generic Class SortedDictionary

A **dictionary** is the general term for a collection of key–value pairs. A hash table is one way to implement a dictionary. The .NET Framework provides several implementations of dictionaries, both generic and nongeneric, all of which implement the `IDictionary` interface (described in Fig. 21.1). The app in Fig. 21.8 is a modification of Fig. 21.7 that uses the generic class `SortedDictionary`. Generic class `SortedDictionary` does *not* use a hash table, but instead stores its key–value pairs in a binary search tree. (We discussed binary trees in depth in Section 19.7.) As the class name suggests, the entries in `SortedDictionary` are sorted in the tree by key. When the key implements generic interface `IComparable<T>`, the `SortedDictionary` uses the results of `IComparable<T>` method `CompareTo` to sort the keys. Notice that despite these implementation details, we use the same public methods, properties and indexers with classes `Hashtable` and `SortedDictionary` in the same ways. In fact, except for the generic-specific syntax, Fig. 21.8 looks remarkably similar to Fig. 21.7. This is the beauty of object-oriented programming.

---

```

1 // Fig. 21.8: SortedDictionaryTest.cs
2 // App counts the number of occurrences of each word in a string
3 // and stores them in a generic sorted dictionary.
4 using System;
5 using System.Text.RegularExpressions;
6 using System.Collections.Generic;
7
8 public class SortedDictionaryTest
9 {
10     public static void Main( string[] args )
11     {
12         // create sorted dictionary based on user input
13         SortedDictionary< string, int > dictionary = CollectWords();
14
15         // display sorted dictionary content
16         DisplayDictionary( dictionary );
17     } // end Main
18
19     // create sorted dictionary from user input
20     private static SortedDictionary< string, int > CollectWords()
21     {
22         // create a new sorted dictionary
23         SortedDictionary< string, int > dictionary =
24             new SortedDictionary< string, int >();
25
26         Console.WriteLine( "Enter a string: " ); // prompt for user input
27         string input = Console.ReadLine(); // get input
28
29         // split input text into tokens
30         string[] words = Regex.Split( input, @"\s+" );
31

```

---

**Fig. 21.8** | App counts the number of occurrences of each word in a `string` and stores them in a generic sorted dictionary. (Part I of 2.)

```

32      // processing input words
33      foreach ( var word in words )
34      {
35          string wordKey = word.ToLower(); // get word in lowercase
36
37          // if the dictionary contains the word
38          if ( dictionary.ContainsKey( wordKey ) )
39          {
40              ++dictionary[ wordKey ];
41          } // end if
42      else
43          // add new word with a count of 1 to the dictionary
44          dictionary.Add( wordKey, 1 );
45      } // end foreach
46
47      return dictionary;
48 } // end method CollectWords
49
50 // display dictionary content
51 private static void DisplayDictionary< K, V >(
52     SortedDictionary< K, V > dictionary )
53 {
54     Console.WriteLine( "\nSorted dictionary contains:\n{0,-12}{1,-12}",
55         "Key:", "Value:" );
56
57     // generate output for each key in the sorted dictionary
58     // by iterating through the Keys property with a foreach statement
59     foreach ( K key in dictionary.Keys )
60         Console.WriteLine( "{0,-12}{1,-12}", key, dictionary[ key ] );
61
62     Console.WriteLine( "\nsize: {0}", dictionary.Count );
63 }
64 } // end method DisplayDictionary
65 } // end class SortedDictionaryTest

```

```

Enter a string:
We few, we happy few, we band of brothers

Sorted dictionary contains:
Key:           Value:
band           1
brothers      1
few,           2
happy          1
of             1
we             3

size: 6

```

**Fig. 21.8** | App counts the number of occurrences of each word in a `string` and stores them in a generic sorted dictionary. (Part 2 of 2.)

Line 6 contains a `using` directive for the `System.Collections.Generic` namespace, which contains class `SortedDictionary`. The generic class `SortedDictionary` takes two type arguments—the first specifies the type of key (i.e., `string`) and the second the type of value (i.e., `int`). We have simply replaced the word `Hashtable` in line 13 and lines 23–

24 with `SortedDictionary<string, int>` to create a dictionary of `int` values keyed with `strings`. Now, the compiler can check and notify us if we attempt to store an object of the wrong type in the dictionary. Also, because the compiler now knows that the data structure contains `int` values, there's no longer any need for the *downcast* in line 40. This allows line 40 to use the much more concise prefix increment (`++`) notation. These changes result in code that can be checked for type safety at compile time.

Static method `DisplayDictionary` (lines 51–63) has been modified to be completely generic. It takes type parameters `K` and `V`. These parameters are used in line 52 to indicate that `DisplayDictionary` takes a `SortedDictionary` with keys of type `K` and values of type `V`. We use type parameter `K` again in line 59 as the type of the iteration key. This use of generics is a marvelous example of *code reuse*. If we decide to change the app to count the number of times each character appears in a string, method `DisplayDictionary` could receive an argument of type `SortedDictionary<char, int>` without modification. This is precisely what you'll do in Exercise 21.12. The key-value pairs displayed are now ordered by key, as shown in Fig. 21.8.



### Performance Tip 21.6

*Because class `SortedDictionary` keeps its elements sorted in a binary tree, obtaining or inserting a key–value pair takes  $O(\log n)$  time, which is fast compared to linear searching, then inserting.*



### Common Programming Error 21.4

*Invoking the `get` accessor of a `SortedDictionary` indexer with a key that does not exist in the collection causes a `KeyNotFoundException`. This behavior is different from that of the `Hashtable` indexer's `get` accessor, which would return `null`.*

## 21.5.2 Generic Class `LinkedList`

The generic `LinkedList` class is a doubly linked list—we can navigate the list both backward and forward with nodes of generic class `LinkedListNode`. Each node contains property `Value` and read-only properties `Previous` and `Next`. The `Value` property's type matches `LinkedList`'s single type parameter because it contains the data stored in the node. The `Previous` property gets a reference to the preceding node in the linked list (or `null` if the node is the first of the list). Similarly, the `Next` property gets a reference to the subsequent reference in the linked list (or `null` if the node is the last of the list). We demonstrate a few linked-list manipulations in Fig. 21.9.

---

```

1 // Fig. 21.9: LinkedListTest.cs
2 // Using LinkedLists.
3 using System;
4 using System.Collections.Generic;
5
6 public class LinkedListTest
7 {
8     private static readonly string[] colors = { "black", "yellow",
9         "green", "blue", "violet", "silver" };

```

**Fig. 21.9** | Using `LinkedLists`. (Part I of 4.)

```

10  private static readonly string[] colors2 = { "gold", "white",
11    "brown", "blue", "gray" };
12
13 // set up and manipulate LinkedList objects
14 public static void Main( string[] args )
15 {
16     LinkedList< string > list1 = new LinkedList< string >();
17
18     // add elements to first linked list
19     foreach ( var color in colors )
20         list1.AddLast( color );
21
22     // add elements to second linked list via constructor
23     LinkedList< string > list2 = new LinkedList< string >( colors2 );
24
25     Concatenate( list1, list2 ); // concatenate list2 onto list1
26     PrintList( list1 ); // display list1 elements
27
28     Console.WriteLine( "\nConverting strings in list1 to uppercase\n" );
29     ToUppercaseStrings( list1 ); // convert to uppercase string
30     PrintList( list1 ); // display list1 elements
31
32     Console.WriteLine( "\nDeleting strings between BLACK and BROWN\n" );
33     RemoveItemsBetween( list1, "BLACK", "BROWN" );
34
35     PrintList( list1 ); // display list1 elements
36     PrintReversedList( list1 ); // display list in reverse order
37 } // end Main
38
39 // display list contents
40 private static void PrintList< T >( LinkedList< T > list )
41 {
42     Console.WriteLine( "Linked list: " );
43
44     foreach ( T value in list )
45         Console.Write( "{0} ", value );
46
47     Console.WriteLine();
48 } // end method PrintList
49
50 // concatenate the second list on the end of the first list
51 private static void Concatenate< T >( LinkedList< T > list1,
52   LinkedList< T > list2 )
53 {
54     // concatenate lists by copying element values
55     // in order from the second list to the first list
56     foreach ( T value in list2 )
57         list1.AddLast( value ); // add new node
58 } // end method Concatenate
59
60 // locate string objects and convert to uppercase
61 private static void ToUppercaseStrings( LinkedList< string > list )
62 {

```

**Fig. 21.9** | Using LinkedLists. (Part 2 of 4.)

```

63     // iterate over the list by using the nodes
64     LinkedListNode< string > currentNode = list.First;
65
66     while ( currentNode != null )
67     {
68         string color = currentNode.Value; // get value in node
69         currentNode.Value = color.ToUpper(); // convert to uppercase
70
71         currentNode = currentNode.Next; // get next node
72     } // end while
73 } // end method ToUppercaseStrings
74
75 // delete list items between two given items
76 private static void RemoveItemsBetween< T >( LinkedList< T > list,
77     T startItem, T endItem )
78 {
79     // get the nodes corresponding to the start and end item
80     LinkedListNode< T > currentNode = list.Find( startItem );
81     LinkedListNode< T > endNode = list.Find( endItem );
82
83     // remove items after the start item
84     // until we find the last item or the end of the linked list
85     while ( ( currentNode.Next != null ) &&
86             ( currentNode.Next != endNode ) )
87     {
88         list.Remove( currentNode.Next ); // remove next node
89     } // end while
90 } // end method RemoveItemsBetween
91
92 // display reversed list
93 private static void PrintReversedList< T >( LinkedList< T > list )
94 {
95     Console.WriteLine( "Reversed List:" );
96
97     // iterate over the list by using the nodes
98     LinkedListNode< T > currentNode = list.Last;
99
100    while ( currentNode != null )
101    {
102        Console.Write( "{0} ", currentNode.Value );
103        currentNode = currentNode.Previous; // get previous node
104    } // end while
105
106    Console.WriteLine();
107 } // end method PrintReversedList
108 } // end class LinkedListTest

```

Linked list:  
black yellow green blue violet silver gold white brown blue gray

Converting strings in list1 to uppercase

**Fig. 21.9** | Using LinkedLists. (Part 3 of 4.)

```

Linked List:
BLACK YELLOW GREEN BLUE VIOLET SILVER GOLD WHITE BROWN BLUE GRAY

Deleting strings between BLACK and BROWN

Linked List:
BLACK BROWN BLUE GRAY
Reversed List:
GRAY BLUE BROWN BLACK

```

**Fig. 21.9** | Using `LinkedLists`. (Part 4 of 4.)

The `using` directive in line 4 allows us to use the `LinkedList` class by its *unqualified name*. Lines 16–23 create `LinkedLists` `list1` and `list2` of strings and fill them with the contents of arrays `colors` and `colors2`, respectively. `LinkedList` is a *generic class* that has one type parameter for which we specify the type argument `string` in this example (lines 16 and 23).

#### ***LinkedList Methods AddLast and AddFirst***

We demonstrate two ways to fill the lists. In lines 19–20, we use the `foreach` statement and method `AddLast` to fill `list1`. The `AddLast` method creates a new `LinkedListNode` (with the given value available via the `Value` property) and appends this node to the end of the list. There's also an `AddFirst` method that inserts a node at the beginning of the list. Line 23 invokes the constructor that takes an `IEnumerable<string>` parameter. All arrays *implicitly* inherit from the generic interfaces `IList` and `IEnumerable` with the type of the array as the type argument, so the `string` array `colors2` implements `IEnumerable<string>`. The type parameter of this generic `IEnumerable` matches the type parameter of the generic `LinkedList` object. This constructor call copies the contents of the array `colors2` to `list2`.

#### ***Methods That Test Class LinkedList***

Line 25 calls *generic method* `Concatenate` (lines 51–58) to append all elements of `list2` to the end of `list1`. Line 26 calls method `PrintList` (lines 40–48) to output `list1`'s contents. Line 29 calls method `ToUppercaseStrings` (lines 61–73) to convert each `string` element to uppercase, then line 30 calls `PrintList` again to display the modified strings. Line 33 calls method `RemoveItemsBetween` (lines 76–90) to remove the elements between "BLACK" and "BROWN"—not including either. Line 35 outputs the list again, then line 36 invokes method `PrintReversedList` (lines 93–107) to display the list in *reverse* order.

#### ***Generic Method Concatenate***

Generic method `Concatenate` (lines 51–58) iterates over `list2` with a `foreach` statement and calls method `AddLast` to append each value to the end of `list1`. The `LinkedList` class's enumerator loops over the values of the nodes, not the nodes themselves, so the iteration variable has type `T`. Notice that this creates a new node in `list1` for each node in `list2`. One `LinkedListNode` cannot be a member of more than one `LinkedList`. If you want the same data to belong to more than one `LinkedList`, you must make a copy of the node for each list to avoid `InvalidOperationExceptions`.

#### ***Generic Method PrintList and Method ToUppercaseStrings***

Generic method `PrintList` (lines 40–48) similarly uses a `foreach` statement to iterate over the values in a `LinkedList`, and outputs them. Method `ToUppercaseStrings` (lines

61–73) takes a linked list of `strings` and converts each `string` value to uppercase. This method replaces the `strings` stored in the list, so we cannot use an enumerator (via a `foreach` statement) as in the previous two methods. Instead, we obtain the first `LinkedListNode` via the `First` property (line 64), and use a `while` statement to loop through the list (lines 66–72). Each iteration of the `while` statement obtains and updates the contents of `currentNode` via property `Value`, using `string` method `ToUpper` to create an uppercase version of `string` `color`. At the end of each iteration, we move the current node to the next node in the list by assigning `currentNode` to the node obtained by its own `Next` property (line 71). The `Next` property of the last node of the list gets `null`, so when the `while` statement iterates past the end of the list, the loop exits.

### ***Method ToUppercaseStrings***

It does not make sense to declare `ToUppercaseStrings` as a generic method, because it uses the `string`-specific methods of the values in the nodes. Methods `PrintList` (lines 40–48) and `Concatenate` (lines 51–58) do not need to use any `string`-specific methods, so they can be declared with generic type parameters to promote maximal code reuse.

### ***Generic Method RemoveItemsBetween***

Generic method `RemoveItemsBetween` (lines 76–90) removes a range of items between two nodes. Lines 80–81 obtain the two “boundary” nodes of the range by using method `Find`. This method performs a linear search on the list and returns the first node that contains a value equal to the passed argument. Method `Find` returns `null` if the value is not found. We store the node preceding the range in local variable `currentNode` and the node following the range in `endNode`.

Lines 85–89 remove all the elements between `currentNode` and `endNode`. On each iteration of the loop, we remove the node following `currentNode` by invoking method `Remove` (line 88). Method `Remove` takes a `LinkedListNode`, splices that node out of the `LinkedList`, and fixes the references of the surrounding nodes. After the `Remove` call, `currentNode`’s `Next` property now gets the node *following* the node just removed, and that node’s `Previous` property now gets `currentNode`. The `while` statement continues to loop until there are no nodes left between `currentNode` and `endNode`, or until `currentNode` is the last node in the list. (There’s also an overloaded version of method `Remove` that performs a linear search for the specified value and removes the first node in the list that contains it.)

### ***Method PrintReversedList***

Method `PrintReversedList` (lines 93–107) displays the list backward by navigating the nodes manually. Line 98 obtains the last element of the list via the `Last` property and stores it in `currentNode`. The `while` statement in lines 100–104 iterates through the list *backward* by moving the `currentNode` reference to the previous node at the end of each iteration, then exiting when we move past the beginning of the list. Note how similar this code is to lines 64–72, which iterated through the list from the beginning to the end.

## **21.6 Covariance and Contravariance for Generic Types**

C# supports *covariance* and *contravariance* of generic interface and delegate types. We’ll consider these concepts in the context of arrays, which have always been covariant and contravariant in C#.

### Covariance in Arrays

Recall our `Employee` class hierarchy from Section 12.5, which consisted of the base class `Employee` and the derived classes `SalariedEmployee`, `CommissionEmployee` and `Base-PlusCommissionEmployee`. Assuming the declarations

```
SalariedEmployee[] salariedEmployees = {
    new SalariedEmployee( "Bob", "Blue", "111-11-1111", 800M ),
    new SalariedEmployee( "Rachel", "Red", "222-22-2222", 1234M ) };
Employee[] employees;
```

we can write the following statement:

```
employees = salariedEmployees;
```

Even though the array type `SalariedEmployee[]` does *not* derive from the array type `Employee[]`, the preceding assignment *is* allowed because class `SalariedEmployee` is a derived class of `Employee`.

Similarly, suppose we have the following method, which displays the `string` representation of each `Employee` in its `employees` array parameter:

```
void PrintEmployees( Employee[] employees )
```

We can call this method with the array of `SalariedEmployee`s, as in:

```
PrintEmployees( salariedEmployees );
```

and the method will correctly display the `string` representation of each `SalariedEmployee` object in the argument array. Assigning an array of a derived-class type to an array variable of a base-class type is an example of **covariance**.

### Covariance in Generic Types

Covariance works with several *generic interface and delegate types*, including `IEnumerable<T>`. Arrays and generic collections implement the `IEnumerable<T>` interface. Using the `salariedEmployees` array declared previously, consider the following statement:

```
IEnumerable< Employee > employees = salariedEmployees;
```

Prior to Visual C# 2010, this generated a compilation error. Interface `IEnumerable<T>` is now covariant, so the preceding statement *is* allowed. If we modify method `PrintEmployees` as in:

```
void PrintEmployees( IEnumerable< Employee > employees )
```

we can call `PrintEmployees` with the array of `SalariedEmployee` objects, because that array implements the interface `IEnumerable<SalariedEmployee>` and because a `SalariedEmployee` *is an Employee* and because `IEnumerable<T>` is covariant. Covariance like this works *only* with reference types that are related by a class hierarchy.

### Contravariance in Arrays

Previously, we showed that an array of a derived-class type (`salariedEmployees`) can be assigned to an array variable of a base-class type (`employees`). Now, consider the following statement, which has *always* worked in C#:

```
SalariedEmployee[] salariedEmployees2 =
    ( SalariedEmployee[] ) employees;
```

Based on the previous statements, we know that the `Employee` array variable `employees` currently refers to an array of `SalariedEmployee`s. Using a *cast operator* to assign `employees`—an array of base-class-type elements—to `salariedEmployees2`—an array of derived-class-type elements—is an example of *contravariance*. The preceding cast will fail at runtime if `employees` is *not* an array of `SalariedEmployee`s.

### *Contravariance in Generic Types*

To understand contravariance in generic types, consider a `SortedSet` of `SalariedEmployee`s. Class `SortedSet<T>` maintains a set of objects in sorted order—*no duplicates* are allowed. The objects placed in a `SortedSet` *must* implement the `IComparable<T>` interface. For classes that *do not* implement this interface, you can still compare their objects using an object that implements the `IComparer<T>` interface. This interface's `Compare` method compares its two arguments and returns 0 if they're equal, a *negative* integer if the first object is less than the second, or a *positive* integer if the first object is greater than the second.

Our `Employee` hierarchy classes do *not* implement `IComparable<T>`. Let's assume we wish to sort `Employees` by social security number. We can implement the following class to compare *any* two `Employees`:

```
class EmployeeComparer : IComparer< Employee >
{
    int IComparer< Employee >.Compare( Employee a, Employee b )
    {
        return a.SocialSecurityNumber.CompareTo(
            b.SocialSecurityNumber );
    } // end method Compare
} // end class EmployeeComparer
```

Method `Compare` returns the result of comparing the two `Employees` social security numbers using `string` method `CompareTo`.

Now consider the following statement, which creates a `SortedSet`:

```
SortedSet< SalariedEmployee > set =
    new SortedSet< SalariedEmployee >( new EmployeeComparer() );
```

When the type argument does *not* implement `IComparable<T>`, you must supply an appropriate `IComparer<T>` object to compare the objects that will be placed in the `SortedSet`. Since, we're creating a `SortedSet` of `SalariedEmployee`s, the compiler expects the `IComparer<T>` object to implement the `IComparer<SalariedEmployee>`. Instead, we provided an object that implements `IComparer<Employee>`. The compiler allows us to provide an `IComparer` for a base-class type where an `IComparer` for a derived-class type is expected because interface `IComparer<T>` supports contravariance.

### *Web Resources*

For a list of covariant and contravariant interface types, visit

```
msdn.microsoft.com/en-us/library/dd799517.aspx#VariantList
```

It's also possible to create your own variant types. For information on this, visit

```
msdn.microsoft.com/en-us/library/dd997386.aspx
```

## 21.7 Wrap-Up

This chapter introduced the .NET Framework collection classes. You learned about the hierarchy of interfaces that many of the collection classes implement. You saw how to use class `Array` to perform array manipulations. You learned that the `System.Collections` and `System.Collections.Generic` namespaces contain many nongeneric and generic collection classes, respectively. We presented the nongeneric classes `ArrayList`, `Stack` and `Hashtable` as well as generic classes `SortedDictionary` and `LinkedList`. In doing so, we discussed data structures in greater depth. We discussed dynamically expandable collections, hashing schemes, and two implementations of a dictionary. You saw the advantages of generic collections over their nongeneric counterparts.

You also learned how to use enumerators to traverse these data structures and obtain their contents. We demonstrated the `foreach` statement with many of the classes of the Framework Class Library, and explained that this works by using enumerators “behind-the-scenes” to traverse the collections.

In Chapter 22, we begin our discussion of databases, which organize data in such a way that the data can be selected and updated quickly. We introduce Structured Query Language (SQL) for writing simple database queries. We then introduce LINQ to SQL, which allows you to write LINQ queries that are automatically converted into SQL queries. These SQL queries are then used to query the database.

---

## Summary

### *Section 21.1 Introduction*

- The prepackaged data-structure classes provided by the .NET Framework are known as collection classes—they store collections of data.
- With collection classes, instead of creating data structures to store these sets of items, the programmer simply uses existing data structures, without concern for how they’re implemented.

### *Section 21.2 Collections Overview*

- The .NET Framework collections provide high-performance, high-quality implementations of common data structures and enable effective software reuse.
- In earlier versions of C#, the .NET Framework primarily provided the collection classes in the `System.Collections` namespace to store and manipulate object references.
- The .NET Framework’s `System.Collections.Generic` namespace contains collection classes that take advantage of .NET’s generics capabilities.

### *Section 21.3 Class Array and Enumerators*

- All arrays implicitly inherit from abstract base class `Array` (namespace `System`).
- The static `Array` method `Sort` sorts an array.
- The static `Array` method `Copy` copies elements from one array to another.
- The static `Array` method `BinarySearch` performs binary searches on an array. This method assumes that it receives a sorted array.
- A collection’s `GetEnumerator` method returns an enumerator that can iterate over the collection.
- All enumerators have methods `MoveNext` and `Reset` and property `Current`.
- `MoveNext` moves the enumerator to the next element in the collection. `MoveNext` returns `true` if there’s at least one more element in the collection; otherwise, the method returns `false`.

- Read-only property `Current` returns the object at the current location in the collection.
- If a collection is modified after an enumerator is created for that collection, the enumerator immediately becomes invalid.
- The `foreach` statement implicitly obtains an enumerator via the `GetEnumerator` method and uses the enumerator's `MoveNext` method and `Current` property to traverse the collection. This can be done with any collection that implements the `IEnumerable` interface—not just arrays.

#### ***Section 21.4.1 Class ArrayList***

- In most programming languages, conventional arrays have a fixed size.
- The .NET Framework's `ArrayList` collection class enhances the functionality of conventional arrays and provides dynamic resizing of the collection.
- `ArrayLists` store references to objects.
- `ArrayList` has a constructor that can initialize the contents of an `ArrayList` with the elements of any `ICollection` passed to it. Many of the collection classes have such a constructor.
- The `Count` and `Capacity` properties correspond, respectively, to the current number of elements in the `ArrayList` and the maximum number of elements that can be stored without allocating more memory to the `ArrayList`.
- Method `IndexOf` returns the position of a value in an `ArrayList`, or `-1` if the element isn't found.
- We can access an element of an `ArrayList` by following the `ArrayList` variable name with square brackets (`[]`) containing the desired index of the element.
- The `Remove` method removes the first occurrence of the specified object. All subsequent elements shift toward the beginning of the `ArrayList` to fill the emptied position.

#### ***Section 21.4.2 Class Stack***

- Class `Stack` has methods `Push` and `Pop` to perform the basic stack operations.
- The non-generic `Stack` class can store only references to objects, so value-type items are implicitly boxed before they're added to the `Stack`.
- Method `Peek` returns the value of the top stack element but does not remove the element.
- Attempting to `Peek` or `Pop` an empty `Stack` causes an `InvalidOperationException`.

#### ***Section 21.4.3 Class Hashtable***

- Hashing is a high-speed scheme for converting keys to unique array indices. The .NET Framework provides class `Hashtable` to enable programmers to employ hashing.
- Class `Hashtable` can accept any object as a key.
- Method `ContainsKey` determines whether a key is in the hash table.
- `Hashtable` method `Add` creates a new entry in the hash table, with the first argument as the key and the second as the value.
- We can use the `Hashtable`'s indexer to obtain and set the key's associated value in the hash table.
- `Hashtable` property `Keys` gets an `ICollection` that contains all the keys.
- If you use a `foreach` statement with a `Hashtable`, the iteration variable is of type `DictionaryEntry`, which has properties `Key` and `Value` for retrieving the key and value of the current element.

#### ***Section 21.5.1 Generic Class SortedDictionary***

- A dictionary is a collection of key–value pairs. A hash table is one way to implement a dictionary.
- Generic class `SortedDictionary` does not use a hash table, but instead stores its key–value pairs in a binary search tree.

- Generic class `SortedDictionary` takes two type arguments—the first specifies the type of key and the second the type of value.
- When the compiler knows the type that the data structure contains, there's no need to downcast when we need to use the type-specific methods.
- Invoking the `get` accessor of a `SortedDictionary` indexer with a key that does not exist in the collection causes a `KeyNotFoundException`. This behavior is different from that of the `Hashtable` indexer's `get` accessor, which would return `null`.

### **Section 21.5.2 Generic Class `LinkedList`**

- The `LinkedList` class is a doubly linked list—we can navigate the list both backward and forward with nodes of generic class `LinkedListNode`.
- Each node contains property `Value` and read-only properties `Previous` and `Next`.
- The `LinkedList` class's enumerator loops over the values of the nodes, not the nodes themselves.
- One `LinkedListNode` cannot be a member of more than one `LinkedList`. Any attempt to add a node from one `LinkedList` to another generates an `InvalidOperationException`.
- Method `Find` performs a linear search on the list and returns the first node that contains a value equal to the passed argument.
- Method `Remove` deletes a node from a `LinkedList`.

### **Section 21.6 Covariance and Contravariance for Generic Types**

- C# supports covariance and contravariance of generic interface and delegate types.
- Assigning an array of a derived-class type to an array variable of a base-class type is an example of covariance.
- Covariance now works with several generic interface types, including `IEnumerable<T>`.
- Covariance in generic collections works *only* with reference types in the same class hierarchy.
- Using a cast operator to assign an array variable of a base-class type to an array variable of a derived-class type is an example of contravariance.
- Class `SortedSet` maintains a set of objects in sorted order—no duplicates are allowed.
- The objects placed in a `SortedSet` must be comparable to determine their sorting order. Objects are comparable if their classes implement the `IComparable<T>` interface.
- For classes that do not implement `IComparable<T>`, you can compare the objects using an object that implements the `IComparer<T>` interface. This interface's `Compare` method compares its two arguments and returns 0 if they are equal, a negative integer if the first object is less than the second, or a positive integer if the first object is greater than the second.
- Providing an `IComparer` for a base-class type where an `IComparer` for a derived-class type is expected is allowed because interface `IComparer<T>` supports contravariance.

## **Terminology**

Add method of class `ArrayList`

capacity

Add method of class `Hashtable`

Capacity property of class `ArrayList`

AddLast method of class `LinkedList`

Clear method of class `Array`

`ArgumentException`

Clear method of class `ArrayList`

`Array` class

collection

`ArrayList` class

collection class

`BinarySearch` method of class `Array`

collision

`BinarySearch` method of class `ArrayList`

Contains method of class `ArrayList`

|                                           |                                           |
|-------------------------------------------|-------------------------------------------|
| Contains method of class Stack            | Last property of class LinkedList         |
| ContainsKey method of class Hashtable     | LastIndexOf method of class Array         |
| contravariance                            | LinkedList generic class                  |
| Copy method of interface ICollection      | LinkedListNode generic class              |
| Count property of interface ICollection   | load factor                               |
| covariance                                | MoveNext method of interface IEnumerator  |
| CreateInstance method of class Array      | Next property of class LinkedListNode     |
| Current property of interface IEnumerator | Peek method of class Stack                |
| dictionary                                | Pop method of class Stack                 |
| DictionaryEntry structure                 | Previous property of class LinkedListNode |
| enumerator                                | Push method of class Stack                |
| Find method of class LinkedList           | Queue class                               |
| First property of class LinkedList        | Remove method of class ArrayList          |
| GetEnumerator method of interface         | Remove method of class LinkedList         |
| IEnumerator                               | RemoveAt method of class ArrayList        |
| GetHashCode method of class object        | RemoveRange method of class ArrayList     |
| hash function                             | Reset method of interface IEnumerator     |
| hash table                                | Sort method of class Array                |
| hashing                                   | Sort method of class ArrayList            |
| Hashtable class                           | SortedDictionary generic class            |
| ICollection interface                     | SortedList class                          |
| IComparable<T> interface                  | SortedSet class                           |
| IComparer<T> interface                    | space/time trade-off                      |
| IDictionary interface                     | Stack class                               |
| IEnumerable interface                     | System.Collections namespace              |
| IEnumerator interface                     | System.Collections.Generic namespace      |
| IList interface                           | System.Collections.Specialized namespace  |
| IndexOf method of class Array             | ToLower method of class string            |
| IndexOf method of class ArrayList         | ToUpper method of class string            |
| int indexer of class ArrayList            | TrimToSize method of class ArrayList      |
| InvalidOperationException                 | Value property of class LinkedListNode    |
| KeyNotFoundException                      | Values property of interface IDictionary  |
| Keys property of interface IDictionary    |                                           |

## Self-Review Exercises

- 21.1** Fill in the blanks in each of the following statements:
- A(n) \_\_\_\_\_ is used to walk through a collection but cannot remove elements from the collection during the iteration.
  - Class \_\_\_\_\_ provides the capabilities of an arraylike data structure that can resize itself dynamically.
  - An element in an ArrayList can be accessed by using the ArrayList's \_\_\_\_\_.
  - IEnumerator method \_\_\_\_\_ advances the enumerator to the next item.
  - If the collection it references has been altered since the enumerator's creation, calling method Reset will cause a(n) \_\_\_\_\_.
- 21.2** State whether each of the following is *true* or *false*. If *false*, explain why.
- Class Stack is in the System.Collections namespace.
  - A Hashtable stores key–value pairs.
  - A class implementing interface IEnumerator must define only methods MoveNext and Reset, and no properties.

- d) Values of simple types may be stored directly in an `ArrayList`.
- e) An `ArrayList` can contain duplicate values.
- f) A `Hashtable` can contain duplicate keys.
- g) A `LinkedList` can contain duplicate values.
- h) `Dictionary` is an interface.
- i) Enumerators can change the values of elements but cannot remove them.
- j) With hashing, as the load factor increases, the chance of collisions decreases.

## Answers to Self-Review Exercises

**21.1** a) enumerator (or `foreach` statement). b) `ArrayList`. c) indexer. d) `MoveNext`. e) `InvalidOperationException`.

**21.2** a) True. b) True. c) False. The class must also implement property `Current`. d) False. An `ArrayList` stores only objects. Autoboxing occurs when adding a value type to the `ArrayList`. You can prevent boxing by instead using generic class `List` with a value type. e) True. f) False. A `Hashtable` cannot contain duplicate keys. g) True. h) False. `Dictionary` is a class; `IDictionary` is an interface. i) False. An enumerator cannot be used to change the values of elements. j) False. With hashing, as the load factor increases, there are fewer available slots relative to the total number of slots, so the chance of selecting an occupied slot (a collision) with a hashing operation increases.

## Exercises

**21.3** (*Collections Terminology*) Define each of the following terms:

- a) `ICollection`
- b) `Array`
- c) `IList`
- d) load factor
- e) `Hashtable` collision
- f) space/time trade-off in hashing
- g) `Hashtable`

**21.4** (*ArrayList Methods*) Explain briefly the operation of each of the following methods of class `ArrayList`:

- a) `Add`
- b) `Insert`
- c) `Remove`
- d) `Clear`
- e) `RemoveAt`
- f) `Contains`
- g) `IndexOf`
- h) `Count`
- i) `Capacity`

**21.5** (*ArrayList Insertion Performance*) Explain why inserting additional elements into an `ArrayList` object whose current size is less than its capacity is a relatively fast operation and why inserting additional elements into an `ArrayList` object whose current size is at capacity is relatively slow.

**21.6** (*Inheritance Negatives*) In our implementation of a stack in Fig. 19.13, we were able to quickly extend a linked list to create class `StackInheritance`. The .NET Framework designers chose not to use inheritance to create their `Stack` class. What are the negative aspects of inheritance, particularly for class `Stack`?

**21.7** (*Collections Short Questions*) Briefly answer the following questions:

- a) What happens when you add a simple type value to a nongeneric collection?

- b) Can you display all the elements in an `IEnumerable` object without explicitly using an enumerator? If yes, how?

**21.8** (*Enumerator Members*) Explain briefly the operation of each of the following enumerator-related methods:

- a) `GetEnumerator`
- b) `Current`
- c) `MoveNext`

**21.9** (*HashTable Methods and Properties*) Explain briefly the operation of each of the following methods and properties of class `Hashtable`:

- a) `Add`
- b) `Keys`
- c) `Values`
- d) `ContainsKey`

**21.10** (*True/False*) Determine whether each of the following statements is *true* or *false*. If *false*, explain why.

- a) Elements in an array must be sorted in ascending order before a `BinarySearch` may be performed.
- b) Method `First` gets the first node in a `LinkedList`.
- c) Class `Array` provides `static` method `Sort` for sorting array elements.

**21.11** (*LinkedList without Duplicates*) Write an app that reads in a series of first names and stores them in a `LinkedList`. Do not store duplicate names. Allow the user to search for a first name.

**21.12** (*Generic SortedDictionary*) Modify the app in Fig. 21.8 to count the number of occurrences of each letter rather than of each word. For example, the string "HELLO THERE" contains two Hs, three Es, two Ls, one O, one T and one R. Display the results.

**21.13** (*SortedDictionary of Colors*) Use a `SortedDictionary` to create a reusable class for choosing from some of the predefined colors in class `Color` (in the `System.Drawing` namespace). The names of the colors should be used as keys, and the predefined `Color` objects should be used as values. Place this class in a class library that can be referenced from any C# app. Use your new class in a Windows app that allows the user to select a color, then changes the background color of the `Form`.

**21.14** (*Duplicate Words in a Sentence*) Write an app that determines and displays the number of duplicate words in a sentence. Treat uppercase and lowercase letters the same. Ignore punctuation.

**21.15** (*Using a Generic List*) Recall from Fig. 21.2 that class `List` is the generic equivalent of class `ArrayList`. Write an app that inserts 25 random integers from 0 to 100 in order into an object of class `List`. The app should calculate the sum of the elements and the floating-point average of the elements.

**21.16** (*Reversing a LinkedList*) Write an app that creates a `LinkedList` object of 10 characters, then creates a second list object containing a copy of the first list, but in reverse order.

**21.17** (*Prime Numbers and Prime Factorization*) Write an app that takes a whole-number input from a user and determines whether it's prime. If the number is not prime, display the unique prime factors of the number. Remember that a prime number's factors are only 1 and the prime number itself. Every number that's not prime has a unique prime factorization. For example, consider the number 54. The prime factors of 54 are 2, 3, 3 and 3. When the values are multiplied together, the result is 54. For the number 54, the prime factors output should be 2 and 3.

**21.18** (*Bucket Sort with LinkedList<int>*) In Exercise 18.7, you performed a bucket sort of `ints` by using a two-dimensional array, where each row of the array represented a bucket. If you use a dynamically expanding data structure to represent each bucket, you do not have to write code that keeps track of the number of `ints` in each bucket. Rewrite your solution to use a one-dimensional array of `LinkedList< int > buckets`.

# Databases and LINQ



*Now go, write it before them in a table, and note it in a book, that it may be for the time to come for ever and ever.*

—Isaiah 30:8

*It is a capital mistake to theorize before one has data.*

—Arthur Conan Doyle

## Objectives

In this chapter you'll:

- Learn about the relational database model.
- Use an ADO.NET Entity Data Model to create classes for interacting with a database via LINQ to Entities.
- Use LINQ to retrieve and manipulate data from a database.
- Add data sources to projects.
- Use the IDE's drag-and-drop capabilities to display database tables in apps.
- Use data binding to move data seamlessly between GUI controls and databases.
- Create Master/Detail views that enable you to select a record and display its details.

|             |                                                                                  |               |                                                |
|-------------|----------------------------------------------------------------------------------|---------------|------------------------------------------------|
| <b>22.1</b> | Introduction                                                                     | <b>22.6.2</b> | Coding the <b>Display Query Results</b> App    |
| <b>22.2</b> | Relational Databases                                                             | <b>22.7</b>   | Retrieving Data from Multiple Tables with LINQ |
| <b>22.3</b> | A Books Database                                                                 | <b>22.8</b>   | Creating a Master/Detail View App              |
| <b>22.4</b> | LINQ to Entities and the ADO.NET Entity Framework                                | 22.8.1        | Creating the Master/Detail GUI                 |
| <b>22.5</b> | Querying a Database with LINQ                                                    | 22.8.2        | Coding the Master/Detail App                   |
| 22.5.1      | Creating the ADO.NET Entity Data Model Class Library                             | <b>22.9</b>   | Address Book Case Study                        |
| 22.5.2      | Creating a Windows Forms Project and Configuring It to Use the Entity Data Model | 22.9.1        | Creating the <b>Address Book</b> App's GUI     |
| 22.5.3      | Data Bindings Between Controls and the Entity Data Model                         | 22.9.2        | Coding the <b>Address Book</b> App             |
| <b>22.6</b> | Dynamically Binding Query Results                                                | <b>22.10</b>  | Tools and Web Resources                        |
| 22.6.1      | Creating the <b>Display Query Results</b> GUI                                    | <b>22.11</b>  | Wrap-Up                                        |

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 22.1 Introduction

A **database** is an organized collection of data. A **database management system** (DBMS) provides mechanisms for storing, organizing, retrieving and modifying data. Today's most popular DBMSs manage *relational databases*, which organize data simply as tables with *rows* and *columns*.

Some popular proprietary DBMSs are Microsoft SQL Server, Oracle, Sybase and IBM DB2. PostgreSQL and MySQL are popular *open-source* DBMSs that can be downloaded and used *freely* by anyone. In this chapter, we use Microsoft's free **SQL Server Express**, which is installed with Visual Studio. It can also be downloaded separately from Microsoft ([www.microsoft.com/express/sql](http://www.microsoft.com/express/sql)).

### *SQL Server Express*

SQL Server Express provides many features of Microsoft's full (fee-based) SQL Server product, but has some limitations, such as a maximum database size of 10GB. A SQL Server Express database file can be easily migrated to a full version of SQL Server—we did this with our [deitel.com](http://deitel.com) website once our database became too large for SQL Server Express. You can learn more about the SQL Server versions at [bit.ly/SQLServerEditions](http://bit.ly/SQLServerEditions). The version of SQL Server Express that's bundled with Visual Studio Express 2012 for Windows Desktop is called **SQL Server Express 2012 LocalDB**. It's meant for development and testing of apps on your computer.

### *Structured Query Language (SQL)*

A language called **Structured Query Language (SQL)**—pronounced “sequel”—is an international standard used with relational databases to perform **queries** (that is, to request information that satisfies given criteria) and to manipulate data. For years, programs that accessed a relational database passed SQL queries as **strings** to the database management system, then processed the results.

### *LINQ to Entities and the ADO.NET Entity Framework*

A logical extension of querying and manipulating data in databases is to perform similar operations on *any* sources of data, such as arrays, collections (like the `Items` collection of a `ListBox`) and files. Chapter 9 introduced *LINQ to Objects* and used it to manipulate data stored in arrays. **LINQ to Entities** allows you to manipulate data stored in a relational database—in our case, a SQL Server Express database. As with LINQ to Objects, the IDE provides *IntelliSense* for your LINQ to Entities queries.

The **ADO.NET Entity Framework** (commonly referred to simply as **EF**) enables apps to interact with data in various forms, including data stored in relational databases. You'll use the ADO.NET Entity Framework and Visual Studio to create a so-called *entity data model* that represents the database, then use LINQ to Entities to manipulate objects in the entity data model. Though, you'll manipulate data in a *SQL Server Express* database in this chapter, the ADO.NET Entity Framework works with *most* popular database management systems. Behind the scenes, the ADO.NET Entity Framework generates SQL statements that interact with a database.

This chapter introduces general concepts of relational databases, then implements several database apps using the ADO.NET Entity Framework, LINQ to Entities and the IDE's tools for working with databases. In later chapters, you'll see other practical database and LINQ to Entities apps, such as a web-based guestbook and a web-based bookstore. Databases are at the heart of most “industrial strength” apps.

### *LINQ to SQL vs. LINQ to Entities*

In the previous edition of this book, we discussed LINQ to SQL. Microsoft stopped further development on LINQ to SQL in 2008 in favor of the newer and more powerful LINQ to Entities and the ADO.NET Entity Framework.

### *Online SQL Introduction*

In prior editions of this book, this chapter included an introduction to SQL. We've moved this introduction to book's website at [www.deitel.com/books/csharphtp5/](http://www.deitel.com/books/csharphtp5/), because we now perform all of the database interactions using LINQ.

## **22.2 Relational Databases**

A **relational database** organizes data in **tables**. Figure 22.1 illustrates a sample `Employees` table that might be used in a personnel system. The table stores the attributes of employees. Tables are composed of **rows** (also called records) and **columns** (also called fields) in which values are stored. This table consists of six rows (one per employee) and five columns (one per attribute). The `ID` column of each row is the table's **primary key**—a column (or group of columns) requiring a *unique* value that cannot be duplicated in other rows. This guarantees that each primary key value can be used to identify *one* row. A primary key composed of two or more columns is known as a **composite key**. Good examples of primary-key columns in other apps are a book's ISBN number in a book information system or a part number in an inventory system—values in each of these columns must be unique. LINQ to Entities requires *every table to have a primary key* to support updating the data in tables. The rows in Fig. 22.1 are displayed in *ascending order* by primary key. But they could be listed in *descending order* or in no particular order at all.

## Table Employees

|       | ID          | Name     | Department | Salary | Location    |
|-------|-------------|----------|------------|--------|-------------|
| Row { | 23603       | Jones    | 413        | 1100   | New Jersey  |
|       | 24568       | Kerwin   | 413        | 2000   | New Jersey  |
|       | 34589       | Larson   | 642        | 1800   | Los Angeles |
|       | 35761       | Myers    | 611        | 1400   | Orlando     |
|       | 47132       | Neumann  | 413        | 9000   | New Jersey  |
|       | 78321       | Stephens | 611        | 8500   | Orlando     |
|       | Primary key |          | Column     |        |             |

**Fig. 22.1** | Employees table sample data.

Each *column* represents a different data *attribute*. Some column values may be duplicated between rows. For example, three different rows in the Employees table's Department column contain the number 413, indicating that these employees work in the same department.

## Selecting Data Subsets

You can use LINQ to Entities to define queries that *select subsets* of the data from a table. For example, a program might select data from the Employees table to create a query result that shows where each department is located, in ascending order by Department number (Fig. 22.2).

| Department | Location    |
|------------|-------------|
| 413        | New Jersey  |
| 611        | Orlando     |
| 642        | Los Angeles |

**Fig. 22.2** | Distinct Department and Location data from the Employees table.

## 22.3 A Books Database

We now consider a simple Books database that stores information about some Deitel books. First, we overview the database’s tables. A database’s tables, their fields and the relationships among them are collectively known as a **database schema**. The ADO.NET Entity Framework uses a database’s schema to define classes that enable you to interact with the database. Sections 22.5–22.7 show how to manipulate the Books database. The database file—Books.mdf—is provided with this chapter’s examples. SQL Server database files have the .mdf (“master data file”) file-name extension.

## *Authors Table of the Books Database*

The database consists of three tables: Authors, Titles and AuthorISBN. The Authors table (described in Fig. 22.3) consists of three columns that maintain each author's unique ID number, first name and last name, respectively. Figure 22.4 contains the data from the Authors table.

| Column    | Description                                                                                                                                                                                                                                                                                                                                   |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AuthorID  | Author's ID number in the database. In the Books database, this integer column is defined as an <b>identity</b> column, also known as an <b>autoincremented</b> column—for each row inserted in the table, the AuthorID value is increased by 1 automatically to ensure that each row has a unique AuthorID. This is the <i>primary key</i> . |
| FirstName | Author's first name (a string).                                                                                                                                                                                                                                                                                                               |
| LastName  | Author's last name (a string).                                                                                                                                                                                                                                                                                                                |

**Fig. 22.3** | Authors table of the Books database.

| AuthorID | FirstName | LastName |
|----------|-----------|----------|
| 1        | Paul      | Deitel   |
| 2        | Harvey    | Deitel   |
| 3        | Abbey     | Deitel   |
| 4        | Dan       | Quirk    |
| 5        | Michael   | Morgano  |

**Fig. 22.4** | Data from the Authors table of the Books database.

### ***Titles Table of the Books Database***

The **Titles** table (described in Fig. 22.5) consists of four columns that maintain information about each book in the database, including its ISBN, title, edition number and copyright year. Figure 22.6 contains the data from the **Titles** table.

| Column        | Description                                                                                                                                                                                                                       |
|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ISBN          | ISBN of the book (a string). The table's primary key. ISBN is an abbreviation for “International Standard Book Number”—a numbering scheme that publishers worldwide use to give every book a <i>unique</i> identification number. |
| Title         | Title of the book (a string).                                                                                                                                                                                                     |
| EditionNumber | Edition number of the book (an integer).                                                                                                                                                                                          |
| Copyright     | Copyright year of the book (a string).                                                                                                                                                                                            |

**Fig. 22.5** | Titles table of the Books database.

| ISBN       | Title                                    | EditionNumber | Copyright |
|------------|------------------------------------------|---------------|-----------|
| 0132151006 | Internet & World Wide Web How to Program | 5             | 2012      |
| 0132575663 | Java How to Program                      | 9             | 2012      |

**Fig. 22.6** | Data from the **Titles** table of the Books database. (Part 1 of 2.)

| ISBN       | Title                                           | EditionNumber | Copyright |
|------------|-------------------------------------------------|---------------|-----------|
| 013299044X | C How to Program                                | 7             | 2013      |
| 0132990601 | Simply Visual Basic 2010                        | 4             | 2013      |
| 0133406954 | Visual Basic 2012 How to Program                | 6             | 2014      |
| 0133379337 | Visual C# 2012 How to Program                   | 5             | 2014      |
| 0136151574 | Visual C++ 2008 How to Program                  | 2             | 2008      |
| 0133378713 | C++ How to Program                              | 9             | 2014      |
| 0132121360 | Android for Programmers: An App-Driven Approach | 1             | 2012      |

**Fig. 22.6** | Data from the **Titles** table of the **Books** database. (Part 2 of 2.)***AuthorISBN Table of the Books Database***

The **AuthorISBN** table (described in Fig. 22.7) consists of two columns that maintain ISBNs for each book and their corresponding authors' ID numbers. This table associates authors with their books. The **AuthorID** column is a **foreign key**—a column in this table that matches the primary-key column in another table (that is, **AuthorID** in the **Authors** table). The **ISBN** column is also a **foreign key**—it matches the primary-key column (that is, **ISBN**) in the **Titles** table. A database might consist of many tables. A goal when designing a database is to *minimize* the amount of *duplicated* data among the database's tables. Foreign keys, which are specified when a database table is created in the database, link the data in *multiple* tables. Together the **AuthorID** and **ISBN** columns in this table form a **composite primary key**. Every row in this table *uniquely* matches *one* author to *one* book's ISBN. Figure 22.8 contains the data from the **AuthorISBN** table of the **Books** database.

| Column          | Description                                                        |
|-----------------|--------------------------------------------------------------------|
| <b>AuthorID</b> | The author's ID number, a foreign key to the <b>Authors</b> table. |
| <b>ISBN</b>     | The ISBN for a book, a foreign key to the <b>Titles</b> table.     |

**Fig. 22.7** | AuthorISBN table of the Books database.

| AuthorID    | ISBN       | AuthorID    | ISBN       |
|-------------|------------|-------------|------------|
| 1           | 0132151006 | (continued) |            |
| 1           | 0132575663 | 1           | 0133379337 |
| 1           | 013299044X | 1           | 0136151574 |
| 1           | 0132990601 | 1           | 0133378713 |
| 1           | 0133406954 | 1           | 0132121360 |
| (continued) |            | 2           | 0132151006 |

**Fig. 22.8** | Data from the **AuthorISBN** table of the **Books** database. (Part 1 of 2.)

| AuthorID    | ISBN       | AuthorID    | ISBN       |
|-------------|------------|-------------|------------|
| 2           | 0132575663 | (continued) |            |
| 2           | 013299044X | 2           | 0132121360 |
| 2           | 0132990601 | 3           | 0132151006 |
| 2           | 0133406954 | 3           | 0132990601 |
| 2           | 0133379337 | 3           | 0132121360 |
| 2           | 0136151574 | 3           | 0133406954 |
| 2           | 0133378713 | 4           | 0136151574 |
| (continued) |            | 5           | 0132121360 |

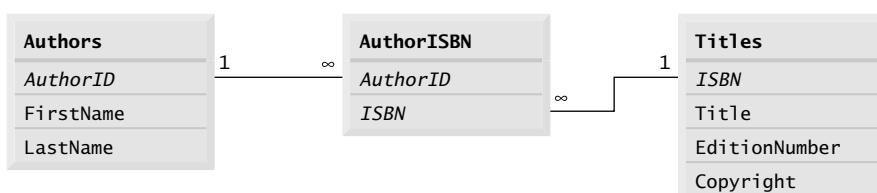
**Fig. 22.8** | Data from the AuthorISBN table of the Books database. (Part 2 of 2.)

Every foreign-key value must appear as another table's primary-key value so the DBMS can ensure that the foreign key value is valid. For example, the DBMS ensures that the AuthorID value for a particular row of the AuthorISBN table (Fig. 22.8) is valid by checking that there is a row in the Authors table with that AuthorID as the primary key.

Foreign keys also allow *related* data in *multiple* tables to be *selected* from those tables—this is known as **joining** the data. There is a **one-to-many relationship** between a primary key and a corresponding foreign key (for example, one author can write many books and one book can be written by many authors). This means that a foreign key can appear *many* times in its own table but only *once* (as the primary key) in another table. For example, the ISBN 0132151006 can appear in several rows of AuthorISBN (because this book has several authors) but only once in Titles, where ISBN is the primary key.

#### *Entity-Relationship Diagram for the Books Database*

Figure 22.9 is an **entity-relationship (ER) diagram** for the Books database. This diagram shows the tables in the database and the relationships among them. The first compartment in each box contains the table's name. The names in italic font are *primary keys*—AuthorID in the Authors table, AuthorID and ISBN in the AuthorISBN table, and ISBN in the Titles table. Every row *must* have a value in the primary-key column (or group of columns), and the value of the key must be *unique* in the table; otherwise, the DBMS will report an error. The names AuthorID and ISBN in the AuthorISBN table are both italic—together these form a *composite primary key* for the AuthorISBN table.



**Fig. 22.9** | Entity-relationship diagram for the Books database.

The lines connecting the tables in Fig. 22.9 represent the *relationships* among the tables. Consider the line between the Authors and AuthorISBN tables. On the Authors end of the line, there's a 1, and on the AuthorISBN end, an infinity symbol ( $\infty$ ). This indicates a *one-to-many relationship*—for each author in the Authors table, there can be an *arbitrary number* of ISBNs for books written by that author in the AuthorISBN table (that is, an author can write *any* number of books). Note that the relationship line links the AuthorID column in the Authors table (where AuthorID is the primary key) to the AuthorID column in the AuthorISBN table (where AuthorID is a foreign key)—the line between the tables links the primary key to the matching foreign key.

The line between the Titles and AuthorISBN tables illustrates a *one-to-many relationship*—one book can be written by many authors. Note that the line between the tables links the primary key ISBN in table Titles to the corresponding foreign key in table AuthorISBN. The relationships in Fig. 22.9 illustrate that the sole purpose of the AuthorISBN table is to provide a **many-to-many relationship** between the Authors and Titles tables—an author can write *many* books, and a book can have *many* authors.

## 22.4 LINQ to Entities and the ADO.NET Entity Framework

When using the ADO.NET Entity Framework, you interact with the database via classes that the IDE generates from the database schema. You'll initiate this process by adding a new **ADO.NET Entity Data Model** to your project (as you'll see in Section 22.5.1).

### *Classes Generated in the Entity Data Model*

For the Authors and Titles tables in the Books database, the IDE creates two classes *each* in the data model:

- The first class represents a row of the table and contains properties for each column in the table. Objects of this class—called **row objects**—store the data from individual rows of the table. The IDE uses the *singular* version of a table's *plural* name as the row class's name. For the Books database's Authors table, the row class's name is **Author**, and for the Titles table, it's **Title**.
- The second class represents the table itself. An object of this class stores a collection of row objects that correspond to all of the rows in the table. The table classes for the Books database are named **Authors** and **Titles**.

Once generated, the entity data model classes have full *IntelliSense* support in the IDE. Section 22.7 demonstrates queries that use the relationships among the Books database's tables to join data.

### *Relationships Between Tables in the Entity Data Model*

You'll notice that we did not mention the Books database's AuthorISBN table. Recall that this table links:

- each author in the Authors table to that author's books in the Titles table, and
- each book in the Titles table to the book's authors in the Authors table.

Relationships between tables are taken into account in the entity data model's generated classes. For example, the Author row class contains a **navigation property** named **Titles**

which you can use to get the `Title` objects that represent all the books written by that author. The IDE automatically adds the “`s`” to “`Title`” to indicate that this property represents a collection of `Title` objects. Similarly, the `Title` row class contains a navigation property named `Authors`, which you can use to get the `Author` objects that represent a given book’s authors.

### ***DbContext* Class**

A **`DbContext`** (namespace `System.Data.Entity`) manages the data flow between the program and the database. When the IDE generates the *entity data model*’s row and table classes, it also creates a derived class of `DbContext` that is specific to the database being manipulated. For the Books database, this derived class has properties for the `Authors` and `Titles` tables. As you’ll see, these can be used as data sources for manipulating data in LINQ queries and in GUIs. Any changes made to the data managed by the `DbContext` can be saved back to the database using the `DbContext`’s **`SaveChanges`** method.

### ***IQueryable<T>* Interface**

LINQ to Entities works through the **`IQueryable<T>`** interface, which inherits from the interface `IEnumerable<T>` introduced in Chapter 9. When a LINQ to Entities query on an `IQueryable<T>` object executes against the database, the results are loaded into objects of the corresponding entity data model classes for convenient access in your code.

### ***Using Extension Methods to Manipulate IQueryable<T> Objects***

Recall that extension methods add functionality to an existing class without modifying the class’s source code. In Chapter 9, we introduced several LINQ extension methods, including `First`, `Any`, `Count`, `Distinct`, `ToArray` and `ToList`. These methods, which are defined as `static` methods of class `Enumerable` (namespace `System.Linq`), can be applied to any object that implements the `IEnumerable<T>` interface, such as arrays, collections and the results of LINQ to Objects queries.

In this chapter, we use a combination of the LINQ query syntax and LINQ extension methods to manipulate database contents. The extension methods we use are defined as `static` methods of class `Queryable` (namespace `System.Linq`) and can be applied to any object that implements the `IQueryable<T>` interface—these include various entity data model objects and the results of LINQ to Entities queries.

## **22.5 Querying a Database with LINQ**

In this section, we demonstrate how to *connect* to a database, *query* it and *display* the results of the query. There is little code in this section—the IDE provides *visual programming tools* and *wizards* that simplify accessing data in apps. These tools establish database connections and create the objects necessary to view and manipulate the data through Windows Forms GUI controls—a technique known as **`data binding`**.

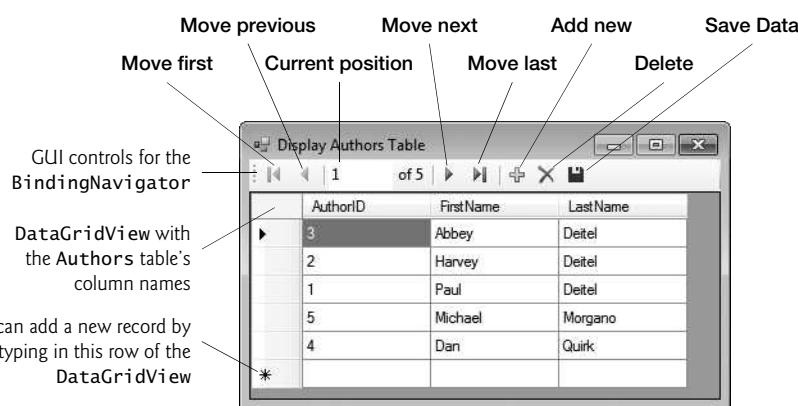
For the examples in Sections 22.5–22.8, we’ll create *one* solution that contains *several* projects. One will be a reusable *class library* containing the ADO.NET Entity Data Model for interacting with the Books database. The other projects will be Windows Forms apps that use the ADO.NET Entity Data Model in the class library to manipulate the database.

Our first example performs a simple query on the Books database from Section 22.3. We retrieve the entire `Authors` table, ordered by the authors’ last name, then first name.

We then use data binding to display the data in a **DataGridView**—a control from namespace `System.Windows.Forms` that can display data from a data source in tabular format. The basic steps we'll perform are:

- Create the ADO.NET entity data model classes for manipulating the database.
- Add the entity data model object that represents the Authors table as a *data source*.
- Drag the Authors table data source onto the **Design** view to create a GUI for displaying the table's data.
- Add code to the Form's code-behind file to allow the app to interact with the database.

The GUI for the program is shown in Fig. 22.10. All of the controls in this GUI are automatically generated when we drag a *data source* that represents the Authors table onto the Form in **Design** view. The **BindingNavigator** toolbar at the top of the window is a collection of controls that allow you to navigate through the records in the DataGridView that fills the rest of the window. The BindingNavigator controls also allow you to add records, delete records, modify existing records and save your changes to the database. You can add a new record by pressing the **Add new** (+) button, then entering the new author's first and last name. You can delete an existing record by selecting an author (either in the DataGridView or via the controls on the BindingNavigator) and pressing the **Delete** (X) button. You can edit an existing record by clicking the first name or last name field for that record and typing the new value. To save your changes to the database, simply click the **Save Data** (floppy disk) button. Empty values are *not* allowed in the Authors table of the Books database, so if you attempt to save a record that does not contain a value for both the first name and last name an exception occurs.



**Fig. 22.10** | GUI for the Display Authors Table app.

### 22.5.1 Creating the ADO.NET Entity Data Model Class Library

This section presents the steps required to create the entity data model from an existing database. A *model* describes the data that you'll be manipulating—in our case, the data represented by the tables in the Books database.

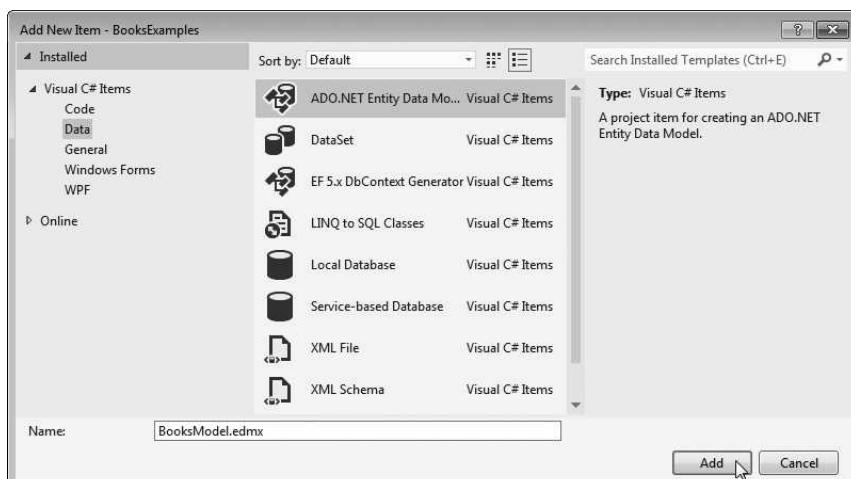
***Step 1: Creating a Class Library Project for the ADO.NET Entity Data Model***

Select FILE > New Project... to display the New Project dialog, then select Class Library from the Visual C# templates and name the project BooksExamples. Click OK to create the project, then delete the Class1.cs file from the Solution Explorer.

***Step 2: Adding the ADO.NET Entity Data Model to the Class Library***

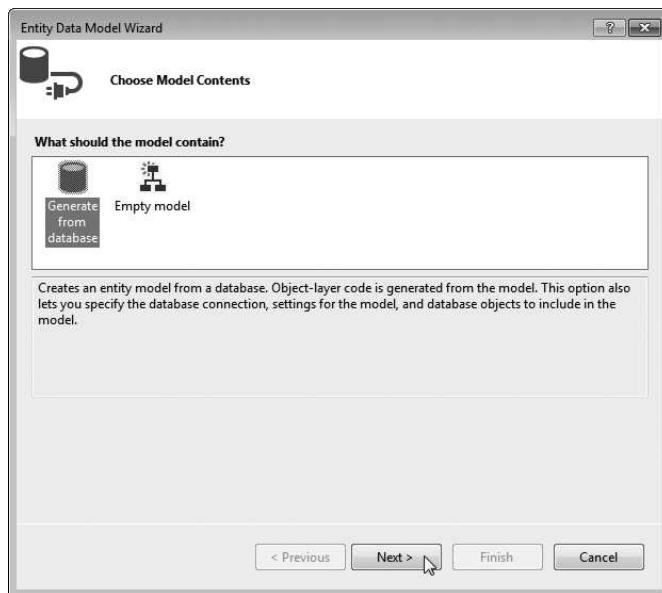
To interact with the database, you'll add an ADO.NET entity data model to the class library project. This will also configure the connection to the database.

1. ***Adding the ADO.NET Entity Data Model.*** Right click the BooksExamples project in the Solution Explorer, then select Add > New Item... to display the Add New Item dialog (Fig. 22.11). From the Data category select ADO.NET Entity Data Model and name the model BooksModel.edmx—this file will contain the information about the entity data model you're about to create. Click Add to add the entity data model to the class library and display the Entity Data Model Wizard dialog.



**Fig. 22.11 |** Selecting ADO.NET Entity Data Model in the Add New Item Dialog.

2. ***Choosing the Model Contents.*** The Choose Model Contents step in the Entity Data Model Wizard dialog (Fig. 22.12) enables you to specify the entity data model's contents. The model in these examples will consist of data from the Books database, so select Generate from Database and click Next > to display the Choose Your Data Connection step.
3. ***Choosing the Data Connection.*** In the Choose Your Data Connection step, click New Connection... to display the Connection Properties dialog (Fig. 22.13). (If the Choose Data Source dialog box appears, select Microsoft SQL Server, then click OK.) The Data source: TextBox should contain Microsoft SQL Server Database File (SqlClient). (If it does not, click Change... to display a dialog where you can change the Data source.) Click Browse... to locate and select the Books.mdf file in the Databases directory included with this chapter's examples. You can click Test Connection to verify that the IDE can connect to the database through

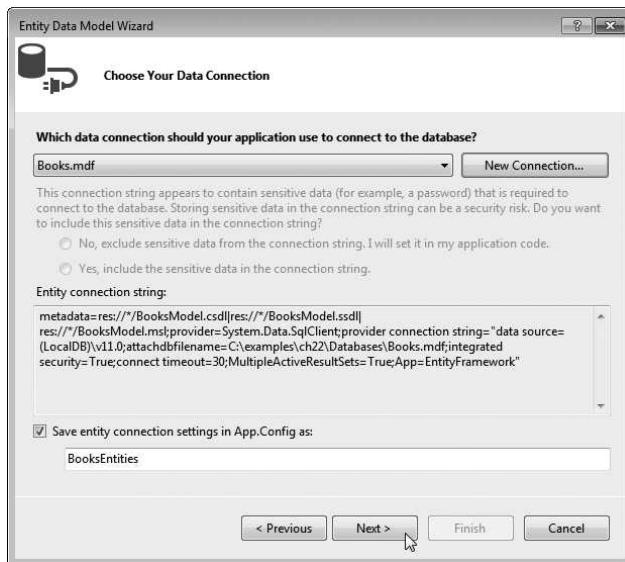


**Fig. 22.12 |** Entity Data Model Wizard dialog's Choose Model Contents step.



**Fig. 22.13 |** Connection Properties dialog.

SQL Server Express. Click **OK** to create the connection. Figure 22.14 shows the **Entity connection string** for the **Books.mdf** database. This string contains the information that the ADO.NET Entity Framework requires to connect to the database at runtime. Click **Next >**. A dialog will appear asking if you'd like to add the database file to your project. Click **Yes** to move to the next step.



**Fig. 22.14 |** Choose Your Data Connection step after selecting Books.mdf.

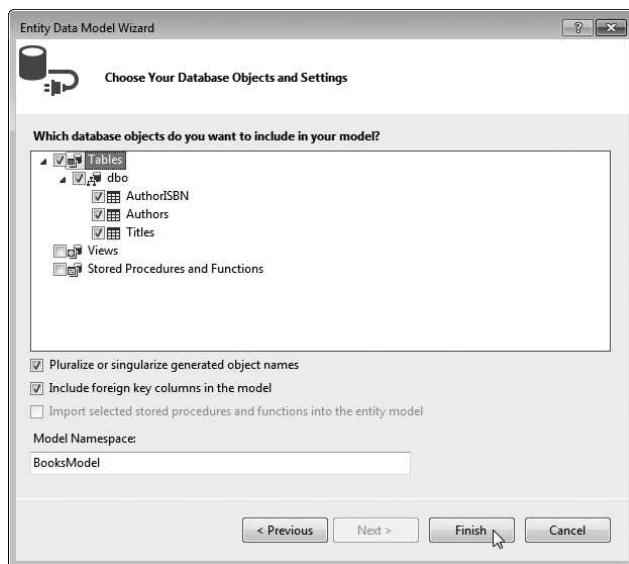


### Error-Prevention Tip 22.1

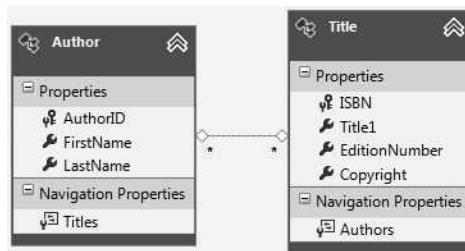
SQL Server Express LocalDB allows only one program at a time to connect to a database file, so ensure that no other program is using the file before connecting to the database.

4. **Choosing the Database Objects to Include in the Model.** In the Choose Your Database Objects and Settings step, you'll specify the parts of the database that should be used in the ADO.NET Entity Data Model. Select the **Tables** node as shown in Fig. 22.15, then click **Finish**.
5. **Viewing the Entity Data Model Diagram in the Model Designer.** At this point, the IDE creates the entity data model and displays a diagram (Fig. 22.16) in the *model designer*. The diagram contains **Author** and **Title entities**—these represent *authors* and *titles* in the database and the properties of each. Notice that the IDE renamed the **Title** column of the **Titles** table as **Title1** to avoid a naming conflict with the class **Title** that represents a row in the table. The line between the entities indicates a *relationship* between authors and titles—this relationship is implemented in the Books database as the **AuthorISBN** table. The asterisk (\*) at each end of the line indicates a *many-to-many relationship*—an author can be an author for *many* titles and a title can have *many* authors. The **Navigation Properties** section in the **Author** entity contains the **Titles** property, which connects an author to all titles written by that author. Similarly, the **Navigation Properties** section in the **Title** entity contains the **Authors** property, which connects a title to all of its authors.
6. **Building the Class Library.** Select **BUILD > Build Solution** to build the class library that you'll reuse in the next several examples—this will compile the entity data model classes that were generated by the IDE. When you build the class library,

the IDE generates the classes that you can use to interact with the database. These include a class for each table you selected from the database and a derived class of `DbContext` named `BooksEntities` that enables you to programmatically interact with the database. [Note: Building the project causes the IDE to execute a script that creates and compiles the entity data model classes. A security warning dialog appears indicating that this script could harm your computer. Click **OK** to allow the script to execute. The warning is intended primarily for cases in which you download from the Internet Visual Studio templates that execute scripts.]



**Fig. 22.15** | Selecting the database's tables to include in the ADO.NET Entity Data Model.



**Fig. 22.16** | Entity data model diagram for the **Author** and **Title** entities.

## 22.5.2 Creating a Windows Forms Project and Configuring It to Use the Entity Data Model

Recall that the next several examples will all be part of *one solution* containing *several projects*—the class library project with our *reusable model* and individual Windows Forms apps

for each example. In this section, you'll create a new Windows Forms app and configure it to be able to use the entity data model that you created in the preceding section.

### *Step 1: Creating the Project*

To add a new Windows Forms project to the existing solution:

1. Right click the solution name in **Solution Explorer** and select **Add > New Project...** to display the **Add New Project** dialog.
2. Select **Windows Forms Application**, name the project **DisplayTable** and click **OK**.
3. Change the name of the **Form1.cs** source file to **DisplayAuthorsTable.cs**. The IDE updates the Form's class name to match the source file. Set the Form's **Text** property to **Display Authors Table**.
4. Configure the solution so that this new project will execute when you select **DEBUG > Start Debugging** (or press **F5**). To do so, right click the **DisplayTable** project's name in the **Solution Explorer**, then select **Set as Startup Project**.

### *Step 2: Adding a Reference to the BooksExamples Class Library*

To use the entity data model classes for data binding, you must first add a *reference* to the class library you created in Section 22.5.1—this allows the new project to use that class library. Each project you create typically contains references to several .NET class libraries (called *assemblies*) by default—for example, a Windows Forms project contains a reference to the **System.Windows.Forms** library. When you compile a class library, the IDE creates a **.dll** file (known as an *assembly*) containing the library's components. To add a reference to the class library containing the entity data model's classes:

1. Right click the **DisplayTable** project's **References** node in the **Solution Explorer** and select **Add Reference....**
2. In the left column of the **Reference Manager** dialog that appears, select **Solution** to display the other projects in this solution, then in center of the dialog select **BooksExamples** and click **OK**. **BooksExamples** should now appear in the projects **References** node.

### *Step 3: Adding References to System.Data.Entity and EntityFramework*

You'll also need references to the **System.Data.Entity** and **EntityFramework** libraries to use the ADO.NET Entity Framework. To add a reference to **System.Data.Entity**, repeat *Step 2* for adding a reference to the **BooksExamples** library, but in the left column of the **Reference Manager** dialog that appears, select **Assemblies** then locate **System.Data.Entity**, ensure that its checkbox is checked and click **OK**. **System.Data.Entity** should now appear in the projects **References** node.

The **EntityFramework** library was added by the IDE to the **BooksExamples** class library project when we created the entity data model, but the **EntityFramework** library is also required in *each* app that will use the entity data model. To add a reference to the **EntityFramework** library:

1. Right click the solution name in the **Solution Explorer** and select **Manage NuGet Packages for Solution...** to display the **Manage NuGet Packages** dialog.

2. In the dialog that appears, click **Manage** to display the **Select Projects** dialog, then select the **DisplayTable** project and click **OK**.
3. Click **Close** to close the **Manage NuGet Packages** dialog. **EntityFramework** should now appear in the projects **References** node.

#### *Step 4: Adding the Connection String to the Windows Forms App*

Each app that will use the entity data model also requires the *connection string* that tells the Entity Framework how to connect to the database. The connection string is stored in the **BooksExamples** class library's **App.Config** file. In the **Solution Explorer**, open the **Books-Examples** class library's **App.Config** file then copy lines 7–9, which have the format:

```
<connectionStrings>
    Connection string information appears here
</connectionStrings>
```

Next, open the **App.Config** file in the **DisplayTable** project and paste the connection string information *after* the line containing **</entityFramework>** and *before* the line containing **</configuration>**. Save the **App.Config** file.

### **22.5.3 Data Bindings Between Controls and the Entity Data Model**

You'll now use the IDE's drag-and-drop GUI design capabilities to create the GUI for interacting with the **Books** database. You must write a small amount of code to enable the *autogenerated* GUI to interact with the entity data model. You'll now perform the steps to display the contents of the **Authors** table in a GUI.

#### *Step 1: Adding a Data Source for the Authors Table*

To use the entity data model classes for data binding, you must first add them as a *data source*. To do so:

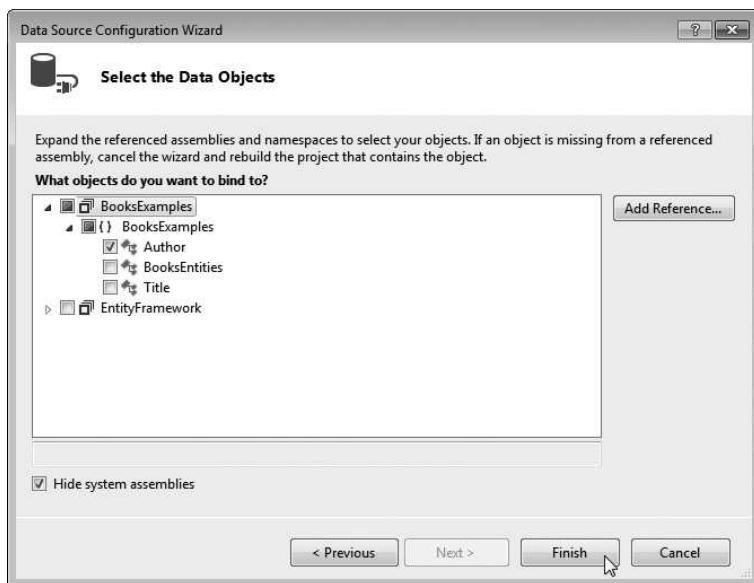
1. Select **VIEW > Other Windows > Data Sources** to display the **Data Sources** window at the left side of the IDE, then in that window click the **Add New Data Source...** link to display the **Data Source Configuration Wizard**.
2. The Entity Data Model classes are used to create *objects* representing the tables in the database, so we'll use an **Object** data source. In the dialog, select **Object** and click **Next >**. Expand the tree view as shown in Fig. 22.17 and ensure that **Author** is checked. An object of this class will be used as the *data source*.
3. Click **Finish**.

The **Authors** table in the database is now a data source from which a data bound GUI control can obtain data. In the **Data Sources** window (Fig. 22.18), you can see the **Author** class that you added in the previous step. Properties representing columns of the database's **Authors** table should appear below it, as well as a **Titles** navigation property representing the relationship between the database's **Authors** and **Titles** tables.

#### *Step 2: Creating GUI Elements*

Next, you'll use the **Design** view to create a **DataGridView** control that can display the **Authors** table's data. To do so:

1. Switch to **Design** view for the **DisplayAuthorsTable** class.



**Fig. 22.17** | Selecting the Author class as the data source.

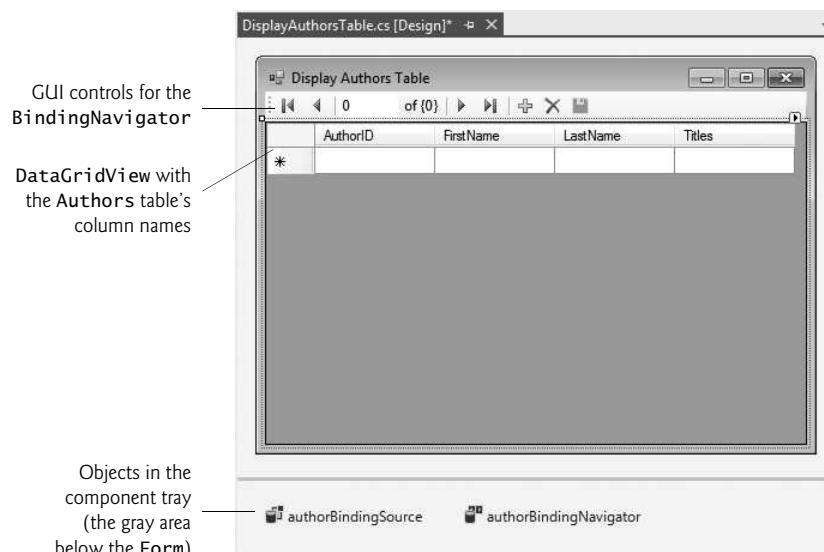


**Fig. 22.18** | Data Sources window showing the Author class as a data source.

2. Click the **Author** node in the **Data Sources** window—it should change to a drop-down list. Open the drop-down by clicking the down arrow and ensure that the **DataGridView** option (which is the default) is selected—this is the GUI control that will be used to display and interact with the data.
3. Drag the **Author** node from the **Data Sources** window onto the **Form** in **Design** view. You'll need to resize the **Form** to fit the **DataGridView**.

The IDE creates a **DataGridView** (Fig. 22.19) with column names representing *all* the properties for an **Author**, including the **Titles** navigation property. The IDE also creates a **BindingNavigator** that contains Buttons for *moving between entries, adding entries, deleting entries and saving changes to the database*. The IDE also generates a **BindingSource** (**authorBindingSource**), which handles the transfer of data between the *data source* and the *data-bound controls* on the **Form**. Nonvisual components such as the **BindingSource** and the non-visual aspects of the **BindingNavigator** appear in the *component tray*—the

gray region below the Form in **Design** view. The IDE names the **BindingNavigator** and **BindingSource** (`authorBindingNavigator` and `authorBindingSource`, respectively) based on the data source's name (`Author`). We use the default names for automatically generated components throughout this chapter to show exactly what the IDE creates.



**Fig. 22.19** | Component tray holds nonvisual components in **Design** view.

To make the **DataGridView** occupy the *entire* window below the **BindingNavigator**, select the **DataGridView**, then use the **Properties** window to set the **Dock** property to **Fill**. You can stretch the window horizontally to see all the **DataGridView** columns. We do not use the **Titles** column in this example, so with the **DataGridView** selected, click **Edit Columns...** in the **Properties** window to display the **Edit Columns** dialog. Select **Titles** in the **Selected Columns** list, then click **Remove** to remove that column.

### Step 3: Connecting the Data Source to the `authorBindingSource`

The final step is to connect the data source to the `authorBindingSource`, so that the app can interact with the database. Figure 22.20 shows the code needed to *obtain* data from the database and to *save* any changes that the user makes to the data back into the database.

```

1 // Fig. 22.20: DisplayAuthorsTable.cs
2 // Displaying data from a database table in a DataGridView.
3 using System;
4 using System.Data.Entity;
5 using System.Data.Entity.Validation;
```

**Fig. 22.20** | Displaying data from a database table in a **DataGridView**. (Part 1 of 3.)

```
6  using System.Linq;
7  using System.Windows.Forms;
8
9  namespace DisplayTable
10 {
11     public partial class DisplayAuthorsTable : Form
12     {
13         // constructor
14         public DisplayAuthorsTable()
15         {
16             InitializeComponent();
17         } // end constructor
18
19         // Entity Framework DbContext
20         private BooksExamples.BooksEntities dbcontext =
21             new BooksExamples.BooksEntities();
22
23         // load data from database into DataGridView
24         private void DisplayAuthorsTable_Load( object sender, EventArgs e )
25         {
26             // load Authors table ordered by LastName then FirstName
27             dbcontext.Authors
28                 .OrderBy( author => author.LastName )
29                 .ThenBy( author => author.FirstName )
30                 .Load();
31
32             // specify DataSource for authorBindingSource
33             authorBindingSource.DataSource = dbcontext.Authors.Local;
34         } // end method DisplayAuthorsTable_Load
35
36         // click event handler for the Save Button in the
37         // BindingNavigator saves the changes made to the data
38         private void authorBindingNavigatorSaveItem_Click(
39             object sender, EventArgs e )
40         {
41             Validate(); // validate the input fields
42             authorBindingSource.EndEdit(); // complete current edit, if any
43
44             // try to save changes
45             try
46             {
47                 dbcontext.SaveChanges(); // write changes to database file
48             } // end try
49             catch( DbEntityValidationException )
50             {
51                 MessageBox.Show( "FirstName and LastName must contain values",
52                                 "Entity Validation Exception" );
53             } // end catch
54         } // end method authorBindingNavigatorSaveItem_Click
55     } // end class DisplayAuthorsTable
56 } // end namespace DisplayTable
```

Fig. 22.20 | Displaying data from a database table in a DataGridView. (Part 2 of 3.)

	AuthorID	FirstName	LastName
▶	3	Abbey	Deitel
	2	Harvey	Deitel
	1	Paul	Deitel
	5	Michael	Morgano
\*	4	Dan	Quirk

**Fig. 22.20** | Displaying data from a database table in a DataGridView. (Part 3 of 3.)

### *Creating the DbContext Object*

As mentioned in Section 22.4, a `DbContext` object interacts with the database on the app’s behalf. The `BooksEntities` class (a derived class of `DbContext`) was automatically generated by the IDE when you created the entity data model classes to access the Books database (Section 22.5.1). Lines 20–21 create an object of this class named `dbContext`.

### *DisplayAuthorsTable\_Load Event Handler*

You can create the Form’s Load event handler (lines 24–34) by double clicking the Form’s title bar in Design view. In this app, we allow data to move between the `DbContext` and the database by using LINQ to Entities extension methods to extract data from the `BooksEntities`’s `Authors` property (lines 27–30), which corresponds to the `Authors` table in the database. The expression

```
dbContext.Authors
```

indicates that we wish to get data from the `Authors` table.

The **OrderBy** extension method call

```
.OrderBy( author => author.LastName )
```

indicates that the rows of the table should be retrieved in ascending order by the authors’ last names. The argument to `OrderBy` is a **lambda expression** that defines a simple, **anonymous method**. A lambda expression begins with a *parameter list*—`author` in this case, is an object of the `Author` entity data model class. The lambda expression *infers* the lambda parameter’s type from `dbContext.Authors`, which contains `Author` objects. The parameter list is followed by the `=>` **lambda operator** (read as “goes to”) and an expression that represents the body of the function. The value produced by the expression—a given author’s last name—is implicitly returned by the lambda expression. You do not specify a return type for the lambda expression—the return type is inferred from the return value. As we encounter lambda expressions in this chapter, we’ll discuss the syntax we use. You can learn more about lambda expressions at

[msdn.microsoft.com/en-us/library/bb397687.aspx](http://msdn.microsoft.com/en-us/library/bb397687.aspx)

When there are multiple authors with the *same* last name, we’d like them to be listed in ascending order by first name as well. The **ThenBy** extension method call

```
.ThenBy( author => author.FirstName )
```

enables you to order results by an additional column. This is applied to the Author objects that have already been ordered by last name.

Finally, line 30 calls the **Load** extension method (defined in class **DBExtensions** from the namespace **System.Data.Entity**). This method executes the LINQ to Entities query and loads the results into memory. This data is tracked by the **BookEntities** **DbContext** in local memory so that any changes made to the data can eventually be saved into the database. Lines 27–30 are equivalent to using the following statement:

```
(from author in dbcontext.Authors
 orderby author.LastName, author.FirstName
 select author).Load();
```

Line 33 sets the **authorBindingSource**'s **DataSource** property to the **Local** property of the **dbcontext.Authors** object. In this case, the **Local** property is an **ObservableCollection<Author>** that represents the query results that were loaded into memory by lines 27–30. When a **BindingSource**'s **DataSource** property is assigned an **ObservableCollection<T>** (namespace **System.Collections.ObjectModel**), the GUI that's bound to the **BindingSource** is notified of any changes to the data so the GUI can be updated accordingly. In addition, changes made by the user to the data in the GUI will be tracked so the **DbContext** can eventually save those changes to the database.

#### **authorBindingNavigatorSaveItem\_Click** Event Handler: Saving Modifications to the Database

If the user modifies the data in the **DataGridView**, we'd also like to save the modifications in the database. By default, the **BindingNavigator**'s **Save Data** Button (■) is disabled. To enable it, right click this Button's icon in the **BindingNavigator** and select **Enabled**. Then, double click the icon to create its **Click** event handler (lines 38–54).

Saving the data entered in the **DataGridView** back to the database is a three-step process. First, all controls on the form are *validated* (line 41) by calling the **DisplayTableForm**'s inherited **Validate** method—if any control has an event handler for the **Validating** event, it executes. You typically handle this event to determine whether a control's contents are valid. Next, line 42 calls **EndEdit** on the **authorBindingSource**, which forces it to save any pending changes into the **BooksEntities** model *in memory*. Finally, line 47 calls **SaveChanges** on the **BooksEntities** object (**dbcontext**) to store any changes into the database. We placed this call in a **try** statement, because the **Authors** table does not allow empty values for the first name and last name—these rules were configured when we originally created the database. When **SaveChanges** is called, any changes stored into the **Authors** table must satisfy the table's rules. If any of the changes do not, a **DBEntityValidationException** occurs.

## 22.6 Dynamically Binding Query Results

Now that you've seen how to display an entire database table in a **DataGridView**, we show how to perform several different queries and display the results in a **DataGridView**. This app only reads data from the entity data model, so we disabled the buttons in the **BindingNavigator** that enable the user to add and delete records. Later, we'll explain why we do not support modifying the database in this example.

The **Display Query Results** app (Fig. 22.21) allows the user to select a query from the **ComboBox** at the bottom of the window, then displays the results of the query.

a) Results of the “All titles” query, which shows the contents of the **Titles** table ordered by the book titles

	ISBN	Title1	EditionNumber	Copyright
▶	0132121360	Android for Programmers: An App-Driven Approach	1	2012
	013299044X	C How to Program	7	2013
	0133378713	C++ How to Program	9	2014
	0132151006	Internet & World Wide Web How to Program	5	2012
	0132575663	Java How to Program	9	2012
	0132990601	Simply Visual Basic 2010	4	2013
	0133406954	Visual Basic 2012 How to Program	6	2014
	0133379337	Visual C# 2012 How to Program	5	2014
	0136151574	Visual C++ 2008 How to Program	2	2008

b) Results of the “Titles with 2014 copyright” query

	ISBN	Title1	EditionNumber	Copyright
▶	0133378713	C++ How to Program	9	2014
	013406954	Visual Basic 2012 How to Program	6	2014
	0133379337	Visual C# 2012 How to Program	5	2014

c) Results of the “Titles ending with ‘How to Program’” query

	ISBN	Title1	EditionNumber	Copyright
▶	013299044X	C How to Program	7	2013
	0133378713	C++ How to Program	9	2014
	0132151006	Internet & World Wide Web How to Program	5	2012
	0132575663	Java How to Program	9	2012
	013406954	Visual Basic 2012 How to Program	6	2014
	0133379337	Visual C# 2012 How to Program	5	2014
	0136151574	Visual C++ 2008 How to Program	2	2008

**Fig. 22.21** | Sample execution of the **Display Query Results** app.

## 22.6.1 Creating the Display Query Results GUI

Perform the following steps to build the **Display Query Results** app’s GUI.

### Step 1: Creating the Project

Perform the steps in Section 22.5.2 to create a new **Windows Forms Application** project named **DisplayQueryResult** in the same solution as the **DisplayTable** app. Rename the **Form1.cs** source file to **TitleQueries.cs**. Set the Form’s **Text** property to **Display Query Results**. Be sure to set the **DisplayQueryResult** project as the startup project.

### Step 2: Creating a **DataGridView** to Display the **Titles** Table

Follow Steps 1 and 2 in Section 22.5.3 to create the data source and the **DataGridView**. For this example, select the **Title** class (rather than **Author**) as the data source, and drag the **Title** node from the **Data Sources** window onto the form. Remove the **Authors** column from the **DataGridView** as it will not be used in this example.

***Step 3: Adding a ComboBox to the Form***

In **Design** view, add a **ComboBox** named `queriesComboBox` below the **DataGridView** on the **Form**. Users will select which query to execute from this control. Set the **ComboBox**'s **Dock** property to **Bottom** and the **DataGridView**'s **Dock** property to **Fill**.

Next, you'll add the names of the queries to the **ComboBox**. Open the **ComboBox**'s **String Collection Editor** by right clicking the **ComboBox** and selecting **Edit Items....** You can also access the **String Collection Editor** from the **ComboBox**'s *smart tag menu*. A *smart tag menu* provides you with quick access to common properties you might set for a control (such as the **Multiline** property of a **TextBox**), so you can set these properties directly in **Design** view, rather than in the **Properties** window. You can open a control's *smart tag menu* by clicking the small arrowhead (↗) that appears in the control's upper-right corner in **Design** view when the control is selected. In the **String Collection Editor**, add the following three items to `queriesComboBox`—one for each of the queries we'll create:

1. All titles
2. Titles with 2014 copyright
3. Titles ending with "How to Program"

### 22.6.2 Coding the Display Query Results App

Next you'll create the code for this app (Fig. 22.22).

***Customizing the Form's Load Event Handler***

Create the `TitleQueries_Load` event handler (lines 22–29) by double clicking the title bar in **Design** view. When the **Form** loads, it should display the complete list of books from the **Titles** table, sorted by title. Line 24 calls the `Load` extension method on the **BookEntities** `DbContext`'s **Titles** property to load the **Titles** table's contents into memory. Rather than defining the same LINQ query as in lines 40–41, we can programmatically cause the `queriesComboBox_SelectedIndexChanged` event handler to execute simply by setting the `queriesComboBox`'s `SelectedIndex` to 0 (line 28).

---

```

1 // Fig. 22.22: TitleQueries.cs
2 // Displaying the result of a user-selected query in a DataGridView.
3 using System;
4 using System.Data.Entity;
5 using System.Linq;
6 using System.Windows.Forms;
7
8 namespace DisplayQueryResult
9 {
10     public partial class TitleQueries : Form
11     {
12         public TitleQueries()
13         {
14             InitializeComponent();
15         } // end constructor
16

```

**Fig. 22.22** | Displaying the result of a user-selected query in a **DataGridView**. (Part I of 2.)

```
17     // Entity Framework DbContext
18     private BooksExamples.BooksEntities dbcontext =
19         new BooksExamples.BooksEntities();
20
21     // load data from database into DataGridView
22     private void TitleQueries_Load( object sender, EventArgs e )
23     {
24         dbcontext.Titles.Load(); // Load Titles table into memory
25
26         // set the ComboBox to show the default query that
27         // selects all books from the Titles table
28         queriesComboBox.SelectedIndex = 0;
29     } // end method TitleQueries_Load
30
31     // loads data into titleBindingSource based on user-selected query
32     private void queriesComboBox_SelectedIndexChanged(
33         object sender, EventArgs e )
34     {
35         // set the data displayed according to what is selected
36         switch ( queriesComboBox.SelectedIndex )
37         {
38             case 0: // all titles
39                 // use LINQ to order the books by title
40                 titleBindingSource.DataSource =
41                     dbcontext.Titles.Local.OrderBy( book => book.Title1 );
42                 break;
43             case 1: // titles with 2014 copyright
44                 // use LINQ to get titles with 2014
45                 // copyright and sort them by title
46                 titleBindingSource.DataSource =
47                     dbcontext.Titles.Local
48                         .Where( book => book.Copyright == "2014" )
49                         .OrderBy( book => book.Title1 );
50                 break;
51             case 2: // titles ending with "How to Program"
52                 // use LINQ to get titles ending with
53                 // "How to Program" and sort them by title
54                 titleBindingSource.DataSource =
55                     dbcontext.Titles.Local
56                         .Where( book =>
57                             book.Title1.EndsWith( "How to Program" ) )
58                         .OrderBy( book => book.Title1 );
59                 break;
60         } // end switch
61
62         titleBindingSource.MoveFirst(); // move to first entry
63     } // end method queriesComboBox_SelectedIndexChanged
64 } // end class TitleQueries
65 } // end namespace DisplayQueryResult
```

Fig. 22.22 | Displaying the result of a user-selected query in a DataGridView. (Part 2 of 2.)

***queriesComboBox\_SelectedIndexChanged Event Handler***

Next you must write code that executes the appropriate query each time the user chooses a different item from queriesComboBox. Double click queriesComboBox in **Design** view to generate a queriesComboBox\_SelectedIndexChanged event handler (lines 32–63) in the TitleQueries.cs file. In the event handler, add a switch statement (lines 36–60). Each case in the switch will change the titleBindingSource's DataSource property to the results of a query that returns the correct set of data. The data bindings created by the IDE automatically update the titleDataGridView each time we change its DataSource. The **MoveFirst** method of the BindingSource (line 62) moves to the first row of the result each time a query executes. The results of the queries in lines 40–41, 46–49 and 54–58 are shown in Fig. 22.21(a), (b) and (c), respectively. Because we do not modify the data in this app, each of the queries is performed on the in-memory representation of the Titles table, which is accessible through dbcontext.Titles.Local.

***Ordering the Books By Title***

Lines 40–41 invoke the **OrderBy** extension method on dbcontext.Titles.Local to order the Title objects by their **Title1** property values. As we mentioned previously, the IDE renamed the **Title** column of the database's **Titles** table as **Title1** in the generated **Title** entity data model class to avoid a naming conflict with the class's name. Recall that Local returns an **ObservableCollection<T>** containing the row objects of the specified table—in this case, Local returns an **ObservableCollection<Title>**. When you invoke **OrderBy** on an **ObservableCollection<T>**, the method returns an **IEnumerable<T>**. We assign that object to the titleBindingSource's **DataSource** property. When the **DataSource** property changes, the **DataGridView** iterates through the contents of the **IEnumerable<T>** and displays the data.

***Selecting Books with 2014 Copyright***

Lines 46–49 filter the titles displayed by using the **Where** extension method with the lambda expression

```
book => book.Copyright == "2014"
```

as an argument. This lambda expression takes one **Title** object (named **book**) as its parameter and uses it to check whether the given **Title**'s **Copyright** property (a string in the database) is equal to 2014. A lambda expression that's used with the **Where** extension method must return a **bool** value. Only **Title** objects for which this lambda expression returns **true** will be selected. We use **OrderBy** to order the results by the **Title1** property so the books are displayed in ascending order by title. The type of the lambda's **book** parameter is *inferred* from **dbcontext.Titles.Local**, which contains **Title** objects. As soon as the titleBindingSource's **DataSource** property changes, the **DataGridView** is updated with the query results.

***Selecting Books with Titles That End in “How to Program”***

Lines 54–58 filter the titles displayed by using the **Where** extension method with the lambda expression

```
book => book.Title1.EndsWith( "How to Program" )
```

as an argument. This lambda expression takes one `Title` object (named `book`) as its parameter and uses it to check whether the given `Title`'s `Title1` property value ends with "How to Program". The expression `books.Title1` returns the string stored in that property, then we use the string class's `EndsWith` method to perform the test. We order the results by the `Title1` property so the books are displayed in ascending order by title.

## 22.7 Retrieving Data from Multiple Tables with LINQ

In this section, you'll perform LINQ to Entities queries using the LINQ query syntax that was introduced in Chapter 9. In particular, you'll learn how to obtain query results that combine data from multiple tables (Fig. 22.23).

- a) List of authors and the ISBNs of the books they've authored; sort the authors by last name then first name

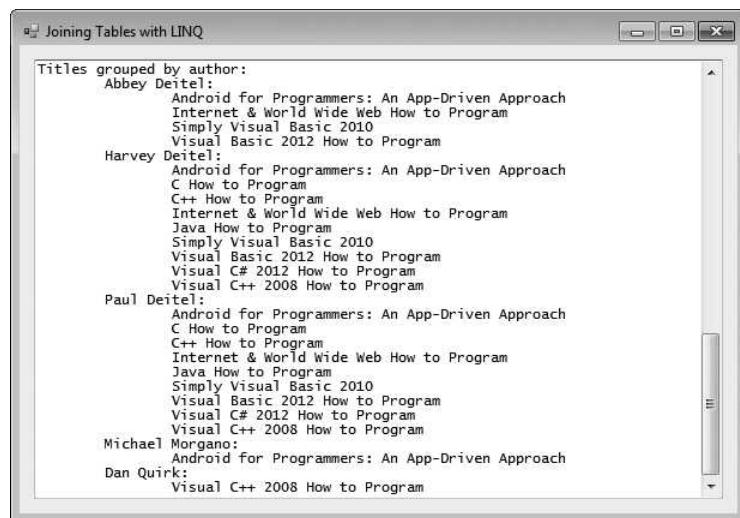
Joining Tables with LINQ		
Authors and ISBNs:		
Abbey	Deitel	0132121360
Abbey	Deitel	0132151006
Abbey	Deitel	0132990601
Abbey	Deitel	0133406954
Harvey	Deitel	0132121360
Harvey	Deitel	0132151006
Harvey	Deitel	0132575663
Harvey	Deitel	013299044X
Harvey	Deitel	0132990601
Harvey	Deitel	0133378713
Harvey	Deitel	0133379337
Harvey	Deitel	0133406954
Harvey	Deitel	0136151574
Paul	Deitel	0132121360
Paul	Deitel	0132151006
Paul	Deitel	0132575663
Paul	Deitel	013299044X
Paul	Deitel	0132990601
Paul	Deitel	0133378713
Paul	Deitel	0133379337
Paul	Deitel	0133406954
Paul	Deitel	0136151574
Michael	Morgano	0132121360
Dan	Quirk	0136151574

- b) List of authors and the titles of the book's they've authored; sort the authors by last name then first name; for a given author, sort the titles alphabetically

Joining Tables with LINQ		
Authors and titles:		
Abbey	Deitel	Android for Programmers: An App-Driven Approach
Abbey	Deitel	Internet & World Wide Web How to Program
Abbey	Deitel	Simply Visual Basic 2010
Abbey	Deitel	Visual Basic 2012 How to Program
Harvey	Deitel	Android for Programmers: An App-Driven Approach
Harvey	Deitel	C How to Program
Harvey	Deitel	C++ How to Program
Harvey	Deitel	Internet & World Wide Web How to Program
Harvey	Deitel	Java How to Program
Harvey	Deitel	Simply Visual Basic 2010
Harvey	Deitel	Visual Basic 2012 How to Program
Harvey	Deitel	Visual C# 2012 How to Program
Harvey	Deitel	Visual C++ 2008 How to Program
Paul	Deitel	Android for Programmers: An App-Driven Approach
Paul	Deitel	C How to Program
Paul	Deitel	C++ How to Program
Paul	Deitel	Internet & World Wide Web How to Program
Paul	Deitel	Java How to Program
Paul	Deitel	Simply Visual Basic 2010
Paul	Deitel	Visual Basic 2012 How to Program
Paul	Deitel	Visual C# 2012 How to Program
Paul	Deitel	Visual C++ 2008 How to Program
Michael	Morgano	Android for Programmers: An App-Driven Approach
Dan	Quirk	Visual C++ 2008 How to Program

Fig. 22.23 | Outputs from the Joining Tables with LINQ app. (Part 1 of 2.)

c) List of titles grouped by author; sort the authors by last name then first name; for a given author, sort the titles alphabetically



**Fig. 22.23** | Outputs from the Joining Tables with LINQ app. (Part 2 of 2.)

The **Joining Tables with LINQ** app uses LINQ to Entities to combine and organize data from multiple tables, and shows the results of queries that perform the following tasks:

- Get a list of all the authors and the ISBNs of the books they've authored, sorted by last name then first name (Fig. 22.23(a)).
- Get a list of all the authors and the titles of the books they've authored, sorted by last name then first; for each author sort the titles alphabetically (Fig. 22.23(b)).
- Get a list of all the book titles grouped by author, sorted by last name then first; for a given author sort the titles alphabetically (Fig. 22.23(c)).

#### *GUI for the Joining Tables with LINQ App*

For this example (Fig. 22.24–Fig. 22.27), perform the steps in Section 22.5.2 to create a new **Windows Forms Application** project named **JoinQueries** in the same solution as the previous examples. Rename the **Form1.cs** source file to **JoiningTableData.cs**. Set the Form's **Text** property to **Joining Tables with LINQ**. Be sure to set the **JoinQueries** project as the startup project. We set the following properties for the **outputTextBox**:

- **Font** property: Set to **Lucida Console** to display the output in a fixed-width font.
- **Anchor** property: Set to **Top, Bottom, Left, Right** so that you can resize the window and the **outputTextBox** will resize accordingly.
- **Scrollbars** property: Set to **Vertical**, so that you can scroll through the output.

#### *Creating the DbContext*

The code uses the entity data model classes to combine data from the tables in the Books database and display the relationships between the authors and books in three different ways. We split the code for class **JoiningTableData** into several figures (Figs. 22.24–22.27) for presentation purposes. As in previous examples, the **DbContext** object (Fig. 22.24, lines 19–20) allows the program to interact with the database.

---

```

1 // Fig. 22.24: JoiningTableData.cs
2 // Using LINQ to perform a join and aggregate data across tables.
3 using System;
4 using System.Linq;
5 using System.Windows.Forms;
6
7 namespace JoinQueries
8 {
9     public partial class JoiningTableData : Form
10    {
11        public JoiningTableData()
12        {
13            InitializeComponent();
14        } // end constructor
15
16        private void JoiningTableData_Load(object sender, EventArgs e)
17        {
18            // Entity Framework DbContext
19            BooksExamples.BooksEntities dbcontext =
20                new BooksExamples.BooksEntities();
21

```

**Fig. 22.24** | Creating the BooksDataContext for querying the Books database.

### *Combining Author Names with the ISBNs of the Books They've Written*

The first query (Fig. 22.25, lines 24–27) *joins* data from two tables and returns a list of author names and the ISBNs representing the books they've written, sorted by LastName then FirstName. The query takes advantage of the properties in the entity data model classes that were created based on foreign-key relationships between the database's tables. These properties enable you to easily combine data from related rows in multiple tables.

---

```

22        // get authors and ISBNs of each book they co-authored
23        var authorsAndISBNs =
24            from author in dbcontext.Authors
25            from book in author.Titles
26            orderby author.LastName, author.FirstName
27            select new { author.FirstName, author.LastName, book.ISBN };
28
29        outputTextBox.AppendText( "Authors and ISBNs:" );
30
31        // display authors and ISBNs in tabular format
32        foreach (var element in authorsAndISBNs )
33        {
34            outputTextBox.AppendText(
35                String.Format( "\r\n\t{0,-10} {1,-10} {2,-10}",
36                    element.FirstName, element.LastName, element.ISBN ) );
37        } // end foreach
38

```

**Fig. 22.25** | Getting a list of authors and the ISBNs of the books they've authored.

The first `from` clause (line 24) gets each author from the `Authors` table. The second `from` clause (line 25) uses the generated `Titles` property of the `Author` class to get the ISBNs for the current author. The entity data model uses the foreign-key information stored in the database's `AuthorISBN` table to get the appropriate ISBNs. The combined result of the two `from` clauses is a collection of all the authors and the ISBNs of the books they've authored. The two `from` clauses introduce *two* range variables into the scope of this query—other clauses can access both range variables to combine data from multiple tables. Line 26 orders the results by the author's `LastName`, then `FirstName`. Line 27 creates a new anonymous type that contains the `FirstName` and `LastName` of an author from the `Authors` table with the `ISBN` of a book in the `Titles` table written by that author.

### *Anonymous Types*

As you know, anonymous types allow you to create simple classes used to store data without writing a class definition. An *anonymous type declaration* (line 27)—known formally as an *anonymous object-creation expression*—is similar to an object initializer (Section 10.13). The anonymous type declaration begins with the keyword `new` followed by a member-initializer list in braces (`{}`). No class name is specified after the `new` keyword. The compiler generates a class definition based on the anonymous object-creation expression. This class contains the properties specified in the member-initializer list—`FirstName`, `LastName` and `ISBN`. All properties of an anonymous type are `public`. Anonymous type properties are *read-only*—you cannot modify a property's value once the object is created. Each property's type is *inferred* from the values assigned to it. The class definition is generated automatically by the compiler, so you don't know the class's type name (hence the term *anonymous type*). Thus, you must use *implicitly typed local variables* to store references to objects of anonymous types (e.g., line 32). Though we are not using it here, the compiler defines a `ToString` method when creating the anonymous type's class definition. The method returns a `string` in curly braces containing a comma-separated list of `PropertyName = value` pairs. The compiler also provides an `Equals` method, which compares the properties of the anonymous object that calls the method and the anonymous object that it receives as an argument.

### *Combining Author Names with the Titles of the Books They've Written*

The second query (Fig. 22.26, lines 41–45) gives similar output, but uses the foreign-key relationships to get the title of each book that an author wrote.

---

```

39      // get authors and titles of each book they co-authored
40      var authorsAndTitles =
41          from book in dbcontext.Titles
42          from author in book.Authors
43          orderby author.LastName, author.FirstName, book.Title1
44          select new { author.FirstName, author.LastName,
45              book.Title1 };
46
47      outputTextBox.AppendText( "\r\n\r\nAuthors and titles:" );
48
49      // display authors and titles in tabular format
50      foreach ( var element in authorsAndTitles )
51      {

```

---

**Fig. 22.26** | Getting a list of authors and the titles of the books they've authored. (Part 1 of 2.)

---

```

52         outputTextBox.AppendText(
53             String.Format( "\r\n\t{0,-10} {1,-10} {2}",
54                 element.FirstName, element.LastName, element.Title1 ) );
55     } // end foreach
56

```

**Fig. 22.26** | Getting a list of authors and the titles of the books they've authored. (Part 2 of 2.)

The first `from` clause (line 41) gets each book from the `Titles` table. The second `from` clause (line 42) uses the generated `Authors` property of the `Title` class to get only the authors for the current book. The entity data model uses the foreign-key information stored in the database's `AuthorISBN` table to get the appropriate authors. The `author` objects give us access to the names of the current book's authors. The `select` clause (lines 44–45) uses the `author` and `book` range variables introduced earlier in the query to get the `FirstName` and `LastName` of each author from the `Authors` table and the title of each book from the `Titles` table.

### Organizing Book Titles by Author

Most queries return results with data arranged in a relational-style table of rows and columns. The last query (Fig. 22.27, lines 60–66) returns hierarchical results. Each element in the results contains the name of an `Author` and a list of `Titles` that the author wrote. The LINQ query does this by using a *nested query* in the `select` clause. The outer query iterates over the authors in the database. The inner query takes a specific author and retrieves all titles that the author wrote. The `select` clause (lines 62–66) creates an anonymous type with two properties:

- The property `Name` (line 62) combines each author's name, separating the first and last names by a space.
- The property `Titles` (line 63) receives the result of the nested query, which returns the title of each book written by the current author.

In this case, we're providing names for each property in the new anonymous type. When you create an anonymous type, you can specify the name for each property by using the format `name = value`.

---

```

57         // get authors and titles of each book
58         // they co-authored; group by author
59         var titlesByAuthor =
60             from author in dbcontext.Authors
61             orderby author.LastName, author.FirstName
62             select new { Name = author.FirstName + " " + author.LastName,
63                         Titles =
64                             from book in author.Titles
65                             orderby book.Title1
66                             select book.Title1 };
67
68         outputTextBox.AppendText( "\r\n\r\nTitles grouped by author:" );
69

```

**Fig. 22.27** | Getting a list of titles grouped by authors. (Part 1 of 2.)

```

70         // display titles written by each author, grouped by author
71         foreach ( var author in titlesByAuthor )
72     {
73             // display author's name
74             outputTextBox.AppendText( "\r\n\t" + author.Name + ":" );
75
76             // display titles written by that author
77             foreach ( var title in author.Titles )
78             {
79                 outputTextBox.AppendText( "\r\n\t\t" + title );
80             } // end inner foreach
81         } // end outer foreach
82     } // end method JoiningTableData_Load
83 } // end class JoiningTableData
84 } // end namespace JoinQueries

```

**Fig. 22.27** | Getting a list of titles grouped by authors. (Part 2 of 2.)

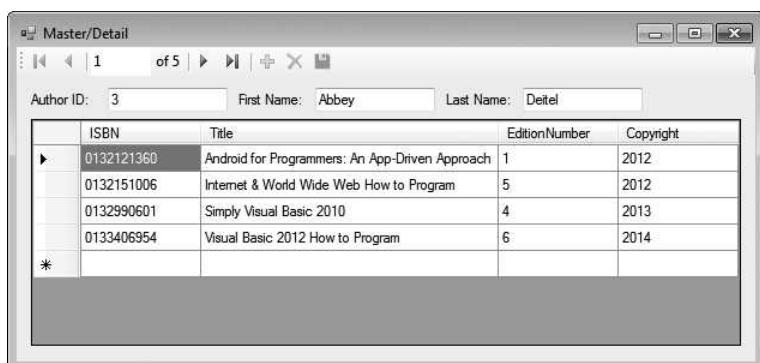
The range variable `book` in the nested query iterates over the current author's books using in the `Titles` property. The `Title1` property of a given book returns the `Title` column from that row of the `Titles` table in the database.

The nested `foreach` statements (lines 71–81) use the properties of the anonymous type created by the query to output the hierarchical results. The outer loop displays the author's name and the inner loop displays the titles of all the books written by that author.

## 22.8 Creating a Master/Detail View App

Figure 22.28 demonstrates a so-called **master/detail** view—one part of the GUI (the master) allows you to select an entry, and another part (the details) displays detailed information about that entry. When the app first loads, it displays the name of the first author in the data source and that author's books (Fig. 22.28(a)). When you use the buttons on the `BindingNavigator` to change authors, the app displays the details of the books written by the corresponding author (Fig. 22.28(b)). This app only reads data from the entity data model, so we disabled the buttons in the `BindingNavigator` that enable the user to add and delete records.

a) Master/Detail app displaying books for the first author in the data source



**Fig. 22.28** | Master/Detail app. (Part 1 of 2.)

- b) Master/Detail app displaying books for the third author in the data source

The screenshot shows a Windows application window titled "Master/Detail". At the top, there is a "BindingNavigator" with buttons for navigating between rows. Below it is a search bar with fields for "Author ID" (set to 1), "First Name" (set to Paul), and "Last Name" (set to Deitel). The main area is a "DataGridView" displaying a list of books. The columns are labeled "ISBN", "Title", "EditionNumber", and "Copyright". The data in the grid is as follows:

ISBN	Title	EditionNumber	Copyright
0132121360	Android for Programmers: An App-Driven Approach	1	2012
0132151006	Internet & World Wide Web How to Program	5	2012
0132575663	Java How to Program	9	2012
013299044X	C How to Program	7	2013
0132990601	Simply Visual Basic 2010	4	2013
0133378713	C++ How to Program	9	2014
0133379337	Visual C# 2012 How to Program	5	2014
0133406954	Visual Basic 2012 How to Program	6	2014
0136151574	Visual C++ 2008 How to Program	2	2008
*			

**Fig. 22.28 |** Master/Detail app. (Part 2 of 2.)

When you run the app, experiment with the `BindingNavigator`'s controls. The DVD-player-like buttons of the `BindingNavigator` allow you to change the currently displayed row.

### 22.8.1 Creating the Master/Detail GUI

You've seen that the IDE can automatically generate the `BindingSource`, `BindingNavigator` and GUI elements when you drag a data source onto the Form. You'll now use two `BindingSources`—one for the master list of authors and one for the titles associated with a given author. Both will be generated by the IDE.

#### *Step 1: Creating the Project*

Follow the instructions in Section 22.5.2 to create and configure a new **Windows Forms Application** project called `MasterDetail1`. Name the source file `Details.cs` and set the Form's `Text` property to **Master/Detail**.

#### *Step 2: Adding a Data Source for the Authors Table*

Follow the steps in Section 22.5.3 to add a data source for the `Authors` table. Although you'll be displaying records from the `Titles` table for each author, you do not need to add a data source for that table. The title information will be obtained from the `Titles` navigation property in the `Author` entity data model class.

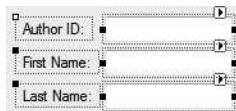
#### *Step 3: Creating GUI Elements*

Next, you'll use the **Design** view to create the GUI components by dragging-and-dropping items from the **Data Sources** window onto the Form. In the earlier sections, you dragged an object from the **Data Sources** window to the Form to create a `DataGridView`. The IDE allows you to specify the type of control(s) that it will create when you drag and drop an object from the **Data Sources** window onto a Form. To do so:

1. Switch to **Design** view for the `Details` class.
2. Click the **Author** node in the **Data Sources** window—it should change to a drop-down list. Open the drop-down by clicking the down arrow and select the **Details**

option—this indicates that we'd like to generate Label–TextBox pairs that represent each column of the Authors table.

3. Drag the **Author** node from the **Data Sources** window onto the **Form** in **Design** view. This creates the **authorBindingSource**, the **authorBindingNavigator** and the Label–TextBox pairs that represent each column in the table. Initially, the controls appear as shown in Fig. 22.29. We rearranged the controls as shown in Fig. 22.28.



**Fig. 22.29** | Details representation of an Author.

4. By default, the **Titles** navigation property is implemented in the entity data model classes as a `HashSet<Title>`. To bind the data to GUI controls properly, you must change this to an `ObservableCollection<Title>`. To do this, expand the class library project's `BooksModel.edmx` node in the **Solution Explorer**, then expand the `BooksModel.tt` node and open `Author.cs` in the editor. Add a `using` statement for the namespace `System.Collections.ObjectModel`. Then, in the `Author` constructor change `HashSet` to `ObservableCollection`. Right click the class library project in the **Solution Explorer** and select **Build** to recompile the class.
5. Next, click the **Titles** node that's nested in the **Author** node in the **Data Sources** window—it should change to a drop-down list. Open the drop-down by clicking the down arrow and ensure that the **DataGridView** option is selected—this is the GUI control that will be used to display the data from the **Titles** table that corresponds to a given author.
6. Drag the **Titles** node onto the **Form** in **Design** view. This creates the **titlesBindingSource** and the **DataGridView**. This control is only for *viewing* data, so set its **ReadOnly** property to **True** using the **Properties** window. Because we dragged the **Titles** node from the **Author** node in the **Data Sources** window, the **DataGridView** will automatically display the books for the currently selected author once we bind the author data to the **authorBindingSource**.

We used the **DataGridView**'s **Anchor** property to anchor it to all four sides of the **Form**. We also set the **Form**'s **Size** and **MinimumSize** properties to **550, 300** to set the **Form**'s initial size and minimum size, respectively. The completed GUI is shown in Fig. 22.30.

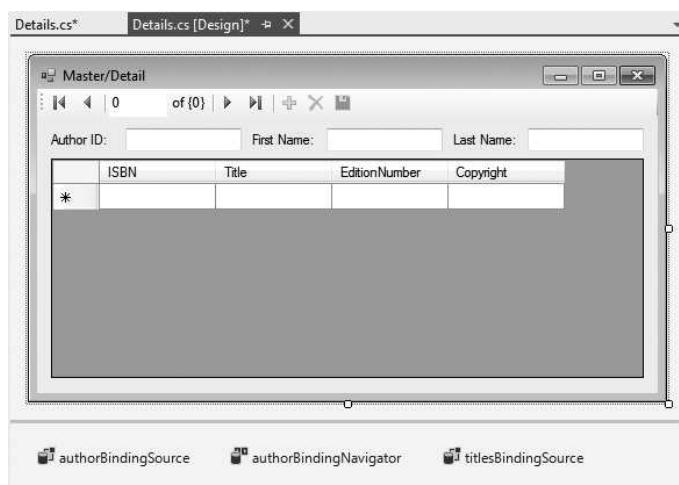
## 22.8.2 Coding the Master/Detail App

The code to display an author and the corresponding books (Fig. 22.31) is straightforward. Lines 17–18 create the `DbContext`. The **Form**'s **Load** event handler (lines 22–32) orders the `Author` objects by `LastName` (line 26) and `FirstName` (line 27), then loads them into memory (line 28). Next, line 31 assigns `dbcontext.Authors.Local` to the `authorBindingSource`'s **DataSource** property. At this point:

- the `BindingNavigator` displays the number of `Author` objects and indicates that the first one in the results is selected,

- the TextBoxes display the currently selected Author's AuthorID, FirstName and LastName property values, and
- the currently selected Author's titles are automatically assigned to the titlesBindingSource's DataSource, which causes the DataGridView to display those titles.

Now, when you use the BindingNavigator to change the selected Author, the corresponding titles are displayed in the DataGridView.



**Fig. 22.30** | Finished design of the **Master/Detail** app.

```

1 // Fig. 22.31: Details.cs
2 // Using a DataGridView to display details based on a selection.
3 using System;
4 using System.Data.Entity;
5 using System.Linq;
6 using System.Windows.Forms;
7
8 namespace MasterDetail
9 {
10     public partial class Details : Form
11     {
12         public Details()
13         {
14             InitializeComponent();
15         } // end constructor
16
17         // Entity Framework DbContext
18         BooksExamples.BooksEntities dbcontext =
19             new BooksExamples.BooksEntities();
20 }
```

**Fig. 22.31** | Using a DataGridView to display details based on a selection. (Part 1 of 2.)

```

21      // initialize data sources when the Form is loaded
22      private void Details_Load( object sender, EventArgs e )
23      {
24          // load Authors table ordered by LastName then FirstName
25          dbcontext.Authors
26              .OrderBy( author => author.LastName )
27              .ThenBy( author => author.FirstName )
28              .Load();
29
30          // specify DataSource for authorBindingSource
31          authorBindingSource.DataSource = dbcontext.Authors.Local;
32      } // end method Details_Load
33  } // end class Details
34 } // end namespace MasterDetail

```

**Fig. 22.31** | Using a DataGridView to display details based on a selection. (Part 2 of 2.)

## 22.9 Address Book Case Study

Our final example (Fig. 22.32) implements a simple AddressBook app that enables users to perform the following tasks on the database `AddressBook.mdf` (which is included in the directory with this chapter's examples):

- Insert new contacts
- Find contacts whose last names begin with the specified letters
- Update existing contacts
- Delete contacts

We populated the database with six fictional contacts.

Rather than displaying a database table in a `DataGridView`, this app presents the details of one contact at a time in several `TextBoxes`. The `BindingNavigator` at the top of the window allows you to control which *row* of the table is displayed at any given time. The `BindingNavigator` also allows you to *add* a contact and *delete* a contact—but only

- a) Use the `BindingNavigator`'s controls to navigate through the contacts in the database



**Fig. 22.32** | Manipulating an address book. (Part 1 of 2.)

b) Type a search **string** in the **Last Name:** **TextBox** then press **Find** to locate contacts whose last names begin with that **string**; only two names start with “Br” so the **BindingNavigator** indicates two matching records



Displaying the first of two matching contacts for the current search

c) Click **Browse All Entries** to clear the search **string** and allow browsing of all contacts in the database



You can now browse through all six contacts

**Fig. 22.32** | Manipulating an address book. (Part 2 of 2.)

when browsing the *complete* contact list. When you filter the contacts by last name, the app disables the **Add new** (+) and **Delete** (X) buttons (we'll explain why shortly). Clicking **Browse All Entries** enables these buttons again. Adding a row clears the **TextBoxes** and sets the **TextBox** to the right of **Address ID** to zero to indicate that the **TextBoxes** now represent a new record. When you save a new entry, the **Address ID** field is automatically changed from zero to a unique ID number by the database. No changes are made to the underlying database unless you click the **Save Data** (■) button.

### 22.9.1 Creating the Address Book App's GUI

We discuss the app's code momentarily. First you'll set up the entity data model and a Windows Forms app.

#### Step 1: Creating a Class Library Project for the Entity Data Model

Perform the steps in Section 22.5.1 to create a **Class Library** project named **AddressExample** that contains an entity data model for the **AddressBook.mdf** database, which contains only an **Addresses** table with **AddressID**, **FirstName**, **Last Name**, **Email** and **PhoneNumber** columns. Name the entity data model **AddressModel.edmx**. The **AddressBook.mdf** database is located in the **Databases** folder with this chapter's examples.

**Step 2: Creating a Windows Forms Application Project for AddressBook App**

Perform the steps in Section 22.5.2 to create a new Windows Forms Application project named AddressBook in the AddressExample solution. Set the Form's filename to `Contacts.cs`, then set the Form's `Text` property to Address Book. Set the AddressBook project as the solution's startup project.

**Step 3: Adding the Address Object as a Data Source**

Add the entity data model's `Address` object as a data source, as you did with the `Author` object in *Step 1* of Section 22.5.3.

**Step 4: Displaying the Details of Each Row**

In Design view, select the `Address` node in the **Data Sources** window. Click the `Address` node's down arrow and select the **Details** option to indicate that the IDE should create a set of Label–`TextBox` pairs to show the details of a single record at a time.

**Step 5: Dragging the Address Data-Source Node to the Form**

Drag the `Address` node from the **Data Sources** window to the Form. This automatically creates a `BindingNavigator` and the Labels and `TextBoxes` corresponding to the columns of the database table. The fields are placed in alphabetical order. Reorder the components, using **Design** view, so they're in the order shown in Fig. 22.32. You'll also want to change the tab order of the controls. To do so, select **VIEW > Tab Order** then click the `TextBoxes` from top to bottom in the order they appear in Fig. 22.32.

**Step 5: Making the AddressID TextBox ReadOnly**

The `AddressID` column of the `Addresses` table is an *autoincremented identity column*, so users should *not* be allowed to edit the values in this column. Select the `TextBox` for the `AddressID` and set its `ReadOnly` property to `True` using the **Properties** window.

**Step 6: Adding Controls to Allow Users to Specify a Last Name to Locate**

While the `BindingNavigator` allows you to browse the address book, it would be more convenient to be able to find a specific entry by last name. To add this functionality to the app, we must create controls to allow the user to enter a last name and provide event handlers to perform the search.

Add a `Label` named `findLabel`, a `TextBox` named `findTextBox`, and a `Button` named `findButton`. Place these controls in a `GroupBox` named `findGroupBox`, then set its `Text` property to **Find an entry by last name**. Set the `Text` property of the `Label` to **Last Name:** and set the `Text` property of the `Button` to **Find**.

**Step 7: Allowing the User to Return to Browsing All Rows of the Database**

To allow users to return to browsing all the contacts after searching for contacts with a specific last name, add a `Button` named `browseAllButton` below the `findGroupBox`. Set the `Text` property of `browseAllButton` to **Browse All Entries**.

## 22.9.2 Coding the Address Book App

The `Contacts.cs` code-behind file is split into several figures (Figs. 22.33–22.37) for presentation purposes.

**Method RefreshContacts**

As we showed in previous examples, we must connect the `addressBindingSource` that controls the GUI with the `DbContext` that interacts with the database. In this example, we declare the `AddressEntities` `DbContext` object at line 20 of Fig. 22.33, but create it and initiate the data binding in the `RefreshContacts` method (lines 23–43), which is called from several other methods in the app. When this method is called, if `dbcontext` is not `null`, we call its `Dispose` method, then create a new `AddressEntities` `DbContext` at line 30. We do this so we can re-sort the data in the entity data model. If we maintained one `dbcontext.Addresses` object in memory for the duration of the program and the user changed a person's last name or first name, the records would still remain in their original order in the `dbcontext.Addresses` object, even if that order is incorrect. Lines 34–37 order the `Address` objects by `LastName`, then `FirstName` and load the objects into memory. Then line 40 sets the `addressBindingSource`'s `DataSource` property to `dbcontext.Addresses.Local` to bind the data in memory to the GUI.

---

```

1 // Fig. 22.33: Contact.cs
2 // Manipulating an address book.
3 using System;
4 using System.Data;
5 using System.Data.Entity;
6 using System.Data.Entity.Validation;
7 using System.Linq;
8 using System.Windows.Forms;
9
10 namespace AddressBook
11 {
12     public partial class Contacts : Form
13     {
14         public Contacts()
15         {
16             InitializeComponent();
17         } // end constructor
18
19         // Entity Framework DbContext
20         private AddressExample.AddressBookEntities dbcontext = null;
21
22         // fill our addressBindingSource with all rows, ordered by name
23         private void RefreshContacts()
24         {
25             // Dispose old DbContext, if any
26             if ( dbcontext != null )
27                 dbcontext.Dispose();
28
29             // create new DbContext so we can reorder records based on edits
30             dbcontext = new AddressExample.AddressBookEntities();
31
32             // use LINQ to order the Addresses table contents
33             // by last name, then first name

```

**Fig. 22.33** | Creating the `BooksDataContext` and defining method `RefreshContacts` for use in other methods. (Part I of 2.)

---

```

34     dbcontext.Addresses
35         .OrderBy( entry => entry.LastName )
36         .ThenBy( entry => entry.FirstName )
37         .Load();
38
39     // specify DataSource for addressBindingSource
40     addressBindingSource.DataSource = dbcontext.Addresses.Local;
41     addressBindingSource.MoveFirst(); // go to first result
42     findTextBox.Clear(); // clear the Find TextBox
43 } // end method RefreshContacts
44

```

---

**Fig. 22.33** | Creating the BooksDataContext and defining method RefreshContacts for use in other methods. (Part 2 of 2.)

#### **Method Contacts\_Load**

Method Contacts\_Load (Fig. 22.34) calls RefreshContacts (line 48) so that the first record is displayed when the app starts. As before, you create the Load event handler by double clicking the Form's title bar.

---

```

45     // when the form loads, fill it with data from the database
46     private void Contacts_Load( object sender, EventArgs e )
47     {
48         RefreshContacts(); // fill binding with data from database
49     } // end method Contacts_Load
50

```

---

**Fig. 22.34** | Calling RefreshContacts to fill the TextBoxes when the app loads.

#### **Method addressBindingNavigatorSaveItem\_Click**

Method addressBindingNavigatorSaveItem\_Click (Fig. 22.35) saves the changes to the database when the BindingNavigator's Save Data Button is clicked. (Remember to enable this button.) The AddressBook database requires values for the first name, last name, phone number and e-mail. If a field is empty when you attempt to save, a DbEntityValidationException exception occurs. We call RefreshContacts after saving to re-sort the data and move back to the first element.

---

```

51     // Click event handler for the Save Button in the
52     // BindingNavigator saves the changes made to the data
53     private void addressBindingNavigatorSaveItem_Click(
54         object sender, EventArgs e )
55     {
56         Validate(); // validate input fields
57         addressBindingSource.EndEdit(); // complete current edit, if any
58
59         // try to save changes
60         try
61         {

```

---

**Fig. 22.35** | Saving changes to the database when the user clicks **Save Data**. (Part 1 of 2.)

---

```

62         dbContext.SaveChanges(); // write changes to database file
63     } // end try
64     catch ( DbEntityValidationException )
65     {
66         MessageBox.Show( "Columns cannot be empty",
67                         "Entity Validation Exception" );
68     } // end catch
69
70     RefreshContacts(); // change back to initial unfiltered data
71 } // end method addressBindingNavigatorSaveItem_Click
72

```

---

**Fig. 22.35** | Saving changes to the database when the user clicks **Save Data**. (Part 2 of 2.)

#### Method **findButton\_Click**

Method `findButton_Click` (Fig. 22.36) uses LINQ query syntax (lines 79–83) to select only people whose last names start with the characters in the `findTextBox`. The query sorts the results by last name then first name. In LINQ to Entities, you *cannot* bind a LINQ query's results directly to a `BindingSource`'s `DataSource`. So, line 86 calls the query object's `ToList` method to get a `List` representation of the filtered data and assigns the `List` to the `BindingSource`'s `DataSource`. When you convert the query result to a `List`, only changes to *existing* records in the `DbContext` are tracked by the `DbContext`—any records that you add or remove while viewing the filtered data would be lost. For this reason we disabled the **Add new** and **Delete** buttons when the data is filtered. When you enter a last name and click **Find**, the `BindingNavigator` allows the user to browse only the rows containing the matching last names. This is because the data source bound to the Form's controls (the result of the LINQ query) has changed and now contains only a limited number of rows.

---

```

73     // use LINQ to create a data source that contains only people
74     // with last names that start with the specified text
75     private void findButton_Click( object sender, EventArgs e )
76     {
77         // use LINQ to filter contacts with last names that
78         // start with findTextBox contents
79         var lastNameQuery =
80             from address in dbContext.Addresses
81             where address.LastName.StartsWith( findTextBox.Text )
82             orderby address.LastName, address.FirstName
83             select address;
84
85         // display matching contacts
86         addressBindingSource.DataSource = lastNameQuery.ToList();
87         addressBindingSource.MoveFirst(); // go to first result
88
89         // don't allow add/delete when contacts are filtered
90         bindingNavigatorAddNewItem.Enabled = false;
91         bindingNavigatorDeleteItem.Enabled = false;
92     } // end method findButton_Click
93

```

---

**Fig. 22.36** | Finding the contacts whose last names begin with a specified `String`.

***Method browseAllButton\_Click***

Method `browseAllButton_Click` (Fig. 22.37) allows users to return to browsing all the rows after searching for specific rows. Double click `browseAllButton` to create a Click event handler. The event handler enables the `Add new` and `Delete` buttons then calls `RefreshContacts` to restore the data source to the full list of people (in sorted order) and clear the `findTextBox`.

---

```

94      // reload addressBindingSource with all rows
95      private void browseAllButton_Click( object sender, EventArgs e )
96      {
97          // allow add/delete when contacts are not filtered
98          bindingNavigatorAddNewItem.Enabled = true;
99          bindingNavigatorDeleteItem.Enabled = true;
100         RefreshContacts(); // change back to initial unfiltered data
101     } // end method browseButton_Click
102 } // end class Contacts
103 } // end namespace AddressBook

```

---

**Fig. 22.37** | Allowing the user to browse all contacts.

## 22.10 Tools and Web Resources

Our LINQ Resource Center at [www.deitel.com/LINQ](http://www.deitel.com/LINQ) contains many links to additional information, including blogs by Microsoft LINQ team members, sample chapters, tutorials, videos, downloads, FAQs, forums, webcasts and other resource sites.

A useful tool for learning LINQ is LINQPad ([www.linqpad.net](http://www.linqpad.net)), which allows you to execute and view the results of any C# or Visual Basic expression, including LINQ queries. It also supports the ADO.NET Entity Framework and LINQ to Entities.

This chapter is meant as an introduction to databases, the ADO.NET Entity Framework and LINQ to Entities. Microsoft's Entity Framework site

[msdn.microsoft.com/en-us/data/aa937723](http://msdn.microsoft.com/en-us/data/aa937723)

provides lots of additional information on working with the ADO.NET Entity Framework and LINQ to Entities, including tutorials, videos and more.

## 22.11 Wrap-Up

This chapter introduced the relational database model, the ADO.NET Entity Framework, LINQ to Entities and the Visual Studio 2012's visual programming tools for working with databases. You examined the contents of a simple Books database and learned about the relationships among the tables in the database. You used LINQ to Entities and the entity data model classes generated by the IDE to retrieve data from, add new data to, delete data from and update data in a SQL Server Express database.

We discussed the entity data model classes automatically generated by the IDE, such as the `DbContext` class that manages an app's interactions with a database. You learned how to use the IDE's tools to connect to databases and to generate entity data model classes based on an existing database's schema. You then used the IDE's drag-and-drop capabilities to automatically generate GUIs for displaying and manipulating database data.

In the next chapter, we demonstrate how to build web apps using Microsoft's ASP.NET web forms technology, which is similar similar to building Windows Forms apps, but in the context of web pages. We introduce the concept of a three-tier app, which is divided into three pieces that can reside on the same computer or be distributed among separate computers across a network such as the Internet. One of these tiers—the information tier—typically stores data in a database.

---

## Summary

### *Section 22.1 Introduction*

- A database is an organized collection of data.
- A database management system (DBMS) provides mechanisms for storing, organizing, retrieving and modifying data.
- SQL Server Express provides most of the features of Microsoft's full (fee-based) SQL Server product, but has some limitations, such as a maximum database size.
- A SQL Server Express database can be easily migrated to a full version of SQL Server.
- The ADO.NET Entity Framework and LINQ to Entities allow you to manipulate relational data stored in a relational database, such as a SQL Server Express database.

### *Section 22.2 Relational Databases*

- A relational database organizes data simply in tables.
- Tables are composed of rows and columns (also called fields) in which values are stored.
- A column (or group of columns) of each row is the table's primary key—a column (or group of columns) requiring a unique value that cannot be duplicated in other rows. This guarantees that a primary key value can be used to uniquely identify a row.
- A primary key composed of two or more columns is known as a composite key.
- Each column represents a different data attribute.
- Rows are unique (by primary key) within a table, but some column values may be duplicated between rows.

### *Section 22.3 A Books Database*

- A database's tables, their fields and the relationships between them are collectively known as a database schema.
- A foreign key is a column in one table that matches the primary-key column in another table.
- Foreign keys, which are specified when a database table is created, link the data in multiple tables.
- Every foreign-key value must appear as another table's primary-key value so the DBMS can ensure that the foreign-key value is valid.
- Foreign keys also allow related data in multiple tables to be selected from those tables—this is known as joining the data.
- There's a one-to-many relationship between a primary key and a corresponding foreign key—a foreign key can appear many times in its own table but only once (as the primary key) in another table.
- An entity-relationship (ER) diagram shows the tables in a database and their relationships.
- Every row must have a value in the primary-key column, and the value of the key must be unique in the table.

### **Section 22.4 LINQ to Entities and the ADO.NET Entity Framework**

- With the ADO.NET Entity Framework, you interact with the database via classes that the IDE generates from the database schema when you add a new ADO.NET Entity Data Model to your project.
- The IDE creates two classes for a table. The first class represents a row of the table and contains properties for each table column. Objects of this class are called row objects and store the data from individual rows of the table. The IDE uses the singular version of a table's plural name as the row class's name. The second class represents the table itself. An object of this class stores a collection of row objects that correspond to all of the rows in the table.
- The entity data model classes have full *IntelliSense* support in the IDE.
- Navigation properties in row classes represent the relationships between tables.
- A `DbContext` (namespace `System.Data.Entity`) manages the data flow between the program and the database. When the IDE generates the entity data model's row and table classes, it also creates a derived class of `DbContext` that is specific to the database being manipulated. This class contains properties that represent the database's tables. These can be used as data sources for manipulating data in LINQ queries and in GUIs.
- Changes made to the data managed by a `DbContext` can be saved back to the database using the `DbContext`'s `SaveChanges` method.
- LINQ to Entities works through the `IQueryable<T>` interface, which inherits from the interface `IEnumerable<T>`. When a LINQ to Entities query on an `IQueryable<T>` object executes against the database, the results are loaded into objects of the corresponding entity data model classes for convenient access in your code.
- The extension methods used with LINQ to Entities are defined as `static` methods of class `Queryable` (namespace `System.Linq`) and can be applied to any object that implements the `IQueryable<T>` interface—these include various entity data model objects and the results of LINQ to Entities queries.

### **Section 22.5 Querying a Database with LINQ**

- The IDE provides visual programming tools and wizards that simplify accessing data in your projects. These tools establish database connections and create the objects necessary to view and manipulate the data through the GUI—a technique known as data binding.
- A `DataGridView` (namespace `System.Windows.Forms`) displays data from a data source in tabular format.
- A `BindingNavigator` is a collection of controls that allow you to navigate through the records displayed in a GUI. The `BindingNavigator` controls also allow you to add records, delete records and save your changes to the database.

#### **Section 22.5.1 Creating the ADO.NET Entity Data Model Class Library**

- An entity data model describes as C# classes the data that you'll be manipulating.
- To interact with a database, you add an ADO.NET entity data model to the project (typically a class library project for reuse). This will also configure the connection to the database.
- The ADO.NET entity data model's `.edmx` file contains information about the entity data model.
- When configuring the model, you create a connection to the database and choose the model's contents from the database.
- The entity connection string contains the information that the ADO.NET Entity Framework requires to connect to the database at runtime.
- SQL Server Express allows only one program at a time to connect to a database file.

- The entity data model diagram contains the selected database objects and shows the relationships between them.

### *Section 22.5.2 Creating a Windows Forms Project and Configuring It to Use the Entity Data Model*

- To use the entity data model classes from a class library for data binding, you must first add a reference to the class library to your project. You'll also need to add references to the `System.Data.Entity` and `EntityFramework` libraries.
- The `EntityFramework` library is added by the IDE when you create the entity data model, but it's also required in each app that will use the entity data model. To add a reference to the `EntityFramework` library: Right click the solution name in the **Solution Explorer** and select **Manage NuGet Packages for Solution...** to display the **Manage NuGet Packages** dialog. In the dialog that appears, click **Manage** to display the **Select Projects** dialog, then select your project project and click **OK**. Click **Close** to close the **Manage NuGet Packages** dialog.
- Each app that will use an entity data model also requires the connection string that tells the Entity Framework how to connect to the database. The connection string is stored in the `App.Config` file of the project in which the entity data model is defined and must be copied into the `App.Config` file of the project that uses the entity data model.

### *Section 22.5.3 Data Bindings Between Controls and the Entity Data Model*

- You must write code to enable the autogenerated GUI to interact with the entity data model.
- To use the entity data model classes for data binding, you must first add them as a data source.
- Select **VIEW > Other Windows > Data Sources** to display the **Data Sources** window at the left side of the IDE, then in that window click the **Add New Data Source...** link to display the **Data Source Configuration Wizard**. The entity data model classes are used to create objects representing the tables in the database, so use an **Object** data source. Select the object(s) you need from the model and click **Finish**. You can now drag the data source objects onto the **Form** in **Design** view to generate a GUI.
- The default GUI for a table is a `DataGridView` with column names representing all the properties of the data source object. The IDE also creates a `BindingNavigator` that contains Buttons for moving between entries, adding entries, deleting entries and saving changes to the database. The IDE also generates a `BindingSource`, which handles the transfer of data between the data source and the data-bound controls on the **Form**.
- Nonvisual components such as the `BindingSource` and the non-visual aspects of the `BindingNavigator` appear in the component tray—the gray region below the **Form** in **Design** view.
- The IDE names the `BindingNavigator` and `BindingSource` based on the data source's name.
- To edit the columns displayed in a `DataGridView`, select it, then click **Edit Columns...** in the **Properties** window to display the **Edit Columns** dialog.
- To complete the data binding, you must create an object of the entity data model's `DbContext` derived class and use it to obtain data.
- The `OrderBy` extension method orders rows in ascending order by the property specified in its lambda expression argument.
- A lambda expression represents an anonymous function. It begins with a parameter list. The lambda expression infers the lambda parameter's type. The parameter list is followed by the `=>` lambda operator (read as “goes to”) and an expression that represents the body of the function.

The value produced by the expression is implicitly returned by the lambda expression. The return type is inferred from the return value.

- The `ThenBy` extension method enables you to order results by an additional column.
- The `Load` extension method (defined in class `DBExtensions` from the namespace `System.Data.Entity`) loads data into memory. This data is tracked by the `DbContext` in local memory so that any changes made to the data can eventually be saved into the database.
- The `Local` property of a `DbContext` property is an `ObservableCollection<Author>` that represents the data in memory.
- When a `BindingSource`'s `DataSource` property is assigned an `ObservableCollection<T>` (namespace `System.Collections.ObjectModel`), the GUI that's bound to the `BindingSource` is notified of any changes to the data so the GUI can be updated accordingly. In addition, changes made by the user to the data in the GUI will be tracked so the `DbContext` can eventually save those changes to the database.
- Calling `EndEdit` on the `BindingSource` forces it to save any pending changes into the `DbContext` model in memory.
- Calling `SaveChanges` on the `DbContext` object stores any changes into the database.

### ***Section 22.6 Dynamically Binding Query Results***

- The data bindings created by the IDE automatically update a `DataGridView` each time its `BindingSource`'s `DataSource` changes.
- The `MoveFirst` method of the `BindingSource` moves to the first row of the data source.
- When you invoke `OrderBy` on an `ObservableCollection<T>`, the method returns an `IEnumerable<T>`.
- A lambda expression that's used with the `Where` extension method must return a `bool` value.

### ***Section 22.7 Retrieving Data from Multiple Tables with LINQ***

- To join data from multiple tables you use the properties that the entity data model contains based on foreign-key relationships between the database's tables. These properties enable you to easily access related rows in other tables.
- Most queries return result with data arranged in relational-style rows and columns. With LINQ to Entities you can create queries that return hierarchical results in which each item in the result contains a collection of other items.
- Use anonymous types to create simple classes used to store data without writing a class definition.
- An anonymous type declaration—also called an anonymous object-creation expression—begins with the keyword `new` followed by a member-initializer list.
- The compiler generates a new class definition based on the anonymous object-creation expression, containing the properties specified in the member-initializer list.
- All properties of an anonymous type are `public`.
- Properties of anonymous types are read-only.
- Each property's type is inferred from the value assigned to it.
- Objects of anonymous types are stored in implicitly typed local variables.
- The compiler defines the `ToString` method when creating the anonymous type's class definition. The method returns a `string` of comma-separated `PropertyName = value` pairs in curly braces.
- The `Equals` method, generated for any anonymous type, compares the properties of the anonymous object that calls the method and the anonymous object that it receives as an argument.

### Section 22.8 Creating a Master/Detail View App

- In a master/detail view, one part of the GUI (the master) allows you to select an entry, and another part (the details) displays detailed information about that entry.
- The IDE allows you to specify the type of control(s) that it will create when you drag and drop an object from the **Data Sources** window onto a Form. To do so, click a data source object's node in the **Data Sources** window—it should change to a drop-down list from which you can select the controls to use on the GUI. The **Details** option indicates that the IDE should generate **Label**–**TextBox** pairs that represent each column of the data source object.
- Dragging a navigation property from a data source object in the **Data Sources** window creates a **BindingSource** and a GUI for the items in another table that are associated with the data source object. The items in this second **BindingSource** will automatically update based on the currently selected master object.

### Section 22.9 Address Book Case Study

- If the data in the **DbContext** needs to be reordered, you'll need to call **Dispose** on the existing one, then create a new **DbContext**.
- You cannot bind a LINQ to Entities query's results directly to a **BindingSource**'s **DataSource**.
- When you convert a query result to a **List**, only changes to existing records in the **DbContext** are tracked by the **DbContext**—any records that you add or remove while viewing the filtered data in a **List** would be lost.

## Terminology

ADO.NET Entity Framework	lambda expression
anonymous method	lambda operator =>
autoincremented database column	LINQ to Entities
<b>BindingNavigator</b> class	Load extension method of class <b>DBExtensions</b>
<b>BindingSource</b> class	many-to-many relationship
column of a database table	master/detail view
composite key	Microsoft SQL Server Express
connection to a database	<b>MoveFirst</b> method of class <b>BindingSource</b>
data binding	navigation property
<b>Data Sources</b> window	<b>Object</b> data source
<b>Data Source Configuration Wizard</b> window	<b>ObservableCollection&lt;T&gt;</b> class
database	one-to-many relationship
database management system (DBMS)	<b>OrderBy</b> extension method of class <b>Queryable</b>
database schema	primary key
database table	query
<b>DataGridView</b> class	<b>Queryable</b> class
<b>DataSource</b> property of class <b>BindingSource</b>	relational database
<b>DbContext</b> class	row object
<b>Edit</b> method of class <b>BindingSource</b>	row of a database table
entity data model	<b>SaveChanges</b> method of a <b>DbContext</b>
entity-relationship (ER) diagram	smart tag menu
<b>Enumerable</b> class	Structured Query Language (SQL)
field in a database table	<b>System.Data.Entity</b>
foreign key	table in a database
identity column in a database table	<b>ThenBy</b> extension method of class <b>Queryable</b>
<b>IQueryable&lt;T&gt;</b> interface	<b>Where</b> extension method of class <b>Queryable</b>
joining database tables	

## Self-Review Exercises

**22.1** Fill in the blanks in each of the following statements:

- A table in a relational database consists of \_\_\_\_\_ and \_\_\_\_\_ in which values are stored.
- The \_\_\_\_\_ uniquely identifies each row in a relational database table.
- A relational database can be manipulated with the ADO.NET Entity Framework via an object of a derived class of \_\_\_\_\_, which contains properties for accessing each table in the database.
- The \_\_\_\_\_ control (presented in this chapter) displays data in rows and columns that correspond to the rows and columns of a data source.
- Merging data from multiple relational database tables is called \_\_\_\_\_ the data.
- A(n) \_\_\_\_\_ is a column (or group of columns) in a relational database table that matches the primary-key column (or group of columns) in another table.
- A(n) \_\_\_\_\_ object serves as an intermediary between a data source and its corresponding data-bound GUI control.
- The \_\_\_\_\_ property of a control specifies where it gets the data it displays.

**22.2** State whether each of the following is *true* or *false*. If *false*, explain why.

- Providing the same value for a foreign key in multiple rows causes the DBMS to report an error.
- Providing a foreign-key value that does not appear as a primary-key value in another table is an error.
- The result of a query can be sorted in ascending or descending order.
- A `BindingNavigator` object can extract data from a database.
- A `DbContext` automatically saves changes made back to the database.

## Answers to Self-Review Exercises

**22.1** a) rows, columns. b) primary key. c) `DbContext`. d) `DataGridView`. e) joining. f) foreign key. g) `BindingSource`. h) `DataSource`.

**22.2** a) False. Multiple rows can have the same value for a foreign key. Providing the same value for the primary key in multiple rows causes the DBMS to report an error, because duplicate primary keys would prevent each row from being identified uniquely. b) True. c) True. d) False. A `BindingNavigator` allows users to browse and manipulate data displayed by another GUI control. A `DbContext` can extract data from a database. e) False. You must call the `SaveChanges` method of the `DbContext` to save the changes made back to the database.

## Exercises

**22.3** (*Display Authors Table App Modification*) Modify the app in Section 22.5 to contain a `TextBox` and a `Button` that allow the user to search for specific authors by last name. Include a `Label` to identify the `TextBox`. Using the techniques presented in Section 22.9, create a LINQ query and change the `DataSource` property of `authorBindingSource` to contain only the specified authors. Also, provide a `Button` that enables the user to return to browsing the complete set of authors.

**22.4** (*Display Query Results App Modification*) Modify the app in Section 22.6 to contain a `TextBox` and a `Button` that allow the user to perform a search of the book titles in the `Titles` table of the `Books` database. Use a `Label` to identify the `TextBox`. When the user clicks the `Button`, the app should execute and display the result of a query that selects all the rows in which the search term entered by the user in the `TextBox` appears anywhere in the `Title` column. For example, if the user enters the search term “Visual,” the `DataGridView` should display the rows for *Simply Visual Basic*

2010, Visual Basic 2012 How to Program, Visual C# 2012 How to Program and Visual C++ 2008 How to Program. If the user enters “Simply,” the DataGridView should display only the row for *Simply Visual Basic 2012*. [Hint: Use the Contains method of the String class.] Also, provide a Button that enables the user to return to browsing the complete set of titles.

**22.5 (Joining Tables with LINQ App Modification)** Create an app like the one in Section 22.7 that uses the Books database and displays the results of the following queries:

- a) Get a list of all the titles and the authors who wrote them. Sort the results by title.
- b) Get a list of all the titles and the authors who wrote them. Sort the results by title. For each title sort the authors alphabetically by last name, then first name.
- c) Get a list of all the authors grouped by title, sorted by title; for a given title sort the author names alphabetically by last name then first name.

**22.6 (Baseball Database App)** Build an app that executes a query against the `Players` table of the `Baseball` database included in the `Databases` folder with this chapter’s examples. Display the table in a `DataGridView`, and add a `TextBox` and `Button` to allow the user to search for a specific player by last name. Use a `Label` to identify the `TextBox`. Clicking the `Button` should execute the appropriate query. Also, provide a `Button` that enables the user to return to browsing the complete set of players.

**22.7 (Baseball Database App Modification)** Modify Exercise 22.6 to allow the user to locate players with batting averages in a specific range. Add a `minimumTextBox` for the minimum batting average (0.000 by default) and a `maximumTextBox` for the maximum batting average (1.000 by default). Use a `Label` to identify each `TextBox`. Add a `Button` for executing a query that selects rows from the `Players` table in which the `BattingAverage` column is greater than or equal to the specified minimum value and less than or equal to the specified maximum value.

# Web App Development with ASP.NET

# 23



*If any man will draw up his case, and put his name at the foot of the first page, I will give him an immediate reply. Where he compels me to turn over the sheet, he must wait my leisure.*

—Lord Sandwich

## Objectives

In this chapter you'll learn:

- Web app development using ASP.NET.
- To handle the events from a Web Form's controls.
- To use validation controls to ensure that data is in the correct format before it's sent from a client to the server.
- To maintain user-specific information.
- To create a data-driven web app using ASP.NET and the ADO.NET Entity Framework.

# Outline

<b>23.1</b>	Introduction	<b>23.7.3</b>	Options.aspx: Selecting a Programming Language
<b>23.2</b>	Web Basics	<b>23.7.4</b>	Recommendations.aspx: Displaying Recommendations Based on Session Values
<b>23.3</b>	Multitier App Architecture	<b>23.8</b>	Case Study: Database-Driven ASP.NET Guestbook
<b>23.4</b>	Your First Web App	<b>23.8.1</b>	Building a Web Form that Displays Data from a Database
23.4.1	Building the WebTime App	<b>23.8.2</b>	Modifying the Code-Behind File for the Guestbook App
23.4.2	Examining WebTime.aspx's Code-Behind File	<b>23.9</b>	Online Case Study: ASP.NET AJAX
<b>23.5</b>	Standard Web Controls: Designing a Form	<b>23.10</b>	Online Case Study: Password-Protected Books Database App
<b>23.6</b>	Validation Controls	<b>23.11</b>	Wrap-Up
<b>23.7</b>	Session Tracking		
23.7.1	Cookies		
23.7.2	Session Tracking with HttpSessionState		

[Summary](#) | [Terminology](#) | [Self-Review Exercises](#) | [Answers to Self-Review Exercises](#) | [Exercises](#)

## 23.1 Introduction

In this chapter, we introduce **web-app development** with Microsoft's ASP.NET technology. Web-based apps create web content for web-browser clients.

We present several examples that demonstrate web-app development using **Web Forms**, **web controls** (also called **ASP.NET server controls**) and Visual C# programming. Web Form files have the filename extension **.aspx** and contain the web page's GUI. You customize Web Forms by adding web controls including labels, textboxes, images, buttons and other GUI components. The Web Form file represents the web page that's sent to the client browser. We often refer to Web Form files as **ASPx files**.

An ASPX file created in Visual Studio has a corresponding class written in a .NET language—we use Visual C# in this book. This class contains event handlers, initialization code, utility methods and other supporting code. The file that contains this class is called the **code-behind file** and provides the ASPX file's programmatic implementation.

### *Software Used in This Chapter*

To develop the code and GUIs in this chapter, we used Microsoft's **Visual Studio Express 2012 for Web**—a free IDE designed for developing ASP.NET web apps. The full version of Visual Studio 2012 includes the functionality of Visual Studio Express 2012 for Web, so the instructions we present in this chapter also apply to Visual Studio 2012. See the Before You Begin section that follows the Preface for additional information on downloading and installing the software for this chapter.

### *Online Chapter—Web App Development with ASP.NET: A Deeper Look*

In the online Chapter 29, Web App Development with ASP.NET: A Deeper Look, we present several additional web-app development topics, including:

- master pages to maintain a uniform look-and-feel across the pages in a web app
- creating password-protected websites with registration and login capabilities

- using the **Web Site Administration Tool** to specify which parts of a website are password protected
- using ASP.NET AJAX to quickly and easily improve the user experience for your web apps, giving them responsiveness comparable to that of desktop apps.

## 23.2 Web Basics

In this section, we discuss what occurs when a user requests a web page in a browser. In its simplest form, a *web page* is nothing more than an *HTML (HyperText Markup Language) document* (with the extension `.html` or `.htm`) that describes to a web browser the document's content and how to format it.

HTML documents normally contain *hyperlinks* that link to different pages or to other parts of the same page. When the user clicks a hyperlink, a **web server** locates the requested web page and sends it to the user's web browser. Similarly, the user can type the *address of a web page* into the browser's *address field* and press *Enter* to view the specified page.

In this chapter, we develop web apps using visual development techniques that are similar to those you used with Windows Forms in Chapters 14–15. To take full advantage of web app development, you'll also want to learn HTML5, CSSS and JavaScript—topics that we cover in our textbook *Internet & World Wide Web How to Program*, 5/e. You can learn more about this book at [deitel.com/books/iw3htp5](http://deitel.com/books/iw3htp5).

### *URIs and URLs*

*URIs (Uniform Resource Identifiers)* identify resources on the Internet. URIs that start with `http://` are called *URLs (Uniform Resource Locators)*. Common URLs refer to files, directories or server-side code that performs tasks such as database lookups, Internet searches and business application processing. If you know the URL of a publicly available resource anywhere on the web, you can enter that URL into a web browser's address field and the browser can access that resource.

### *Parts of a URL*

A URL contains information that directs a browser to the resource that the user wishes to access. Web servers make such resources available to web clients. Popular web servers include Microsoft's Internet Information Services (IIS), Apache's HTTP Server and Nginx.<sup>1</sup>

Let's examine the components of the URL

```
http://www.deitel.com/books/downloads.html
```

The `http://` indicates that the HyperText Transfer Protocol (HTTP) should be used to obtain the resource. HTTP is the web protocol that enables clients and servers to communicate. Next in the URL is the server's fully qualified **hostname** (`www.deitel.com`)—the name of the web server computer on which the resource resides. This computer is referred to as the **host**, because it houses and maintains resources. The hostname `www.deitel.com` is translated into an **IP (Internet Protocol) address**—a numerical value that uniquely identifies the server on the Internet. A **Domain Name System (DNS) server** maintains a database of hostnames and their corresponding IP addresses, and performs the translations automatically.

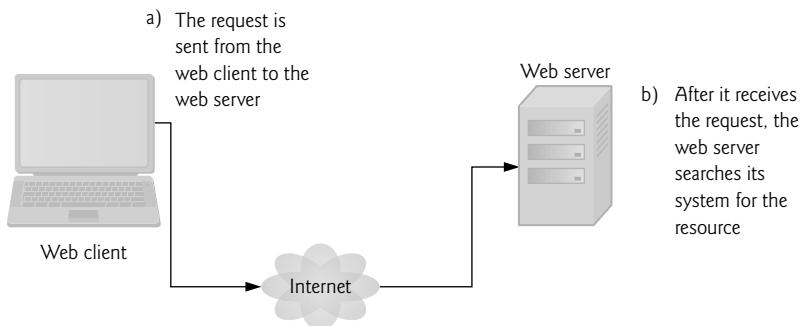
---

1. [w3techs.com/](http://w3techs.com/).

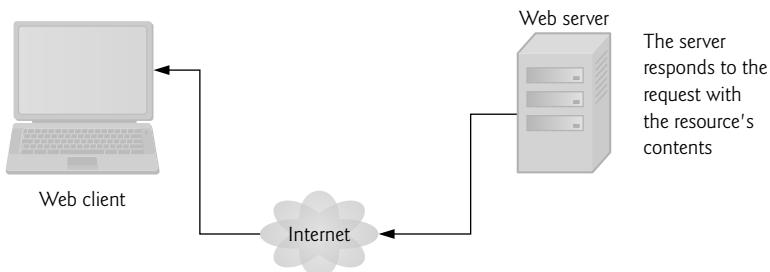
The remainder of the URL (`/books/downloads.html`) specifies the resource's location (`/books`) and name (`downloads.html`) on the web server. The location could represent an actual directory on the web server's file system. For *security* reasons, however, the location is typically a *virtual directory*. The web server translates the virtual directory into a real location on the server, thus hiding the resource's true location.

### ***Making a Request and Receiving a Response***

When given a URL, a web browser uses HTTP to retrieve the web page found at that address. Figure 23.1 shows a web browser sending a request to a web server. Figure 23.2 shows the web server responding to that request.



**Fig. 23.1** | Client requesting a resource from a web server.



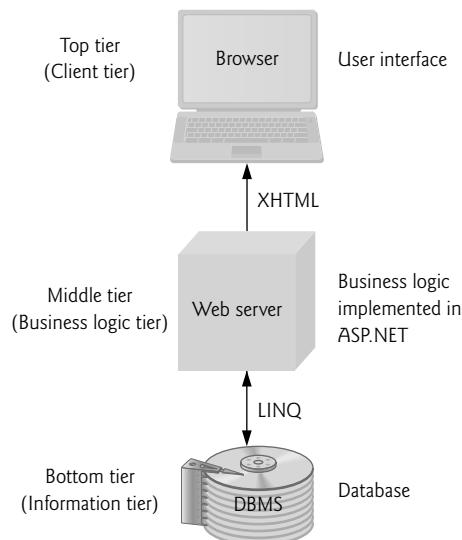
**Fig. 23.2** | Client receiving a response from the web server.

## **23.3 Multitier App Architecture**

Web-based apps are **multitier apps** (sometimes referred to as *n-tier apps*). Multitier apps divide functionality into separate **tiers** (that is, logical groupings of functionality). Although tiers can be located on the *same* computer, the tiers of web-based apps commonly reside on *separate* computers for *security* and *scalability*. Figure 23.3 presents the basic architecture of a three-tier web-based app.

### ***Information Tier***

The **bottom tier** (also called the **information tier**) maintains the app's data. This tier typically stores data in a relational database management system. For example, a retail store might have a database for storing product information, such as descriptions, prices and quantities in stock. The same database also might contain customer information, such as user names, billing addresses and credit card numbers. This tier can contain multiple databases, which together comprise the data needed for an app.



**Fig. 23.3** | Three-tier architecture.

### ***Business Logic***

The **middle tier** implements **business logic**, **controller logic** and **presentation logic** to control interactions between the app's clients and its data. The middle tier acts as an intermediary between data in the information tier and the app's clients. The middle-tier controller logic processes client requests (such as requests to view a product catalog) and retrieves data from the database. The middle-tier presentation logic then processes data from the information tier and presents the content to the client. Web apps present data to clients as web pages.

Business logic in the middle tier enforces *business rules* and ensures that data is reliable before the server app updates the database or presents the data to users. Business rules dictate how clients can and cannot access app data, and how apps process data. For example, a business rule in the middle tier of a retail store's web-based app might ensure that all product quantities remain positive. A client request to set a negative quantity in the bottom tier's product information database would be rejected by the middle tier's business logic.

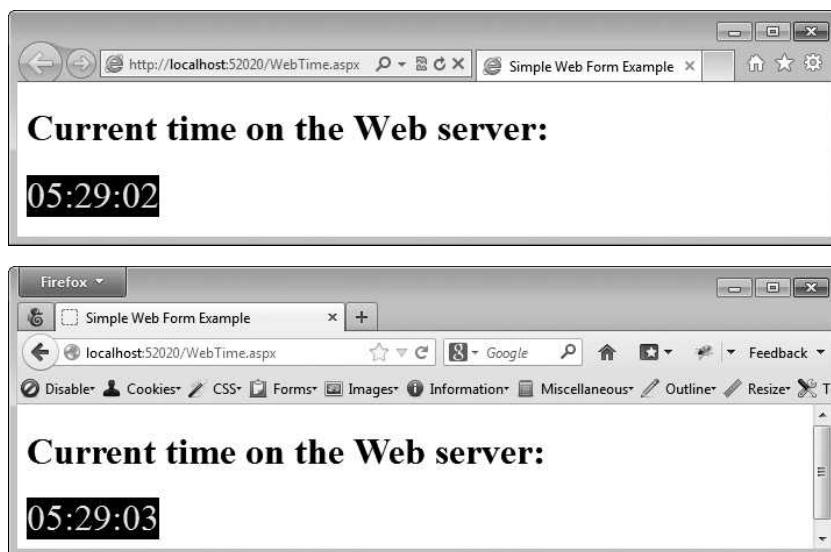
### ***Client Tier***

The **top tier**, or **client tier**, is the app's user interface, which gathers input and displays output. Users interact directly with the app through the user interface (typically viewed in

a web browser), keyboard and mouse. In response to user actions (for example, clicking a hyperlink), the client tier interacts with the middle tier to make requests and to retrieve data from the information tier. The client tier then displays to the user the data retrieved from the middle tier. The client tier *never* directly interacts with the information tier.

## 23.4 Your First Web App

Our first example displays the web server's time of day in a browser window (Fig. 23.4). When this app executes—that is, a web browser requests the app's web page—the web server executes the app's code, which gets the current time and displays it in a Label1. The web server then returns the result to the web browser that made the request, and the web browser *renders* the web page containing the time. We executed this app in both the *Internet Explorer* and *Firefox* web browsers to show you that the web page renders identically in different browsers—the page should look the same in most Web browsers.

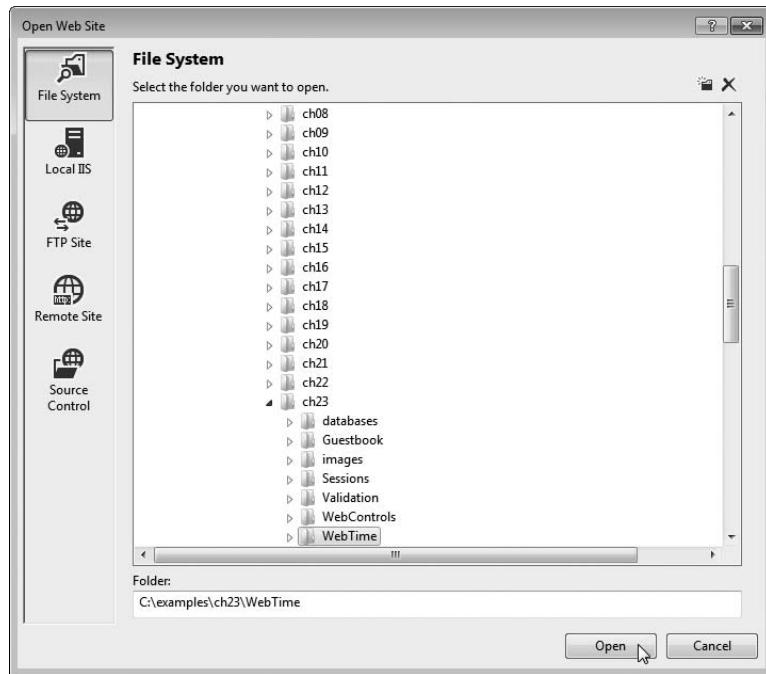


**Fig. 23.4** | WebTime web app running in both Internet Explorer and Firefox.

### Testing the App in Your Default Web Browser

To test this app in your default web browser, perform the following steps:

1. Open Visual Studio Express For Web.
2. Select **Open Web Site...** from the **FILE** menu.
3. In the **Open Web Site** dialog (Fig. 23.5), ensure that **File System** is selected, then navigate to this chapter's examples, select the **WebTime** folder and click the **Open** Button.
4. Select **WebTime.aspx** in the **Solution Explorer**, then type **Ctrl + F5** to execute the web app.

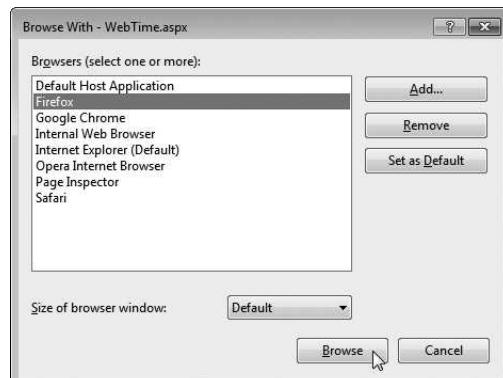


**Fig. 23.5 |** Open Web Site dialog.

#### *Testing the App in a Selected Web Browser*

If you wish to execute the app in another web browser, you can copy the web page's address from your default browser's address field and paste it into another browser's address field, or you can perform the following steps:

1. In the Solution Explorer, right click `WebTime.aspx` and select **Browse With...** to display the **Browse With** dialog (Fig. 23.6).



**Fig. 23.6 |** Selecting another web browser to execute the web app.

- From the **Browsers** list, select the browser in which you'd like to test the web app and click the **Browse Button**.

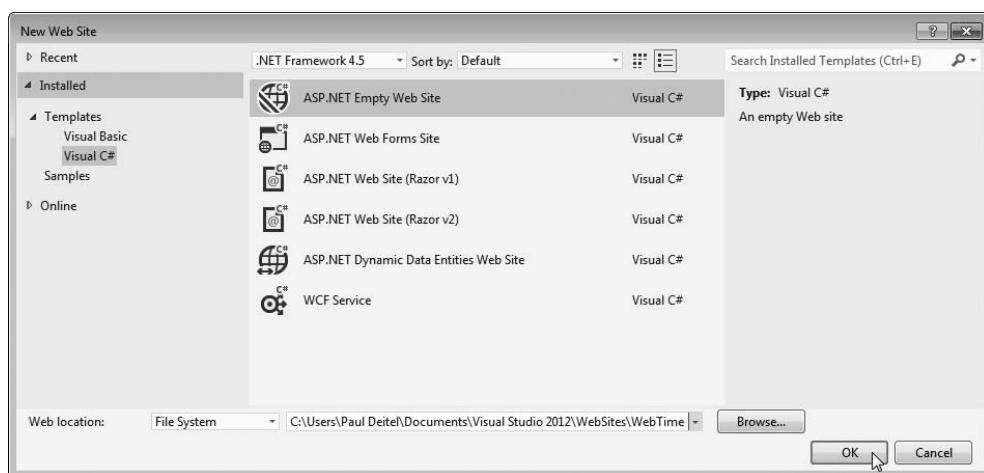
If the browser you wish to use is not listed, you can use the **Browse With** dialog to add items to or remove items from the list of web browsers.

### 23.4.1 Building the WebTime App

Now that you've tested the app, let's create it in Visual Studio Express For Web.

#### *Step 1: Creating the Web Site Project*

Select **FILE > New Web Site...** to display the **New Web Site** dialog (Fig. 23.7). In the left column of this dialog, ensure that **Visual C#** is selected, then select **ASP.NET Empty Web Site** in the middle column. At the bottom of the dialog you can specify the location and name of the web app.



**Fig. 23.7 |** Creating an **ASP.NET Web Site** in Visual Studio Express For Web.

The **Web location:** ComboBox provides the following options:

- File System:** Creates a new website for testing on your local computer. Such websites execute on your local machine in **IIS Express** and can be accessed only by web browsers running on the same computer. IIS Express is a version of Microsoft's Internet Information Services (IIS) web server that allows you to test your web apps locally. You can later publish your website to a production IIS web server for access via a local network or the Internet. Each example in this chapter uses the **File System** option, so select it now.
- HTTP:** Creates a new website on an IIS web server and uses HTTP to allow you to put your website's files on the server. IIS is Microsoft's software that's used to run production websites. If you own a website and have your own web server, you might use this to build a new website directly on that server computer. You must be an Administrator on the computer running IIS to use this option.

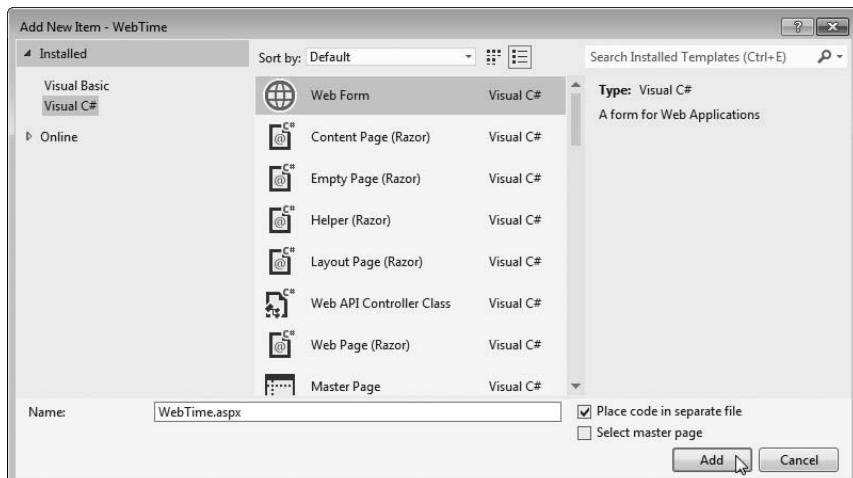
- **FTP:** Uses File Transfer Protocol (FTP) to allow you to put your website's files on the server. The server administrator must first create the website on the server for you. FTP is commonly used by so-called "hosting providers" to allow website owners to share a server computer that runs many websites.

Change the name of the web app from **WebSite1** to **WebTime**, then click **OK** to create the website.

### **Step 2: Adding a Web Form to the Website and Examining the Solution Explorer**

A **Web Form** represents one page in a web app—we'll often use the terms "page" and "Web Form" interchangeably. A Web Form contains a web app's GUI. To create the **WebTime.aspx** Web Form:

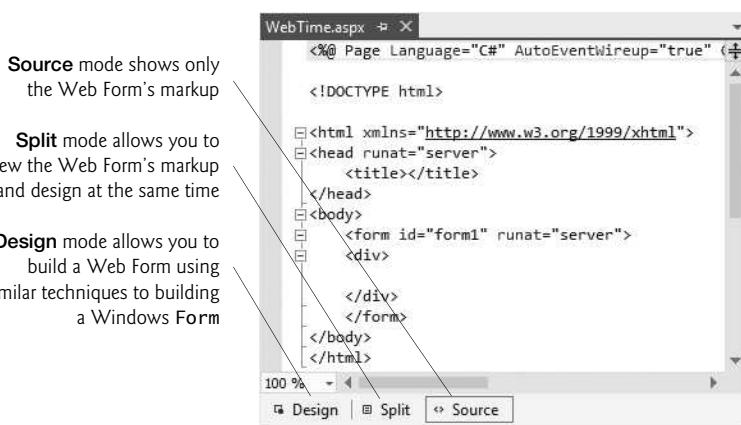
1. Right click the project name in the **Solution Explorer** and select **Add > Add New Item...** to display the **Add New Item** dialog (Fig. 23.8).



**Fig. 23.8 |** Adding a new **Web Form** to the website with the **Add New Item** dialog.

2. In the left column, ensure that **Visual C#** is selected, then select **Web Form** in the middle column.
3. In the **Name:** TextBox, change the file name to **WebTime.aspx**, then click the **Add** Button.

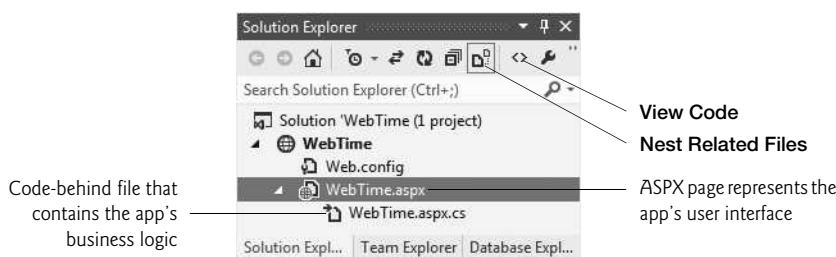
After you add the Web Form, the IDE opens it in **Source** view by default (Fig. 23.9). This view displays the markup for the Web Form. As you become more familiar with ASP.NET and building web sites in general, you might use **Source** view to perform high precision adjustments to your design (in HTML and/or CSS) or to program in the JavaScript language that executes in web browsers. For the purposes of this chapter, we'll keep things simple by working exclusively in **Design** mode. To switch to **Design** mode, you can click the **Design** Button at the bottom of the code editor window.



**Fig. 23.9** | Web Form in **Source** view.

### The Solution Explorer

The **Solution Explorer** (Fig. 23.10) shows the contents of the website. We expanded the node for `WebTime.aspx` to show you its *code-behind file* `WebTime.aspx.cs`. Visual Studio Express For Web's **Solution Explorer** contains a **Nest Related Files** button that organizes each Web Form and its code-behind file.



**Fig. 23.10** | Solution Explorer window for an Empty Web Site project after adding the Web Form `WebTime.aspx`.

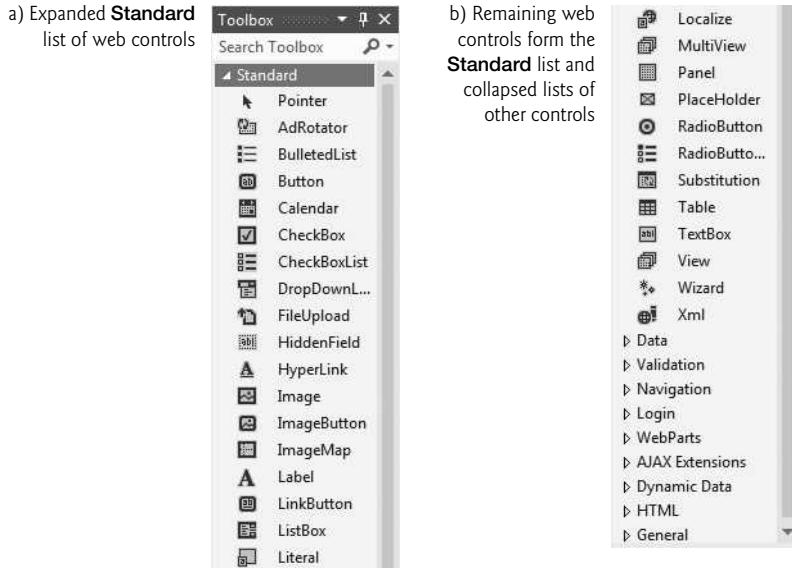
If the **ASPX** file is not open in the IDE, you can open it in **Design** mode by double clicking it in the **Solution Explorer** then selecting the **Design** tab, or by right clicking it in the **Solution Explorer** and selecting **View Designer**. To open the code-behind file in the code editor, you can double click it in the **Solution Explorer** or

- select the **ASPX** file in the **Solution Explorer**, then click the **View Code** ( $\leftrightarrow$ ) Button
- right click the **ASPX** file in the **Solution Explorer**, then select **View Code**
- right click the code-behind file in the **Solution Explorer** and select **Open**

### The Toolbox

Figure 23.11 shows the **Toolbox** displayed in the IDE when the project loads. Part (a) displays the beginning of the **Standard** list of web controls, and part (b) displays the remain-

ing web controls and the list of other control groups. We discuss specific controls listed in Fig. 23.11 as they're used throughout the chapter. Many of the controls have similar or identical names to Windows Forms controls presented earlier in the book.



**Fig. 23.11** | **Toolbox** in Visual Studio Express For Web.

### *The Web Forms Designer*

Figure 23.12 shows the initial Web Form in **Design** mode. You can drag and drop controls from the **Toolbox** onto the Web Form. You can also type at the current cursor location to add so-called *static text* to the web page. In response to such actions, the IDE generates the appropriate markup in the ASPX file.



**Fig. 23.12** | **Design** mode of the Web Forms Designer.

### *Step 3: Changing the Title of the Page*

Before designing the Web Form's content, you'll change its title to **Simple Web Form Example**. This title is typically displayed in the web browser's title bar or on the browser tab that is displaying the page (see Fig. 23.4). It's also used by search engines like Google and

Bing when they index real websites for searching. Every page should have a title. To change the title:

1. Ensure that the ASPX file is open in **Design** view.
2. In the **Properties** window's drop-down list, view the Web Form's properties by selecting **DOCUMENT**, which represents the Web Form. A web page is often called a document.
3. Modify the page's **Title** property by setting it to **Simple Web Form Example**.

### *Designing a Page*

Designing a Web Form is similar to designing a Windows Form. To add controls to the page, drag-and-drop them from the **Toolbox** onto the Web Form in **Design** view. The Web Form itself and the control's you add to the Web Form are objects that have properties, methods and events. You can set these properties visually using the **Properties** window, programmatically in the code-behind file or by editing the markup directly in the **.aspx** file. You can also type text directly on a Web Form at the cursor location.

Controls and other elements are placed sequentially on a Web Form one after another in the order in which you drag-and-drop them onto the Web Form. The cursor indicates the insertion point in the page. If you want to position a control between existing text or controls, you can drop the control at a specific position between existing page elements. You can also rearrange controls with drag-and-drop actions in **Design** view. The positions of controls and other elements are relative to the Web Form's upper-left corner. This type of layout is known as *relative positioning* and it allows the browser to move elements and resize them based on the size of the browser window. Relative positioning is the *default*, and we'll use it throughout this chapter.

For precise control over the location and size of elements, you can use absolute positioning in which controls are located exactly where you drop them on the Web Form. If you wish to use absolute positioning:

1. Select **TOOLS > Options....**, to display the **Options** dialog.
2. Expand the **HTML Designer** node, select the **CSS Styling** node and ensure that the checkbox labeled **Change positioning to absolute for controls added using Toolbox, paste or drag and drop** is selected.

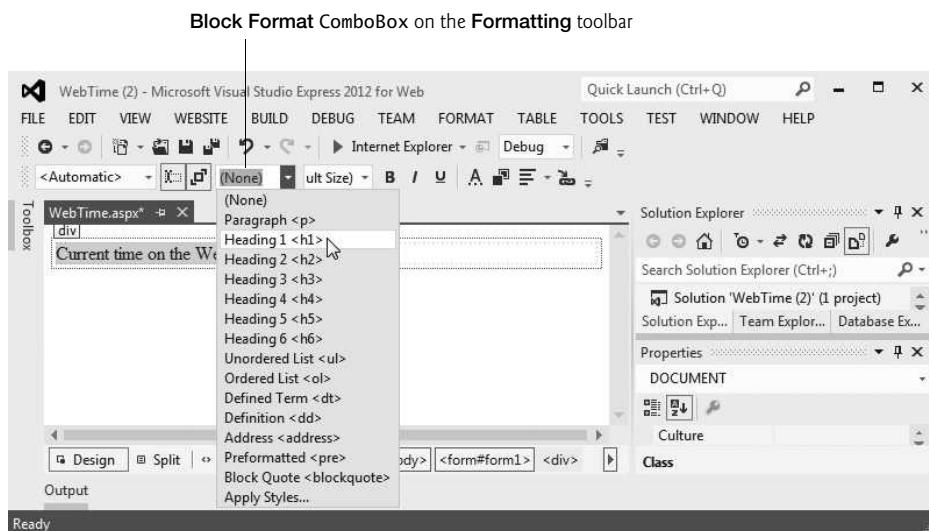
### *Step 4: Adding Text and a Label*

You'll now add some text and a **Label** to the Web Form. Perform the following steps to add the text:

1. Ensure that the Web Form is open in **Design** mode.
2. Type the following text at the current cursor location:

Current time on the Web server:

3. Select the text you just typed, then select **Heading 1** from the **Block Format Combo-Box** (Fig. 23.13) in the IDE's **Formatting** toolbar. This formats the text as a first-level heading that typically appears in a larger bold font. In more complex pages, headings help you specify the relative importance of parts of the content—like chapters in a book and sections in a chapter.



**Fig. 23.13** | Changing the text to **Heading 1** heading.

4. Click to the right of the text you just typed and press the *Enter* key to start a new paragraph in the page. The Web Form should now appear as in Fig. 23.14.



**Fig. 23.14** | WebTime.aspx after inserting text and a new paragraph.

5. Next, drag a **Label** control from the **Toolbox** into the new paragraph or double click the **Label** control in the **Toolbox** to insert the **Label** at the current cursor position.
6. Using the **Properties** window, set the **Label**'s **(ID)** property to **timeLabel**. This specifies the variable name that will be used to *programmatically* change the **Label**'s **Text**.
7. Because the **Label**'s **Text** will be set programmatically, delete the current value of the **Label**'s **Text** property. When a **Label** does not contain text, its name is displayed in square brackets in **Design** view (Fig. 23.15) as a placeholder for design and layout purposes. This text is not displayed at execution time.



**Fig. 23.15** | WebTime.aspx after adding a Label.

#### Step 5: Formatting the Label

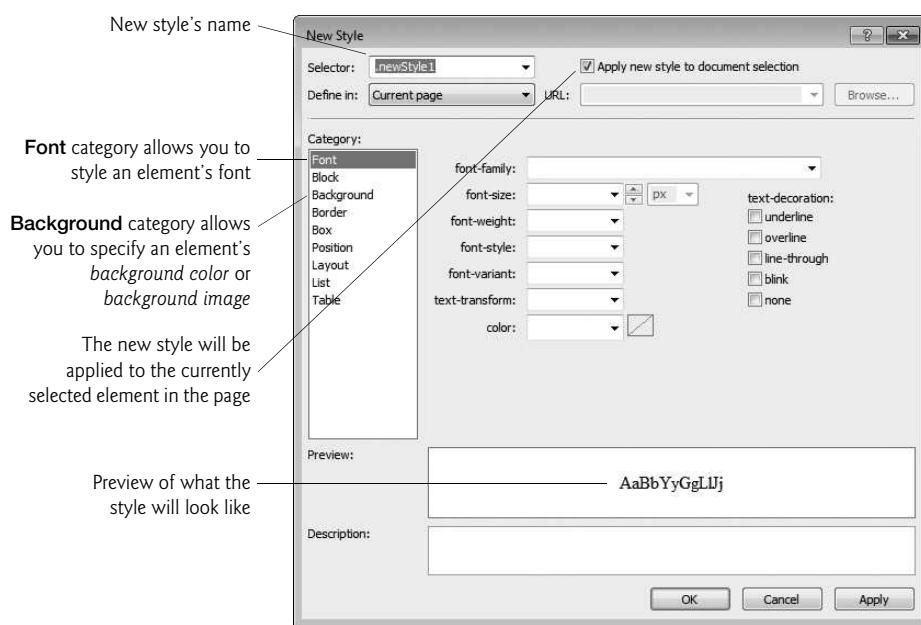
Formatting in a web page is performed with *CSS (Cascading Style Sheets)*. The details of CSS are beyond the scope of this book. However, it's easy to use CSS to format text and elements in a Web Form via the tools built into Visual Studio Express For Web. In this example, we'd like to change the Label's *background color* to black, its *foreground color* to yellow and make its *text size* larger. To format the Label, perform the following steps:

1. Click the Label in Design view to ensure that it's selected.
2. Select **VIEW > CSS Properties** to display the **CSS Properties** window at the left side of the IDE (Fig. 23.16).



**Fig. 23.16** | CSS Properties window.

3. Right click below **Applied Rules** and select **New Style...** to display the **New Style** dialog (Fig. 23.17).
4. Type the new style's name in the **Selector: ComboBox**—we chose `.timeStyle` since this will be the style used to format the time that's displayed in the page. Styles that apply to specific elements must be named with a dot (.) preceding the name. Such a style is called a **CSS class**.
5. Each item you can set in the **New Style** dialog is known as a *CSS attribute*. To change `timeLabel`'s *foreground color*, select the **Font** category from the **Category** list, then select the yellow color swatch for the **color** attribute.
6. Next, change the **font-size** attribute to `xx-large`.



**Fig. 23.17 |** New Style dialog.

- To change `timeLabel`'s *background color*, select the **Background** category, then select the black color swatch for the `background-color` attribute.

The **New Style** dialog should now appear as shown in Fig. 23.18. Click the **OK** Button to apply the style to the `timeLabel` so that it appears as shown in Fig. 23.19. Also, notice that the Label's *CssClass* property is now set to `timeStyle` in the **Properties** window.

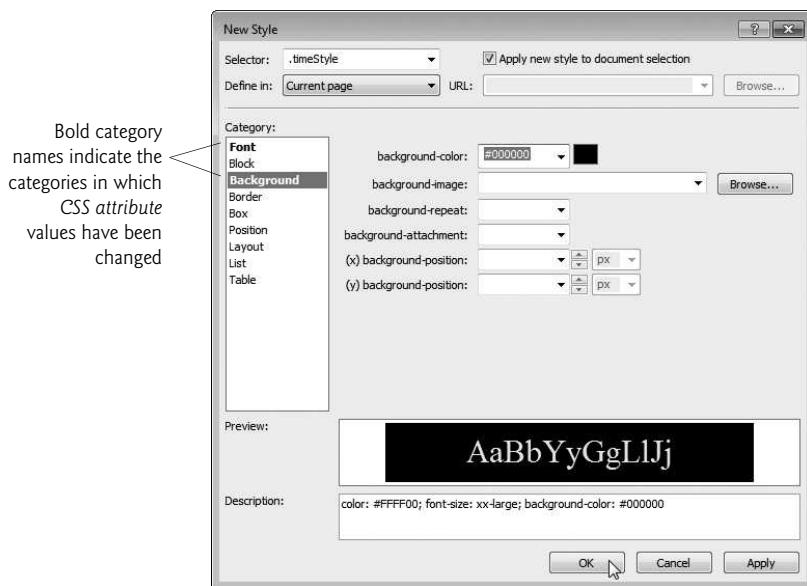
#### Step 6: Adding Page Logic

Now that you've designed the GUI, you'll write code in the *code-behind file* to obtain the server's time and display it on the `Label`. Open `WebTime.aspx.cs` by double clicking it in the **Solution Explorer**. In this example, you'll add an event handler to the code-behind file to handle the Web Form's **Init** event, which occurs when the page is requested by a web browser. The event handler for this event—named `Page_Init`—initializes the page. The only initialization required for this example is to set the `timeLabel`'s `Text` property to the time on the web server computer. The code-behind file initially contains a `Page_Load` event handler. To create the `Page_Init` event handler, simply rename `Page_Load` as `Page_Init`. Then complete the event handler by inserting the following code in its body:

```
// display the server's current time in timeLabel
timeLabel.Text = DateTime.Now.ToString("hh:mm:ss");
```

#### Step 7: Setting the Start Page and Running the Program

To ensure that `WebTime.aspx` loads when you execute this app, right click it in the **Solution Explorer** and select **Set As Start Page**. You can now run the program in one of several ways. At the beginning of Fig. 23.4, you learned how to view the Web Form by typing *Ctrl + F5*.



**Fig. 23.18** | New Style dialog after changing the Label's style.



**Fig. 23.19** | Design view after changing the Label's style.

You can also right click an ASPX file in the **Solution Explorer** and select **View in Browser**. Both of these techniques execute *IIS Express*, open your *default web browser* and load the page into the browser, thus running the web app. IIS Express stops when you exit Visual Studio Express For Web.

If problems occur when running your app, you can run it in *debug mode* by selecting **DEBUG > Start Debugging**, by clicking the **Start Debugging Button** (▶) or by typing **F5** to view the web page in a web browser with *debugging enabled*. You cannot debug a web app unless debugging is *explicitly* enabled in the app's **Web.config** file—a file that's generated when you create an ASP.NET web app. This file stores the app's configuration settings. You'll rarely need to manually modify **Web.config**. The first time you select **DEBUG > Start Debugging** in a project, a dialog appears and asks whether you want the IDE to modify the **Web.config** file to enable debugging. After you click **OK**, the IDE executes the app. You can stop debugging by selecting **DEBUG > Stop Debugging**.

Regardless of how you execute the web app, the IDE will compile the project before it executes. In fact, ASP.NET compiles your web page whenever it changes between HTTP requests. For example, suppose you browse the page, then modify the ASPX file or add code to the code-behind file. When you reload the page, ASP.NET recompiles the page on the server before returning the response to the browser. This important behavior ensures that clients always see the latest version of the page. You can manually compile an entire website by selecting **Build Web Site** from the **DEBUG** menu in Visual Studio Express For Web.

### 23.4.2 Examining WebTime.aspx's Code-Behind File

Figure 23.20 presents the code-behind file `WebTime.aspx.cs`. Line 5 begins the declaration of class `WebTime`. A class declaration can span multiple source-code files—the separate portions of the class declaration in each file are known as **partial classes**. The **partial** modifier indicates that the code-behind file is part of a larger class. Like Windows Forms apps, the rest of the class's code is generated for you based on your visual interactions to create the app's GUI in **Design** mode. That code is stored in other source code files as partial classes with the same name. The compiler assembles all the partial classes that have the same into a single class declaration.

---

```

1 // Fig. 23.20: WebTime.aspx.cs
2 // Code-behind file for a page that displays the web server's time.
3 using System;
4
5 public partial class WebTime : System.Web.UI.Page
6 {
7     // initializes the contents of the page
8     protected void Page_Init( object sender, EventArgs e )
9     {
10         // display the server's current time in timeLabel
11         timeLabel.Text = DateTime.Now.ToString( "hh:mm:ss" );
12     } // end method Page_Init
13 } // end class WebTime

```

---

**Fig. 23.20** | Code-behind file for a page that displays the web server's time.

Line 5 indicates that `WebTime` inherits from class `Page` in namespace `System.Web.UI`. This namespace contains classes and controls for building web-based apps. Class `Page` represents the default capabilities of each page in a web app—all pages inherit directly or indirectly from this class.

Lines 8–12 define the `Page_Init` event handler, which initializes the page in response to the page's `Init` event. The only initialization required for this page is to set the `timeLabel`'s `Text` property to the time on the web server computer. The statement in line 11 retrieves the current time (`DateTime.Now`) and formats it as *hh:mm:ss*. For example, 9 AM is formatted as 09:00:00, and 2:30 PM is formatted as 02:30:00. As you'll see, variable `timeLabel` represents an *ASP.NET Label control*. The *ASP.NET controls* are defined in namespace `System.Web.UI.WebControls`.

## 23.5 Standard Web Controls: Designing a Form

This section introduces some of the web controls located in the **Standard** section of the **Toolbox** (Fig. 23.11). Figure 23.21 summarizes the controls used in the next example.

Web control	Description
TextBox	Gathers user input and displays text.
Button	Triggers an event when clicked.
HyperLink	Displays a hyperlink.
DropDownList	Displays a drop-down list of choices from which a user can select an item.
RadioButtonList	A group of radio buttons.
Image	Displays images (for example, PNG, GIF and JPG).

**Fig. 23.21** | Commonly used web controls.

### *A Form Gathering User Input*

Figure 23.22 depicts a form for gathering user input. This example does not perform any tasks—that is, no action occurs when the user clicks **Register**. As an exercise, we ask you to provide the functionality. Here we focus on the steps for adding these controls to a Web Form and for setting their properties. Subsequent examples demonstrate how to handle the events of many of these controls. To execute this app:

1. Select **Open Web Site...** from the **FILE** menu.
2. In the **Open Web Site** dialog, ensure that **File System** is selected, then navigate to this chapter's examples, select the **WebControls** folder and click the **Open** button.
3. Select **WebControls.aspx** in the **Solution Explorer**, then type *Ctrl + F5* to execute the web app in your default web browser.

### *Step 1: Creating the Web Site*

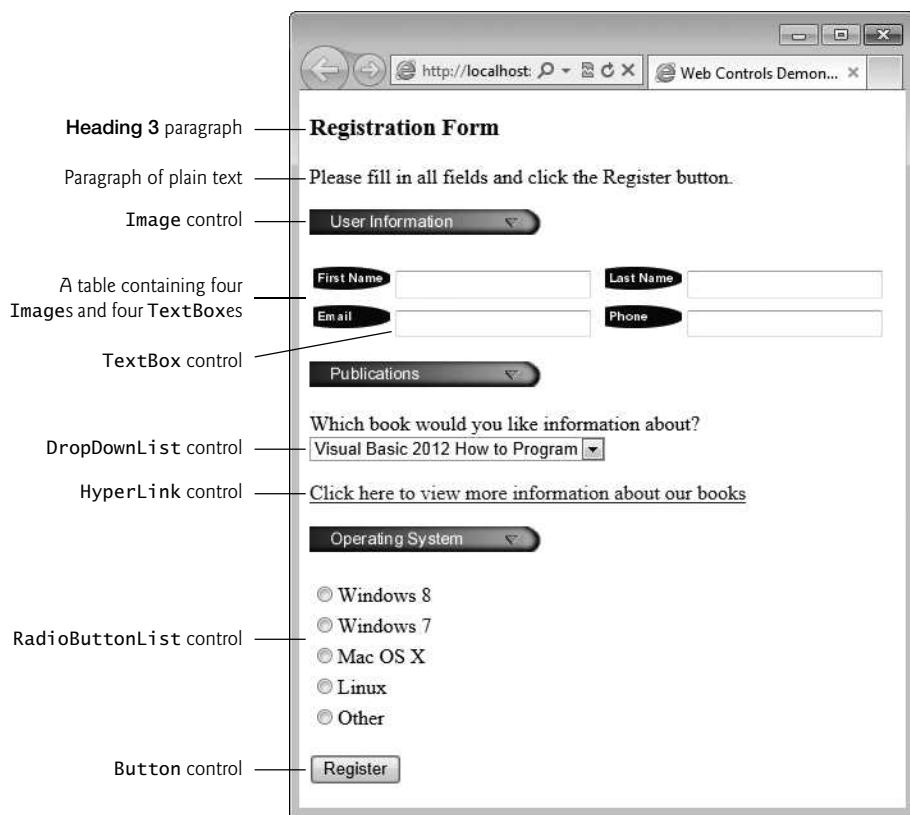
To begin, follow the steps in Section 23.4.1 to create an **Empty Web Site** named **WebControls**, then add a Web Form named **WebControls.aspx** to the project. Set the document's **Title** property to "Web Controls Demonstration". Right click **WebControls.aspx** in the **Solution Explorer** and select **Set As Start Page** to ensure that this page loads when you execute the app.

### *Step 2: Adding the Images to the Project*

The images used in this example are located in the **images** folder with this chapter's examples. Before you can display this app's images in the Web Form, they must be added to your project. To add the **images** folder to your project:

1. Open Windows Explorer.
2. Locate and open this chapter's examples folder (**ch23**).
3. Drag the **images** folder from Windows Explorer into Visual Studio Express For Web's **Solution Explorer** window and drop the folder on the name of your project.

The IDE will automatically copy the folder and its contents into your project.



**Fig. 23.22** | Web Form that demonstrates web controls.

### Step 3: Adding Text and an Image to the Form

Next, you'll begin creating the page. Perform the following steps:

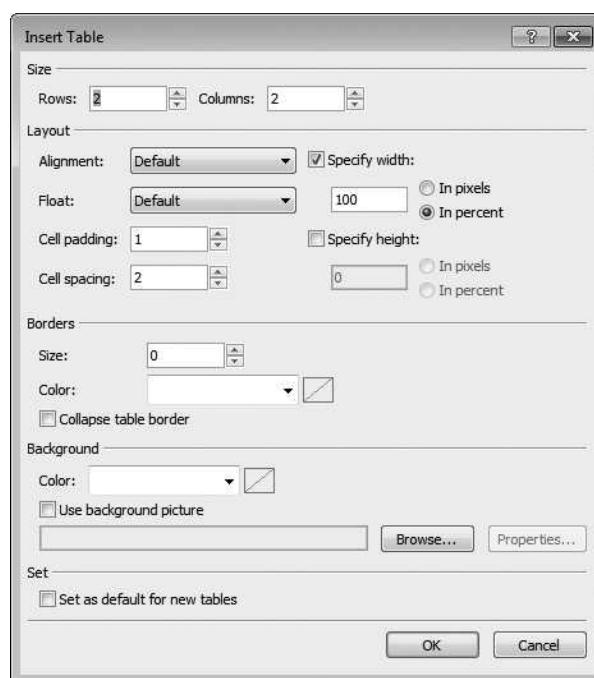
1. First create the page's heading. At the current cursor position on the page, type the text "Registration Form", then use the **Block Format ComboBox** in the IDE's toolbar to change the text to **Heading 3** format.
2. Press *Enter* to start a new paragraph, then type the text "Please fill in all fields and click the Register button.".
3. Press *Enter* to start a new paragraph, then double click the **Image** control in the **Toolbox**. This control inserts an image into a web page, at the current cursor position. Set the **Image**'s (**ID**) property to **userInformationImage**. The **ImageUrl** property specifies the location of the image to display. In the **Properties** window, click the ellipsis for the **ImageUrl** property to display the **Select Image** dialog. Select the **images** folder under **Project folders**: to display the list of images. Then select the image **user.png**.
4. Click **OK** to display the image in **Design** view, then click to the right of the **Image** and press *Enter* to start a new paragraph.

#### Step 4: Adding a Table to the Form

Form elements are sometimes placed in tables for layout purposes—like the elements that represent the first name, last name, e-mail and phone information in Fig. 23.22. Next, you'll create a table with two rows and two columns in **Design** mode.

1. Select **Table > Insert Table** to display the **Insert Table** dialog (Fig. 23.23). This dialog allows you to configure the table's options.
2. Under **Size**, ensure that the values of **Rows** and **Columns** are both 2—these are the default values.
3. Click **OK** to close the **Insert Table** dialog and create the table.

By default, the contents of a table cell are aligned *vertically* in the *middle* of the cell.



**Fig. 23.23 |** Insert Table dialog.

After creating the table, controls and text can be added to particular cells to create a neatly organized layout. Next, add **Image** and **TextBox** controls to each the four table cells as follows:

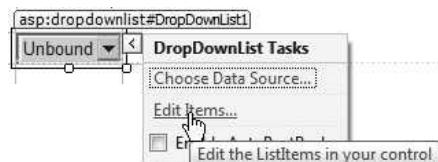
1. Click the table cell in the first row and first column of the table, then double click the **Image** control in the **Toolbox**. Set its **(ID)** property to **firstNameImage** and set its **ImageUrl** property to the image **fname.png**.
2. Next, double click the **TextBox** control in the **Toolbox**. Set its **(ID)** property to **firstNameTextBox**. As in Windows Forms, a **TextBox** control allows you to obtain text from the user and display text to the user.

3. Repeat this process in the first row and second column, but set the Image's (ID) property to lastNameImage and its ImageUrl property to the image lname.png, and set the TextBox's (ID) property to lastNameTextBox.
4. Repeat *Steps 1* and *2* in the second row and first column, but set the Image's (ID) property to emailImage and its ImageUrl property to the image email.png, and set the TextBox's (ID) property to emailTextBox.
5. Repeat *Steps 1* and *2* in the second row and second column, but set the Image's (ID) property to phoneImage and its ImageUrl property to the image phone.png, and set the TextBox's (ID) property to phoneTextBox.

#### *Step 5: Creating the Publications Section of the Page*

This section contains an Image, some text, a DropDownList control and a HyperLink control. Perform the following steps to create this section:

1. Click below the table, then use the techniques you've already learned in this section to add an Image named publicationsImage that displays the publications.png image.
2. Click to the right of the Image, then press *Enter* and type the text "Which book would you like information about?" in the new paragraph.
3. Hold the *Shift* key and press *Enter* to create a new line in the current paragraph, then double click the **DropDownList** control in the **Toolbox**. Set its (ID) property to booksDropDownList. This control is similar to the Windows Forms ComboBox control, but doesn't allow users to type text. When a user clicks the drop-down list, it expands and displays a list from which the user can make a selection.
4. You can add items to the DropDownList using the **ListItem Collection Editor** by clicking the ellipsis next to the DropDownList's Items property in the **Properties** window, or by using the **DropDownList Tasks** smart-tag menu. To open this menu, click the small arrowhead that appears in the upper-right corner of the control in **Design** mode (Fig. 23.24). Visual Studio Express 2012 for Web displays smart-tag menus for many ASP.NET controls to facilitate common tasks. Clicking **Edit Items...** in the **DropDownList Tasks** menu opens the **ListItem Collection Editor**, which allows you to add ListItem elements to the DropDownList. Add items for "Visual Basic 2012 How to Program", "Visual C# 2012 How to Program", "Java



**Fig. 23.24** | DropDownList Tasks smart-tag menu.

"How to Program" and "C++ How to Program" by clicking the **Add** Button four times. For each item, select it, then set its **Text** property to one of the four book titles.

5. Click to the right of the **DropDownList** and press *Enter* to start a new paragraph, then double click the **HyperLink** control in the **Toolbox** to add a hyperlink to the web page. Set its **(ID)** property to **booksHyperLink** and its **Text** property to "Click here to view more information about our books". Set the **NavigateUrl** property to <http://www.deitel.com>. This specifies the resource or web page that will be requested when the user clicks the **HyperLink**. Setting the **Target** property to **\_blank** specifies that the requested web page should open in a new tab or browser window. By default, **HyperLink** controls cause pages to open in the *same* browser window.

#### *Step 6: Completing the Page*

Next you'll create the **Operating System** section of the page and the **Register** Button. This section contains a **RadioButtonList** control, which provides a series of radio buttons from which the user can select only one. The **RadioButtonList Tasks** smart-tag menu provides an **Edit Items...** link to open the **ListItem Collection Editor** so that you can create the items in the list. Perform the following steps:

1. Click to the right of the **HyperLink** control and press *Enter* to create a new paragraph, then add an **Image** named **osImage** that displays the **os.png** image.
2. Click to the right of the **Image** and press *Enter* to create a new paragraph, then add a **RadioButtonList**. Set its **(ID)** property to **osRadioButtonList**. Use the **ListItem Collection Editor** to add the items shown in Fig. 23.22.
3. Finally, click to the right of the **RadioButtonList** and press *Enter* to create a new paragraph, then add a **Button**. A **Button** web control represents a button that triggers an action when clicked. Set its **(ID)** property to **registerButton** and its **Text** property to **Register**. As stated earlier, clicking the **Register** button in this example does not do anything.

You can now execute the app (*Ctrl + F5*) to see the Web Form in your browser.

## 23.6 Validation Controls

This section introduces a different type of web control, called a **validation control** or **validator**, which determines whether the *data* in another web control is in the proper *format*. For example, validators can determine whether a user has provided information in a required field or whether a zip-code field contains exactly five digits. Validators provide a mechanism for *validating user input* on the client and the server. When the page is sent to the client, the validator is converted into JavaScript that performs the validation in the client web browser. JavaScript is a scripting language that enhances the functionality of web pages and is typically executed on the client. Unfortunately, some client browsers might not support scripting or the user might disable it. For this reason, you should *always perform validation on the server*. ASP.NET validation controls can function on the *client*, on the *server* or *both*.

### *Validating Input in a Web Form*

The Web Form in Fig. 23.25 prompts the user to enter a name, e-mail address and phone number. A website could use a form like this to collect contact information from visitors.

After the user enters any data, but before the data is sent to the web server, validators ensure that the user *entered a value in each field* and that the e-mail address and phone-number values are in an acceptable format. In this example, (555) 123-4567, 555-123-4567 and 123-4567 are all considered valid phone numbers. Once the data is submitted, the web server responds by displaying a message that repeats the submitted information. A real business app would typically store the submitted data in a database or in a file on the server. We simply send the data back to the client to demonstrate that the server received the data. To execute this app:

1. Select **Open Web Site...** from the **FILE** menu.
2. In the **Open Web Site** dialog, ensure that **File System** is selected, then navigate to this chapter's examples, select the **Validation** folder and click the **Open** Button.
3. Select **Validation.aspx** in the **Solution Explorer**, then type ***Ctrl + F5*** to execute the web app in your default web browser.

In the sample output:

- Fig. 23.25(a) shows the initial Web Form.
- Fig. 23.25(b) shows the result of submitting the form before typing any data in the **TextBoxes**.
- Fig. 23.25(c) shows the results after entering data in each **TextBox**, but specifying an invalid e-mail address and invalid phone number.
- Fig. 23.25(d) shows the results after entering valid values for all three **TextBoxes** and submitting the form.

#### *Step 1: Creating the Web Site*

To begin, follow the steps in Section 23.4.1 to create an **Empty Web Site** named **Validation**, then add a Web Form named **Validation.aspx** to the project. Set the document's **Title** property to "Demonstrating Validation Controls". To ensure that **Validation.aspx** loads when you execute this app, right click it in the **Solution Explorer** and select **Set As Start Page**.

a) Initial Web Form

The screenshot shows a web browser window with the following details:

- Title Bar:** The title bar displays the URL `http://localhost:` and the text `Demonstrating Validation`.
- Content Area:**
  - A heading **Please fill in all the fields in the following form:**
  - Three text input fields labeled **Name:**, **E-mail:**, and **Phone:**. The **E-mail:** field contains `email@domain.com` and the **Phone:** field contains `(555) 555-1234`.
  - A **Submit** button at the bottom.

**Fig. 23.25** | Validators in a Web Form that retrieves user contact information. (Part 1 of 2.)

- b) Web Form after the user presses the **Submit Button** without having entered any data in the **TextBoxes**; each **TextBox** is followed by an error message that was displayed by a validation control

**RequiredFieldValidator**  
controls

The screenshot shows a web browser window with the URL <http://localhost/>. The page title is "Demonstrating Valid". The content is a form with the heading "Please fill in all the fields in the following form:". It contains three text input fields:

- Name:  Please enter your name
- E-mail:  email@domain.com Please enter your e-mail address
- Phone:  (555) 555-1234 Please enter your phone number

A legend on the left indicates that the lines pointing to the text boxes are labeled "RequiredFieldValidator controls".

- c) Web Form after the user enters a name, an invalid e-mail address and an invalid phone number in the **TextBoxes**, then presses the **Submit Button**; the validation controls display error messages in response to the invalid e-mail and phone number values

**RegularExpressionValidator**  
controls

The screenshot shows a web browser window with the URL <http://localhost/>. The page title is "Demonstrating Valid". The content is a form with the heading "Please fill in all the fields in the following form:". It contains three text input fields:

- Name:  Bob White
- E-mail:  bwhite Please enter an e-mail address in a valid format
- Phone:  55 1234 Please enter a phone number in a valid format

A legend on the left indicates that the lines pointing to the text boxes are labeled "RegularExpressionValidator controls".

- d) The Web Form after the user enters valid values for all three **TextBoxes** and presses the **Submit Button**

**outputLabel** is displayed once the user provides valid form input and submits the form

The screenshot shows a web browser window with the URL <http://localhost/>. The page title is "Demonstrating Valid". The content is a form with the heading "Please fill in all the fields in the following form:". It contains three text input fields:

- Name:  Bob White
- E-mail:  bwhite@fakeemail.com email@domain.com
- Phone:  (555) 555-5555 (555) 555-1234

Below the form, an **outputLabel** displays the message: "Thank you for your submission  
We received the following information:  
Name: Bob White  
E-mail: bwhite@fakeemail.com  
Phone: (555) 555-5555".

**Fig. 23.25** | Validators in a Web Form that retrieves user contact information. (Part 2 of 2.)

### Step 2: Creating the GUI

To create the page, perform the following steps:

1. Type "Please fill in all the fields in the following form:", then use the **Block Format** ComboBox in the IDE's toolbar to change the text to **Heading 3** format and press *Enter* to create a new paragraph.
2. Insert a three-row and two-column table. You'll add elements to the table momentarily.
3. Click below the table and add a **Button**. Set its **(ID)** property to `submitButton` and its **Text** property to `Submit`. By default, a **Button** control in a Web Form sends the contents of the form back to the server for processing. Select the **Button** then use the **Block Format** ComboBox in the IDE's toolbar to wrap the **Button** in a **Paragraph** format—this places additional space above and below the **Button**.
4. Click to the right of the **Button**, then press *Enter* to create a new paragraph. Add a **Label**. Set its **(ID)** property to `outputLabel` and clear its **Text** property—you'll set it *programmatically* when the user clicks the `submitButton`. Set the `outputLabel`'s **Visible** property to `false`, so the **Label** does *not* appear in the client's browser when the page loads for the *first* time. You'll *programmatically* display this **Label** after the user submits valid data.

Next you'll add text and controls to the table you created in *Step 2* above. Perform the following steps:

1. In the left column, type the text "Name:" in the first row, "E-mail:" in the second row and "Phone:" in the third row.
2. In the right column of the first row, add a **TextBox** and set its **(ID)** property to `nameTextBox`.
3. In the right column of the second row, add a **TextBox** and set its **(ID)** property to `emailTextBox`. Set its **TextMode** property to `Email`—this produces an HTML5 e-mail input field when the web page is rendered in the client web browser. Click to the right of the **TextBox** and type the text "`email@domain.com`" to show an example of what the user should enter in that **TextBox**.
4. In the right column of the third row, add a **TextBox** and set its **(ID)** property to `phoneTextBox`. Set its **TextMode** property to `Phone`—this produces an HTML5 phone input field when the web page is rendered in the client web browser. Click to the right of the **TextBox** and type the text "`(555) 555-1234`" to show an example of what the user should enter in that **TextBox**.

### Step 3: Using **RequiredFieldValidator** Controls

We use three **RequiredFieldValidator** controls (found in the **Validation** section of the **Toolbox**) to ensure that the name, e-mail address and phone number **TextBoxes** are *not empty* when the form is submitted. A **RequiredFieldValidator** makes an *input control* a required field. If such a field is *empty*, validation fails. Add a **RequiredFieldValidator** as follows:

1. Click to the right of the `nameTextBox` in the table and press *Enter* to move to the next line.

2. Add a **RequiredFieldValidator**, set its (ID) to `nameRequiredFieldValidator` and set the `ForeColor` property to Red.
3. Set the validator's **ControlToValidate** property to `nameTextBox` to indicate that this validator verifies the `nameTextBox`'s contents.
4. Set the validator's **ErrorMessage** property to "Please enter your name". This is displayed on the Web Form only if the validation fails.
5. Set the validator's **Display** property to `Dynamic`, so the validator occupies space on the Web Form only when validation fails. When this occurs, space is allocated dynamically, causing the controls below the validator to shift downward to accommodate the `ErrorMessage`, as seen in Fig. 23.25(a)–(c).

Repeat these steps to add two more **RequiredFieldValidator**s in the second and third rows of the table. Set their (ID) properties to `emailRequiredFieldValidator` and `phoneRequiredFieldValidator`, respectively, and set their `ErrorMessage` properties to "Please enter your email address" and "Please enter your phone number", respectively.

#### **Step 4: Using RegularExpressionValidator Controls**

This example also uses two **RegularExpressionValidator** controls to ensure that the e-mail address and phone number entered by the user are in a valid format. Visual Studio Express 2012 for Web provides several *predefined* regular expressions that you can simply select to take advantage of this powerful validation control. Add a **RegularExpressionValidator** as follows:

1. Click to the right of the `emailRequiredFieldValidator` in the second row of the table and add a **RegularExpressionValidator**, then set its (ID) to `emailRegularExpressionValidator` and its `ForeColor` property to Red.
2. Set the **ControlToValidate** property to `emailTextBox` to indicate that this validator verifies the `emailTextBox`'s contents.
3. Set the validator's **ErrorMessage** property to "Please enter an e-mail address in a valid format".
4. Set the validator's **Display** property to `Dynamic`, so the validator occupies space on the Web Form only when validation fails.

Repeat the preceding steps to add another **RegularExpressionValidator** in the third row of the table. Set its (ID) property to `phoneRegularExpressionValidator` and its `ErrorMessage` property to "Please enter a phone number in a valid format", respectively.

A **RegularExpressionValidator**'s **ValidationExpression** property specifies the regular expression that validates the **ControlToValidate**'s contents. Clicking the ellipsis next to property **ValidationExpression** in the **Properties** window displays the **Regular Expression Editor** dialog, which contains a list of **Standard expressions** for phone numbers, zip codes and other formatted information. For the `emailRegularExpressionValidator`, we selected the standard expression **Internet e-mail address**. If the user enters text in the `emailTextBox` that does not have the correct format and either clicks in a different text box or attempts to submit the form, the `ErrorMessage` text is displayed in red.

For the `phoneRegularExpressionValidator`, we selected **U.S. phone number** to ensure that a phone number contains an optional three-digit area code either in paren-

theses and followed by an optional space or without parentheses and followed by a required hyphen. After an optional area code, a phone number must contain three digits, a hyphen and another four digits. For example, (555) 123-4567, 555-123-4567 and 123-4567 are all valid phone numbers.

### *Submitting the Web Form’s Contents to the Server*

If all five validators are successful (that is, each TextBox is filled in, and the e-mail address and phone number provided are valid), clicking the **Submit** button sends the form’s data to the server. As shown in Fig. 23.25(d), the server then responds by displaying the submitted data in the **outputLabel**.

### *Examining the Code-Behind File for a Web Form That Receives User Input*

Figure 23.26 shows the code-behind file for this app. Notice that this code-behind file does not contain any implementation related to the validators. We’ll say more about this soon. In this example, we respond to the page’s **Load** event to process the data submitted by the user. Like the **Init** event, the **Load** event occurs each time the page loads into a web browser—the difference is that on a *postback* you cannot access the posted data in the controls from the **Init** handler. The event handler for this event is **Page\_Load** (lines 8–33). The event handler for the **Load** event is created for you when you add a new Web Form. To complete the event handler, insert the code from Fig. 23.26.

---

```

1 // Fig. 23.26: Validation.aspx.cs
2 // Code-behind file for the form demonstrating validation controls.
3 using System;
4
5 public partial class Validation : System.Web.UI.Page
6 {
7     // Page_Load event handler executes when the page is loaded
8     protected void Page_Load( object sender, EventArgs e )
9     {
10         // disable unobtrusive validation
11         UnobtrusiveValidationMode =
12             System.Web.UI.UnobtrusiveValidationMode.None;
13
14         // if this is not the first time the page is loading
15         // (i.e., the user has already submitted form data)
16         if ( IsPostBack )
17         {
18             Validate(); // validate the form
19
20             // if the form is valid
21             if ( IsValid )
22             {
23                 // retrieve the values submitted by the user
24                 string name = nameTextBox.Text;
25                 string email = emailTextBox.Text;
26                 string phone = phoneTextBox.Text;
27

```

---

**Fig. 23.26** | Code-behind file for the form demonstrating validation controls. (Part I of 2.)

---

```

28         // show the submitted values
29         outputLabel.Text = "Thank you for your submission<br/>" +
30             "We received the following information:<br/>";
31         outputLabel.Text +=
32             String.Format("Name: {0}{1}E-mail:{2}{1}Phone:{3}",
33                 name, "<br/>", email, phone);
34         outputLabel.Visible = true; // display the output message
35     } // end if
36 } // end if
37 } // end method Page_Load
38 } // end class Validation

```

---

**Fig. 23.26** | Code-behind file for the form demonstrating validation controls. (Part 2 of 2.)

### *ASP.NET 4.5 Unobtrusive Validation*

Prior to ASP.NET 4.5, when you used the validation controls presented in this section, ASP.NET would embed substantial amounts of JavaScript code in a web page to perform the work of the validation controls in the client web browser. ASP.NET 4.5 now uses **unobtrusive validation**, which significantly reduces the amount of JavaScript that gets embedded into the web page—this, in turn, can improve the performance of your website by making pages load faster. When you create an ASP.NET Web Forms website, everything you need for unobtrusive validation is normally configured for you—*unless* you create an *ASP.NET Empty Web Site*, as we've done for the examples in this chapter so far. To enable this app to execute correctly in the web browser, lines 11–12 *disable* unobtrusive validation. In the online Chapter 29, Web App Development with ASP.NET: A Deeper Look, we'll create a website in which unobtrusive validation is properly enabled.

### *Differentiating Between the First Request to a Page and a Postback*

Web programmers using ASP.NET often design their web pages so that the current page reloads when the user submits the form; this enables the program to receive input, process it as necessary and display the results in the same page when it's loaded the second time. These pages usually contain a form that, when submitted, sends the values of all the controls to the server and causes the current page to be requested again. This event is known as a **postback**. Line 16 uses the **IsPostBack** property of class **Page** to determine whether the page is being loaded due to a postback. The first time that the web page is requested, **IsPostBack** is **false**, and the page displays only the form for user input. When the postback occurs (from the user clicking **Submit**), **IsPostBack** is **true**.

### *Server-Side Web Form Validation*

Server-side Web Form validation must be implemented *programmatically*. Line 18 calls the current **Page**'s **Validate** method to validate the information in the request. This validates the information as specified by the validation controls in the Web Form. Line 21 uses the **IsValid** property of class **Page** to check whether the validation succeeded. If this property is set to **true** (that is, validation succeeded and the Web Form is valid), then we display the Web Form's information. Otherwise, the web page loads without any changes, except that any validator that failed now displays its **ErrorMessage**.

### *Processing the Data Entered by the User*

Lines 24–26 retrieve the values of nameTextBox, emailTextBox and phoneTextBox. When data is posted to the web server, the data that the user entered is accessible to the web app through the web controls' properties. Next, lines 29–33 set outputLabel's Text to display a message that includes the name, e-mail and phone information that was submitted to the server. In lines 29, 30 and 33, notice the use of `<br/>` rather than `\n` to start new lines in the outputLabel—`<br/>` is the markup for a line break in a web page. Line 34 sets the outputLabel's Visible property to true, so the user can see the thank-you message and submitted data when the page reloads in the client web browser.

## **23.7 Session Tracking**

Originally, critics accused the Internet and e-businesses of failing to provide the customized service typically experienced in “brick-and-mortar” stores. To address this problem, businesses established mechanisms by which they could *personalize* users’ browsing experiences, tailoring content to individual users. Businesses can achieve this level of service by tracking each customer’s movement through the Internet and combining the collected data with information provided by the consumer, including billing information, personal preferences, interests and hobbies.

### *Personalization*

**Personalization** makes it possible for businesses to communicate effectively with their customers and also improves users’ ability to locate desired products and services. Companies that provide content of particular interest to users can establish relationships with customers and build on those relationships over time. Furthermore, by targeting consumers with personal offers, recommendations, advertisements, promotions and services, businesses create customer loyalty. Websites can use sophisticated technology to allow visitors to customize home pages to suit their individual needs and preferences. Similarly, online shopping sites often store personal information for customers, tailoring notifications and special offers to their interests. Such services encourage customers to visit sites more frequently and make purchases more regularly.

### *Privacy*

A trade-off exists between personalized business service and protection of privacy. Some consumers embrace tailored content, but others fear the possible adverse consequences if the info they provide to businesses is released or collected by tracking technologies. Consumers and privacy advocates ask: What if the business to which we give personal data sells or gives that information to other organizations without our knowledge? What if we do not want our actions on the Internet—a supposedly anonymous medium—to be tracked and recorded by unknown parties? What if unauthorized parties gain access to sensitive private data, such as credit-card numbers or medical history? These are questions that must be addressed by programmers, consumers, businesses and lawmakers alike.

### *Recognizing Clients*

To provide personalized services to consumers, businesses must be able to recognize clients when they request information from a site. As we’ve discussed, the request-response system on which the web operates is facilitated by HTTP. Unfortunately, HTTP is a *stateless*

*protocol*—it *does not* provide information that would enable web servers to maintain state information regarding particular clients. This means that web servers cannot determine whether a request comes from a particular client or whether the same or different clients generate a series of requests.

To circumvent this problem, sites can provide mechanisms by which they identify individual clients. A *session* represents a unique client on a website. If the client leaves a site and then returns later, the client will still be recognized as the same user. When the user closes the browser, the session typically ends. To help the server distinguish among clients, each client must identify itself to the server. Tracking individual clients is known as **session tracking**. One popular session-tracking technique uses cookies (discussed in Section 23.7.1); another uses ASP.NET’s `HttpSessionState` object (used in Section 23.7.2). Additional session-tracking techniques are beyond this book’s scope.

### 23.7.1 Cookies

Cookies provide you with a tool for personalizing web pages. A cookie is a piece of data stored by web browsers in a small text file on the user’s computer. A cookie maintains information about the client during and between browser sessions. The first time a user visits the website, the user’s computer might receive a cookie from the server; this cookie is then reactivated each time the user revisits that site. The collected information is intended to be an anonymous record containing data that’s used to personalize the user’s future visits to the site. For example, cookies in a shopping app might store unique identifiers for users. When a user adds items to an online shopping cart or performs another task resulting in a request to the web server, the server receives a cookie containing the user’s unique identifier. The server then uses the unique identifier to locate the shopping cart and perform any necessary processing.

In addition to identifying users, cookies also can indicate users’ shopping *preferences*. When a Web Form receives a request from a client, the Web Form can examine the cookie(s) it sent to the client during previous communications, identify the user’s preferences and immediately display products of interest to the client.

Every HTTP-based interaction between a client and a server includes a header containing information either about the request (when the communication is from the client to the server) or about the response (when the communication is from the server to the client). When a Web Form receives a request, the header includes information such as the request type and any cookies that have been sent previously from the server to be stored on the client machine. When the server formulates its response, the header information contains any cookies the server wants to store on the client computer and other information, such as the type of data in the response.

The **expiration date** of a cookie determines how long the cookie remains on the client’s computer. If you do not set an expiration date for a cookie, the web browser maintains the cookie for the duration of the browsing session. Otherwise, the web browser maintains the cookie until the expiration date occurs. Cookies are deleted when they expire.



#### Portability Tip 23.1

*Users may disable cookies in their web browsers to help ensure their privacy. Such users will experience difficulty using web apps that depend on cookies to maintain state information.*

### 23.7.2 Session Tracking with HttpSessionState

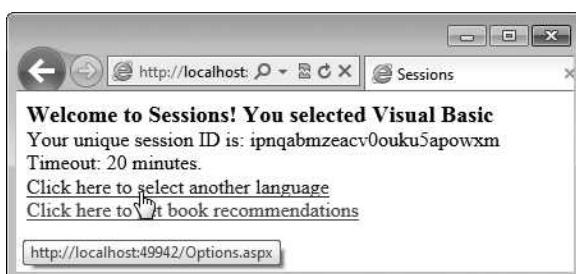
The next web app demonstrates session tracking using class **HttpSessionState**. When you execute this app, the **Options.aspx** page (Fig. 23.27(a)), which is the app's **Start Page**, allows the user to select a programming language from a group of radio buttons. [Note: You might need to right click **Options.aspx** in the **Solution Explorer** and select **Set As Start Page** before running this app.] When the user clicks **Submit**, the selection is sent to the web server for processing. The web server uses an **HttpSessionState** object to store the chosen language and the ISBN number for one of our books on that topic. Each user that visits the site has a unique **HttpSessionState** object, so the selections made by one user are maintained separately from all other users. After storing the selection, the server returns the page to the browser (Fig. 23.27(b)) and displays the user's selection and some information about the user's unique session (which we show just for demonstration purposes). The page also includes links that allow the user to choose between selecting another programming language or viewing the **Recommendations.aspx** page (Fig. 23.27(e)), which lists recommended books pertaining to the programming language(s) that the user selected previously. If the user clicks the link for book recommendations, the information stored in the user's unique **HttpSessionState** object is read and used to form the list of recommendations. To test this app:

1. Select **Open Web Site...** from the **FILE** menu.
2. In the **Open Web Site** dialog, ensure that **File System** is selected, then navigate to this chapter's examples, select the **Sessions** folder and click the **Open Button**.
3. Select **Options.aspx** in the **Solution Explorer**, then type ***Ctrl + F5*** to execute the web app in your default web browser.

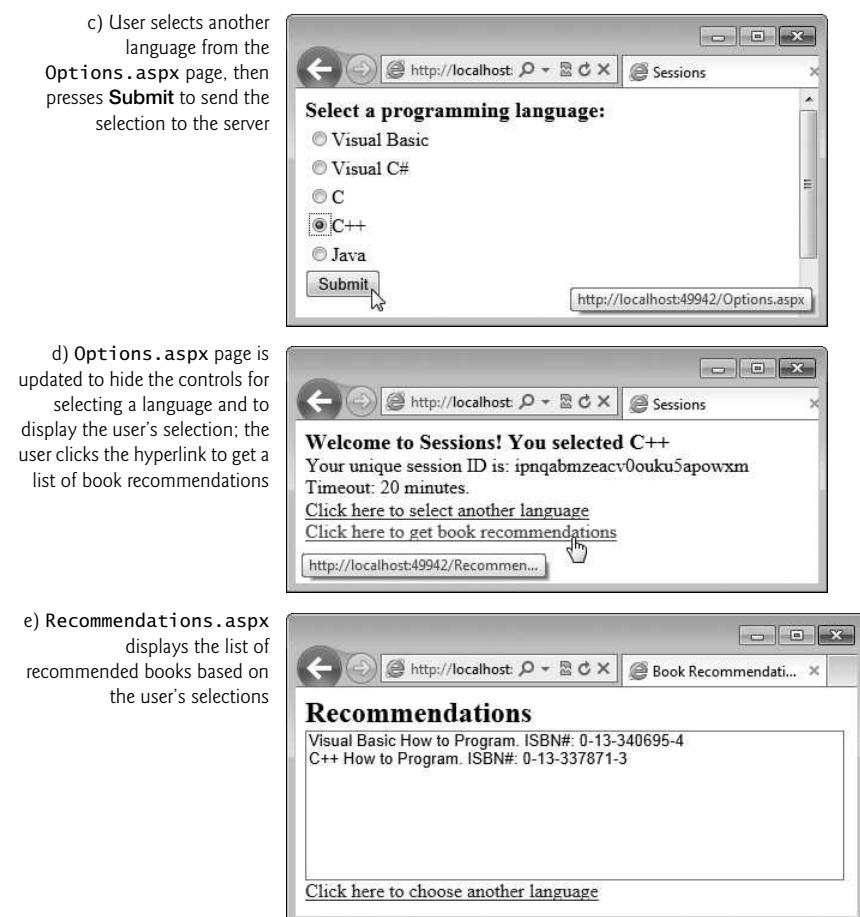
- a) User selects a language from the **Options.aspx** page, then presses **Submit** to send the selection to the server



- b) **Options.aspx** page is updated to hide the controls for selecting a language and to display the user's selection; the user clicks the hyperlink to return to the list of languages and make another selection



**Fig. 23.27** | ASPX file that presents a list of programming languages. (Part 1 of 2.)



**Fig. 23.27** | ASPX file that presents a list of programming languages. (Part 2 of 2.)

### Creating the Web Site

To begin, follow the steps in Section 23.4.1 to create an **Empty Web Site** named **Sessions**, then add two Web Forms named **Options.aspx** and **Recommendations.aspx** to the project. Set the **Options.aspx** document's **Title** property to "Sessions" and the **Recommendations.aspx** document's **Title** property to "Book Recommendations". To ensure that **Options.aspx** is the first page to load for this app, right click it in the **Solution Explorer** and select **Set As Start Page**.

### 23.7.3 Options.aspx: Selecting a Programming Language

The **Options.aspx** page Fig. 23.27(a) contains the following controls arranged *vertically*:

1. A **Label** with its **(ID)** property set to **promptLabel** and its **Text** property set to "**Select a programming language:**". We used the techniques shown in *Step 5* of Section 23.4.1 to create a *CSS style* for this label named **.labelStyle**, and set the style's **font-size** attribute to **large** and the **font-weight** attribute to **bold**.

2. The user selects a programming language by clicking one of the radio buttons in a `RadioButtonList`. Each radio button has a `Text` property and a `Value` property. The `Text` property is displayed next to the radio button and the `Value` property represents a value that's sent to the server when the user selects that radio button and submits the form. In this example, we'll use the `Value` property to represent the ISBN for the recommended book. Create a `RadioButtonList` with its `(ID)` property set to `languageList`. Use the **ListItem Collection Editor** to add five radio buttons with their `Text` properties set to Visual Basic, Visual C#, C, C++ and Java, and their `Value` properties set to 0-13-340695-4, 0-13-337933-7, 0-13-299044-X, 0-13-337871-3 and 0-13-294094-9, respectively.
3. A `Button` with its `(ID)` property set to `submitButton` and its `Text` property set to `Submit`. In this example, we'll handle this `Button`'s `Click` event. You can create its event handler by double clicking the `Button` in **Design** view.
4. A `Label` with its `(ID)` property set to `responseLabel` and its `Text` property set to "Welcome to Sessions!". This `Label` should be placed immediately to the right of the `Button` so that the `Label` appears at the top of the page when we hide the preceding controls on the page. Reuse the CSS style you created in *Step 1* by setting this `Label`'s `CssClass` property to `labelStyle`.
5. Two more `Labels` with their `(ID)` properties set to `idLabel` and `timeoutLabel`, respectively. Clear the text in each `Label`'s `Text` property—you'll set these *programmatically* with information about the current user's session.
6. A `HyperLink` with its `(ID)` property set to `languageLink` and its `Text` property set to "Click here to choose another language". Set its `NavigateUrl` property by clicking the ellipsis next to the property in the **Properties** window and selecting `Options.aspx` from the **Select URL** dialog.
7. A `HyperLink` with its `(ID)` property set to `recommendationsLink` and its `Text` property set to "Click here to get book recommendations". Set its `NavigateUrl` property by clicking the ellipsis next to the property in the **Properties** window and selecting `Recommendations.aspx` from the **Select URL** dialog.
8. Initially, the controls in *Steps 4–7* will not be displayed, so set each control's `Visible` property to `false`.

### **Session Property of a Page**

Every ASP.NET Web app includes a user-specific `HttpSessionState` object, which is accessible through property `Session` of class `Page`. Throughout this section, we use this property to manipulate the current user's `HttpSessionState` object. When the user first requests a page in a Web app, a unique `HttpSessionState` object is created by ASP.NET and assigned to the `Page`'s `Session` property. The same object is also available to the app's other pages.

### **Code-Behind File for Options.aspx**

Fig. 23.28 presents the code-behind file for the `Options.aspx` page. When this page is requested, the `Page_Load` event handler (lines 10–40) executes before the response is sent to the client. Since the first request to a page is *not a postback*, the code in lines 16–38 *does not* execute the first time the page loads.

```
1 // Fig. 23.28: Options.aspx.cs
2 // Processes user's selection of a programming language by displaying
3 // links and writing information in an HttpSessionState object.
4 using System;
5
6 public partial class Options : System.Web.UI.Page
7 {
8     // if postback, hide form and display links to make additional
9     // selections or view recommendations
10    protected void Page_Load( object sender, EventArgs e )
11    {
12        if ( IsPostBack )
13        {
14            // user has submitted information, so display message
15            // and appropriate hyperlinks
16            responseLabel.Visible = true;
17            idLabel.Visible = true;
18            timeoutLabel.Visible = true;
19            languageLink.Visible = true;
20            recommendationsLink.Visible = true;
21
22            // hide other controls used to make language selection
23            promptLabel.Visible = false;
24            languageList.Visible = false;
25            submitButton.Visible = false;
26
27            // if the user made a selection, display it in responseLabel
28            if ( languageList.SelectedItem != null )
29                responseLabel.Text += " You selected " +
30                    languageList.SelectedItem.Text;
31            else
32                responseLabel.Text += " You did not select a language.";
33
34            // display session ID
35            idLabel.Text = "Your unique session ID is: " + Session.SessionID;
36
37            // display the timeout
38            timeoutLabel.Text = "Timeout: " + Session.Timeout + " minutes.";
39        } // end if
40    } // end method Page_Load
41
42    // record the user's selection in the Session
43    protected void submitButton_Click( object sender, EventArgs e )
44    {
45        // if the user made a selection
46        if ( languageList.SelectedItem != null )
47            // add name-value pair to Session
48            Session.Add( languageList.SelectedItem.Text,
49                languageList.SelectedItem.Value );
50    } // end method submitButton_Click
51 } // end class Options
```

**Fig. 23.28** | Process user's selection of a programming language by displaying links and writing information in an HttpSessionState object.

### *Postback Processing*

When the user presses **Submit**, a postback occurs. The form is submitted to the server and **Page\_Load** executes. Lines 16–20 display the controls shown in Fig. 23.27(b) and lines 23–25 hide the controls shown in Fig. 23.27(a). Next, lines 28–32 ensure that the user selected a language and, if so, display a message in the **responseLabel** indicating the selection. Otherwise, the message "You did not select a language" is displayed.

The ASP.NET app contains information about the **HttpSessionState** object (property **Session** of the **Page** object) for the current client. The object's **SessionID** property (displayed in line 35) contains the **unique session ID**—a sequence of random letters and numbers. The *first* time a client connects to the web server, a unique session ID is created for that client and a temporary cookie is written to the client so the server can identify the client on subsequent requests. When the client makes additional requests, the client's session ID from that temporary cookie is compared with the session IDs stored in the web server's memory to retrieve the client's **HttpSessionState** object. (Since users can disable cookies in their browsers, you can also use cookieless sessions. For more information, see [msdn.microsoft.com/en-us/library/aa479314.aspx](https://msdn.microsoft.com/en-us/library/aa479314.aspx).) **HttpSessionState** property **Timeout** (displayed in line 38) specifies the maximum amount of time that an **HttpSessionState** object can be inactive before it's discarded. By default, if the user does not interact with this web app for 20 minutes, the **HttpSessionState** object is discarded by the server and a new one will be created if the user interacts with the app again. Figure 23.29 lists some common **HttpSessionState** properties.

Properties	Description
<b>Count</b>	Specifies the number of key–value pairs in the <b>Session</b> object.
<b>IsNewSession</b>	Indicates whether this is a new session (that is, whether the session was created during loading of this page).
<b>Keys</b>	Returns a collection containing the <b>Session</b> object's keys.
<b>SessionID</b>	Returns the session's unique ID.
<b>Timeout</b>	Specifies the maximum number of minutes during which a session can be inactive (that is, no requests are made) before the session expires. By default, this property is set to 20 minutes.

**Fig. 23.29** | **HttpSessionState** properties.

### *Method submitButton\_Click*

We store the user's selection in an **HttpSessionState** object when the user clicks the **Submit** Button. The **submitButton\_Click** event handler (lines 43–50) adds a key–value pair to the **HttpSessionState** object for the current user, specifying the language chosen and the ISBN number for a book on that language. The **HttpSessionState** object is a dictionary—a data structure that stores **key–value pairs**. A program uses the key to store and retrieve the associated value in the dictionary. We covered dictionaries in Chapter 21.

The key–value pairs in an **HttpSessionState** object are often referred to as **session items**. They're placed in an **HttpSessionState** object by calling its **Add** method. If the user made a selection (line 46), lines 48–49 get the selection and its corresponding value from

the `languageList` by accessing its `SelectedItem`'s `Text` and `Value` properties, respectively, then call `HttpSessionState` method `Add` to add this name–value pair as a session item in the `HttpSessionState` object (`Session`).

If the app adds a session item that has the same name as an item previously stored in the `HttpSessionState` object, the session item is replaced—session item names *must* be unique. Another common syntax for placing a session item in the `HttpSessionState` object is `Session[Name] = Value`. For example, we could have replaced lines 48–49 with

```
Session[ languageList.SelectedItem.Text ] =
languageList.SelectedItem.Value
```



### Software Engineering Observation 23.1

*A Web Form should not use instance variables to maintain client state information, because each new request or postback is handled by a new instance of the page. Instead, maintain client state information in HttpSessionState objects, because such objects are specific to each client.*



### Software Engineering Observation 23.2

*A benefit of using HttpSessionState objects (rather than cookies) is that they can store any type of object (not just Strings) as attribute values. This provides you with increased flexibility in determining the type of state information to maintain for clients.*

#### 23.7.4 Recommendations.aspx: Displaying Recommendations Based on Session Values

After the postback of `Options.aspx`, the user may request book recommendations. The book-recommendations hyperlink forwards the user to the page `Recommendations.aspx` (Fig. 23.27(e)) to display the recommendations based on the user's language selections. The page contains the following controls arranged *vertically*:

1. A `Label` with its `(ID)` property set to `recommendationsLabel` and its `Text` property set to "Recommendations". We created a CSS style for this label named `.labelStyle`, and set the `font-size` attribute to `x-large` and the `font-weight` attribute to `bold`. (See *Step 5* in Section 23.4.1 for information on creating a CSS style.)
2. A `ListBox` with its `(ID)` property set to `booksListBox`. We created a CSS style for this `ListBox` named `.listBoxStyle`. In the `Position` category, we set the `width` attribute to `450px` and the `height` attribute to `125px`. The `px` indicates that the measurement is in pixels.
3. A `HyperLink` with its `(ID)` property set to `languageLink` and its `Text` property set to "Click here to choose another language". Set its `NavigateUrl` property by clicking the ellipsis next to the property in the `Properties` window and selecting `Options.aspx` from the `Select URL` dialog. When the user clicks this link, the `Options.aspx` page will be reloaded. Requesting the page in this manner *is not* considered a postback, so the original form in Fig. 23.27(a) will be displayed.

#### *Code-Behind File for Recommendations.aspx*

Figure 23.30 presents the *code-behind file* for `Recommendations.aspx`. Event handler `Page_Init` (lines 8–28) retrieves the session information. If a user has not selected a lan-

guage in the Options.aspx page, the HttpSessionState object's **Count** property will be 0 (line 11). This property provides the number of session items contained in a HttpSessionState object. If the Count is 0, then we display the text **No Recommendations** (line 22), hide the **ListBox** (line 23) and update the **Text** of the **HyperLink** back to Options.aspx (line 26).

```

1 // Fig. 23.30: Recommendations.aspx.cs
2 // Creates book recommendations based on a Session object.
3 using System;
4
5 public partial class Recommendations : System.Web.UI.Page
6 {
7     // read Session items and populate ListBox with recommendations
8     protected void Page_Init( object sender, EventArgs e )
9     {
10         // determine whether Session contains any information
11         if ( Session.Count != 0 )
12         {
13             // display Session's name-value pairs
14             foreach ( string keyName in Session.Keys )
15                 booksListBox.Items.Add( keyName +
16                     " How to Program. ISBN#: " + Session[ keyName ] );
17         } // end if
18     else
19     {
20         // if there are no session items, no language was chosen, so
21         // display appropriate message and clear and hide booksListBox
22         recommendationsLabel.Text = "No Recommendations";
23         booksListBox.Visible = false;
24
25         // modify languageLink because no language was selected
26         languageLink.Text = "Click here to choose a language";
27     } // end else
28 } // end method Page_Init
29 } // end class Recommendations

```

**Fig. 23.30** | Session data used to provide book recommendations to the user.

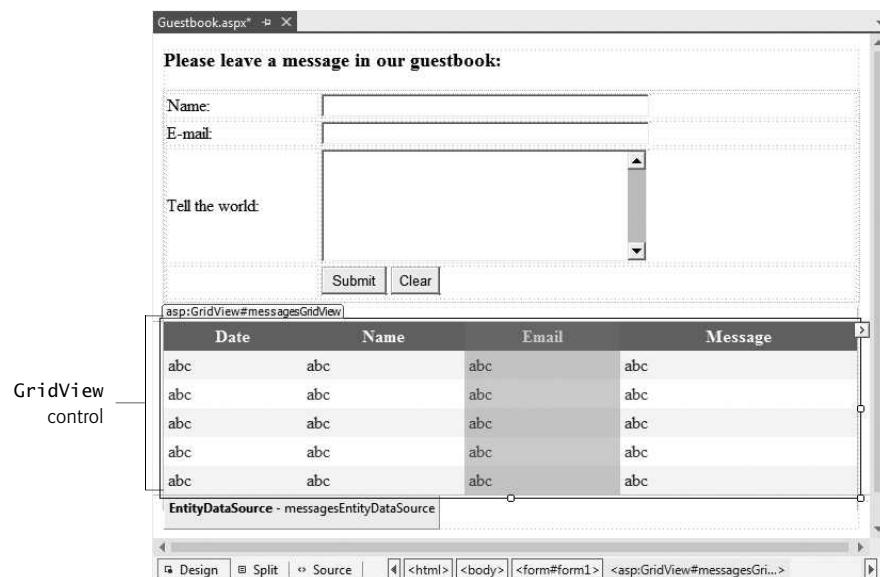
If the user chose at least one language, the loop in lines 14–16 iterates through the HttpSessionState object's keys (line 14) by accessing the HttpSessionState's **Keys** property, which returns a collection containing all the keys in the session. Lines 15–16 concatenate the **keyName**, the String "How to Program. ISBN#: " and the key's corresponding value, which is returned by **Session[keyName]**. This String is the recommendation that's added to the **ListBox**.

## 23.8 Case Study: Database-Driven ASP.NET Guestbook

Many websites allow users to provide feedback about the website in a guestbook. Typically, users click a link on the website's home page to request the guestbook page. This page usually consists of a form that contains fields for the user's name, e-mail address, message/

feedback and so on. Data submitted on the guestbook form is then stored in a database located on the server.

In this section, we create a guestbook Web Form app. The GUI (Fig. 23.31) contains a **GridView** data control, which displays all the entries in the guestbook in tabular format. This control is located in the **Toolbox's Data** section. We explain how to create and configure this data control shortly. The **GridView** displays **abc** in **Design** mode to indicate data that will be retrieved from a data source at runtime. You'll learn how to create and configure the **GridView** shortly.



**Fig. 23.31** | Guestbook app GUI in **Design** mode.

### The Guestbook Database

The app stores the guestbook information in a SQL Server database called **Guestbook.mdf** located on the web server. (We provide this database in the **databases** folder with this chapter's examples.) The database contains a single table named **Messages**.

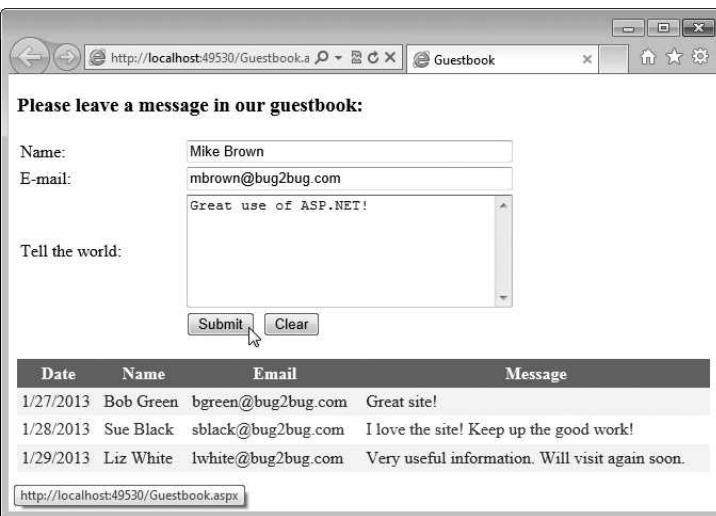
### Testing the App

To test this app:

1. Select **Open Web Site...** from the **FILE** menu.
2. In the **Open Web Site** dialog, ensure that **File System** is selected, then navigate to this chapter's examples, select the **Guestbook** folder and click the **Open** Button.
3. Select **Guestbook.aspx** in the **Solution Explorer**, then type **Ctrl + F5** to execute the web app in your default web browser.

Figure 23.32(a) shows the user submitting a new entry. Figure 23.32(b) shows the new entry as the last row in the **GridView**.

a) User enters data for the name, e-mail and message, then presses **Submit** to send the data to the server



The screenshot shows a web browser window with the URL <http://localhost:49530/Guestbook.aspx>. The page title is "Guestbook". The main content is a form titled "Please leave a message in our guestbook:" with fields for Name (Mike Brown), E-mail (mbrown@bug2bug.com), and a message area containing "Great use of ASP.NET!". Below the form is a **Submit** button and a **Clear** button. At the bottom is a **GridView** control displaying the following data:

Date	Name	Email	Message
1/27/2013	Bob Green	bgreen@bug2bug.com	Great site!
1/28/2013	Sue Black	sblack@bug2bug.com	I love the site! Keep up the good work!
1/29/2013	Liz White	lwhite@bug2bug.com	Very useful information. Will visit again soon.

<http://localhost:49530/Guestbook.aspx>

b) Server stores the data in the database, then refreshes the GridView with the updated data



The screenshot shows the same web browser window after the user has submitted the form. The **GridView** control now includes a new row for the user's submission:

Date	Name	Email	Message
1/27/2013	Bob Green	bgreen@bug2bug.com	Great site!
1/28/2013	Sue Black	sblack@bug2bug.com	I love the site! Keep up the good work!
1/29/2013	Liz White	lwhite@bug2bug.com	Very useful information. Will visit again soon.
1/31/2013	Mike Brown	mbrown@bug2bug.com	Great use of ASP.NET!

**Fig. 23.32** | Sample execution of the Guestbook app.

### 23.8.1 Building a Web Form that Displays Data from a Database

You'll now build this GUI and set up the data binding between the **GridView** control and the database. Many of these steps are similar to those performed in Chapter 22 to access and interact with a database in a Windows app. We discuss the *code-behind file* in Section 23.8.2.

#### Step 1: Creating the Web Site

To begin, follow the steps in Section 23.4.1 to create an **Empty Web Site** named **Guestbook** then add a Web Form named **Guestbook.aspx** to the project. Set the document's **Title** property to "Guestbook". To ensure that **Guestbook.aspx** loads when you execute this app, right click it in the **Solution Explorer** and select **Set As Start Page**.

### *Step 2: Creating the Form for User Input*

In Design mode, add the text `Please leave a message in our guestbook:`, then use the **Block Format ComboBox** in the IDE's toolbar to change the text to **Heading 3** format. Insert a table with four rows and two columns. Place the appropriate text (see Fig. 23.31) in the top three cells in the table's left column. Then place **TextBoxes** named `nameTextBox`, `emailTextBox` and `messageTextBox` in the top three table cells in the right column. Configure the **TextBoxes** as follows:

- Select **FORMAT > New Style...** to display the **New Style** dialog. In the **Selector** field, specify `.textBoxWidth` as the new style's name. Select the **Category** named **Position**, then set the **width:** to `300px` and click **OK** to create the style and dismiss the dialog. Next set the `CssClass` property for both the `nameTextBox` and `emailTextBox` to `textBoxWidth`. This uses the style to set both **TextBoxes** to 300 pixels wide.
- Select **FORMAT > New Style...** to display the **New Style** dialog. In the **Selector** field, specify `.textBoxHeight` as the new style's name. Select the **Category** named **Position**, then set the **height:** to `100px` and click **OK** to create the style and dismiss the dialog. Next set `messageTextBox`'s `CssClass` property to

```
textBoxWidth textBoxHeight
```

This uses both the `.textBoxWidth` and `.textBoxHeight` styles to set `messageTextBox`'s width to 300 pixels and height to 100 pixels. Also set `messageTextBox`'s `TextMode` property to `MultiLine` so the user can type a message containing multiple lines of text.

Finally, add **Buttons** named `submitButton` and `clearButton` to the bottom-right table cell. Set the buttons' `Text` properties to `Submit` and `Clear`, respectively. We discuss the buttons' event handlers when we present the code-behind file. You can create these event handlers now by double clicking each **Button** in **Design** view.

### *Step 3: Adding a **GridView** Control to the Web Form*

Add a **GridView** named `messagesGridView` that will display the guestbook entries. This control is located in the **Toolbox**'s **Data** section. The colors for the **GridView** are specified through the **Auto Format...** link in the **GridView Tasks** smart-tag menu that opens when you place the **GridView** on the page. Clicking this link displays an **AutoFormat** dialog with several choices. In this example, we chose **Professional**. We show how to set the **GridView**'s data source (that is, where it gets the data to display in its rows and columns) shortly.

### *Step 4: Creating the Entity Data Model*

Next, you'll add an entity data model to the project. Perform the following steps:

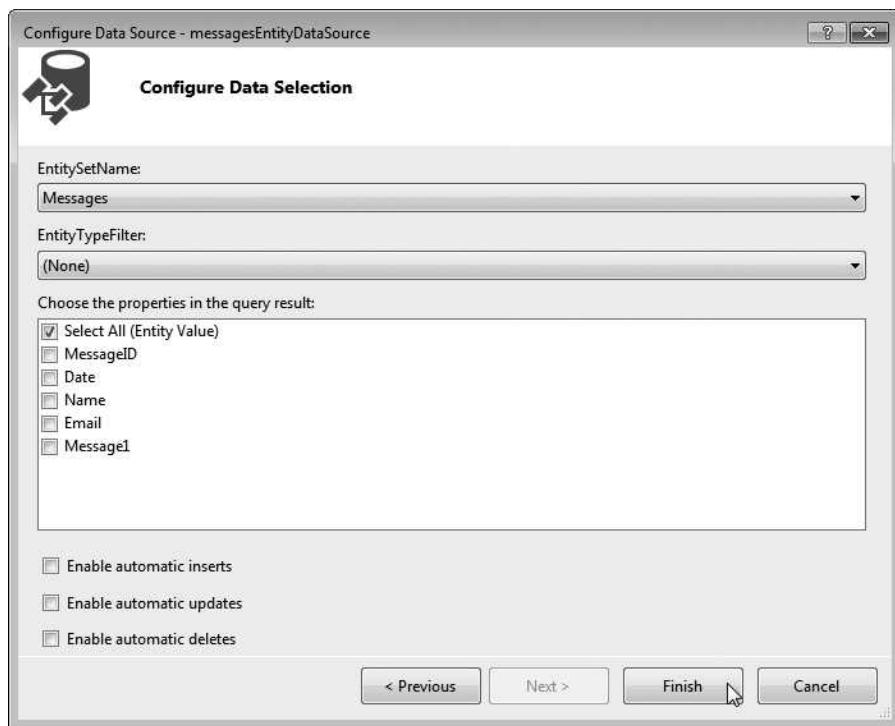
1. Right click the project name in the Solution Explorer and select **Add > Add New Item...** to display the **Add New Item** dialog.
2. Select **ADO.NET Entity Data Model**, change the **Name** to `GuestbookModel.edmx` and click **Add**. A dialog appears asking if you would like to put your new entity data model classes in the `App_Code` folder; click **Yes**. The IDE will create an `App_Code` folder and place the entity data model classes information in that folder. For security reasons, this folder can be accessed only by the web app on the server—clients cannot access this folder over a network.

3. Next, the **Entity Data Model Wizard** dialog appears. Ensure that **Generate from database** is selected so that you can generate the model from the `Guestbook.mdf` database, then click **Next >**.
4. In the **Entity Data Model Wizard** dialog's **Choose Your Data Connection** step, click **New Connection...** then use the **Connection Properties** dialog to locate the `Guestbook.mdf` database file (included in the `databases` folder with this chapter's examples). Click **OK** to create the connection, then click **Next >** to complete the **Choose Your Data Connection** step.
5. A dialog appears asking if you would like to copy the database file into your project. Click **Yes**. The IDE will create an `App_Data` folder and place the `Guestbook.mdf` file in that folder. Like the `App_Code` folder, this folder can be accessed only by the web app on the server.
6. In the **Entity Data Model Wizard** dialog's **Choose Your Database Objects and Settings** step, select the `Messages` table from the database. By default, the IDE names the model `GuestbookModel1`. Ensure that **Pluralize or singularize generated object names** is checked, keep the other default settings and click **Finish**. The IDE displays the `GuestbookModel1` in the editor, where you can see that a `Message` has a `MessageID`, `Date`, `Name`, `Email` and `Message1` property. `Message1` was renamed from `Message` by the IDE so that it does not conflict with the entity data model's `Message` class.
7. Select **BUILD > Build Solution** to ensure that the new entity data model classes are compiled.

**Step 5: Binding the GridView to the Messages Table of the Guestbook Database**

You can now configure the `GridView` to display the database's data.

1. In the `GridView Tasks` smart-tag menu, select `<New data source...>` from the `Choose Data Source` ComboBox to display the **Data Source Configuration Wizard** dialog.
2. In this example, we use a **EntityDataSource** control that allows the app to interact with the `Guestbook.mdf` database. Select **Entity**, then in the **Specify an ID for the data source** field enter `messagesEntityDataSource` and click **OK** to begin the **Configure Data Source** wizard.
3. In the **Configure ObjectContext** step, select `GuestbookEntities` in the **Named Connection** ComboBox, then click **Next >**.
4. The **Configure Data Selection** screen (Fig. 23.33) allows you to specify which data the `EntityDataSource` should retrieve from the data context. The **EntitySetName** drop-down list contains `DbContext` properties that represent database's tables. For the `Guestbook` database, select `Messages` from the drop-down list. In the **Choose the properties in the query result:** pane, ensure that the **Select All** checkbox is selected to indicate that you want to retrieve all the columns in the `Messages` table.
5. Click **Finish** to complete the wizard. A control named `messagesEntityDataSource` now appears on the Web Form directly below the `GridView`. It's represented in **Design** mode as a gray box containing its type and name. It will *not* appear on the web page—the gray box simply provides a way to manipulate the



**Fig. 23.33** | Configuring the EntityDataSource.

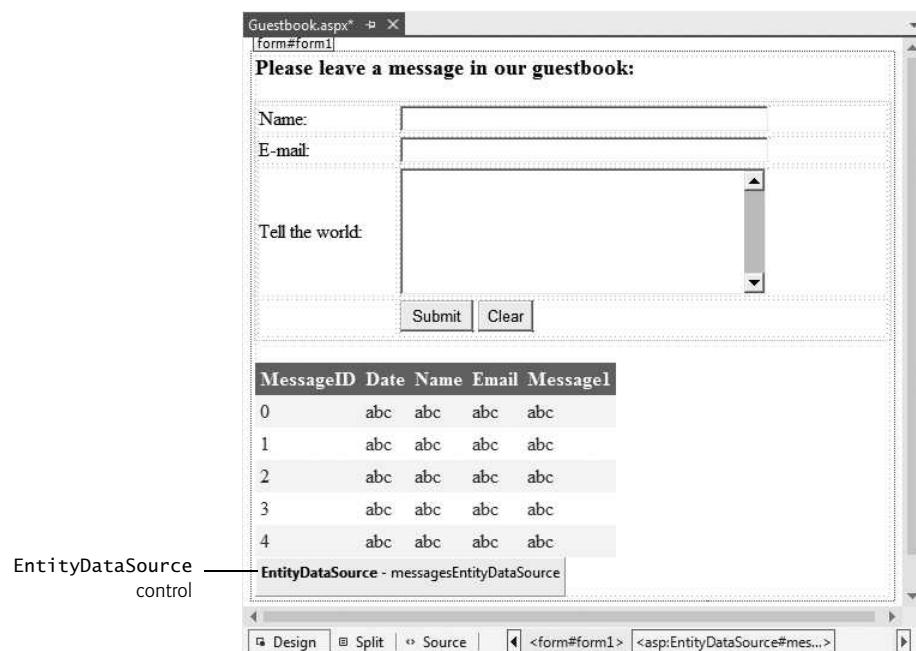
control visually through **Design** mode—similar to how the objects in the component tray are used in **Design** mode for a Windows Forms app.

6. Click the `messagesEntityDataSource`, then select **Refresh Schema** from its smart-tag menu. The `GridView` updates to display column headers that correspond to the columns in the `Messages` table (Fig. 23.34). The rows each contain either a number (which signifies an *autoincremented column*) or abc (which indicates string data). The actual data from the `Guestbook.mdf` database file will appear in these rows when you view the `ASPX` file in a web browser.

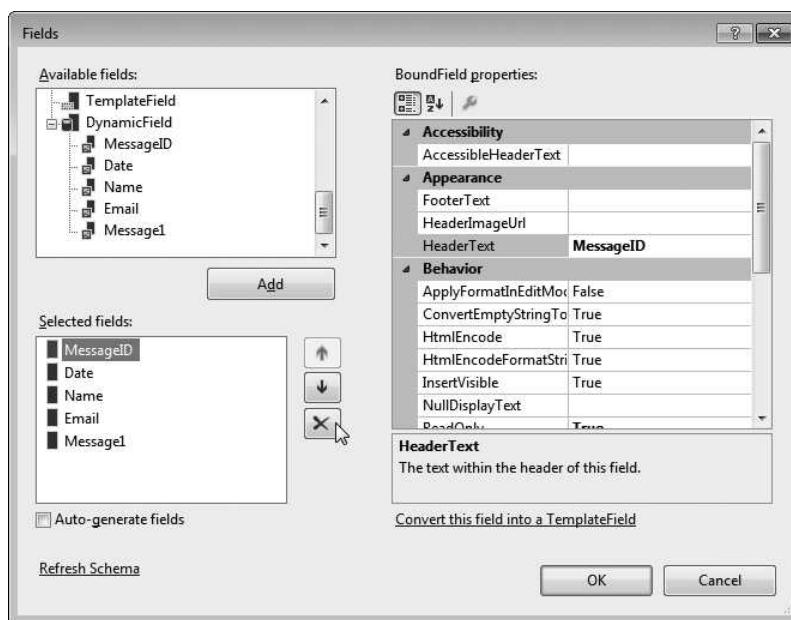
#### *Step 6: Customizing the Columns of the Data Source Displayed in the GridView*

It's not necessary for site visitors to see the `MessageID` column when viewing past guestbook entries—this column is merely a unique primary key required by the `Messages` table within the database. So, let's modify the `GridView` to prevent this column from displaying on the Web Form. We'll also modify the column `Message1` to read `Message`.

1. In the `GridView Tasks` smart tag menu, click **Edit Columns** to display the `Fields` dialog (Fig. 23.35).
2. Select `MessageID` in the **Selected fields** pane, then click the **Button**. This removes the `MessageID` column from the `GridView`.



**Fig. 23.34** | Design mode displaying EntityDataSource control for a GridView.



**Fig. 23.35** | Removing the MessageID column from the GridView.

3. Select **Message1** in the **Selected fields** pane and change its **HeaderText** property to **Message**. The IDE renamed this field to prevent a naming conflict in the entity data model classes. Click **OK** to return to the main IDE window.
4. Next create a style to specify the width of the **GridView**. Select **FORMAT > New Style...** to display the **New Style** dialog. In the **Selector** field, specify **.gridViewWidth** as the new style's name. Select the **Category** named **Position**, then set the **width:** to **650px** and click **OK** to create the style and dismiss the dialog. Next set the **CssClass** property for the **messagesGridView** to **gridViewWidth**.

The **GridView** should now appear as shown in Fig. 23.31.

### 23.8.2 Modifying the Code-Behind File for the Guestbook App

After building the Web Form and configuring the data controls used in this example, double click the **Submit** and **Clear** buttons in **Design** view to create their corresponding **Click** event handlers in the code-behind file (Fig. 23.36). The IDE generates empty event handlers, so we must add the appropriate code to make these buttons work properly. The event handler for **clearButton** (lines 39–44) clears each **TextBox** by setting its **Text** property to an empty string. This resets the form for a new guestbook submission.

---

```

1 // Fig. 23.36: Guestbook.aspx.cs
2 // Code-behind file that defines event handlers for the guestbook.
3 using System;
4
5 public partial class Guestbook : System.Web.UI.Page
6 {
7     // Submit Button adds a new guestbook entry to the database,
8     // clears the form and displays the updated list of guestbook entries
9     protected void submitButton_Click( object sender, EventArgs e )
10    {
11        // use GuestbookEntities DbContext to add a new message
12        using ( GuestbookEntities dbcontext = new GuestbookEntities() )
13        {
14            // create a new Message to add to the database; Message is
15            // the entity data model class representing a table row
16            Message message = new Message();
17
18            // set new Message's properties
19            message.Date = DateTime.Now.ToString("MM/dd/yyyy");
20            message.Name = nameTextBox.Text;
21            message.Email = emailTextBox.Text;
22            message.Message1 = messageTextBox.Text;
23
24            // add new Message to GuestbookEntities DbContext
25            dbcontext.Messages.Add( message );
26            dbcontext.SaveChanges(); // save changes to the database
27        } // end using statement
28

```

---

**Fig. 23.36** | Code-behind file for the guestbook app. (Part 1 of 2.)

---

```

29      // clear the TextBoxes
30      nameTextBox.Text = String.Empty;
31      emailTextBox.Text = String.Empty;
32      messageTextBox.Text = String.Empty;
33
34      // update the GridView with the new database table contents
35      messagesGridView.DataBind();
36  } // submitButton_Click
37
38  // Clear Button clears the Web Form's TextBoxes
39  protected void clearButton_Click( object sender, EventArgs e )
40  {
41      nameTextBox.Text = String.Empty;
42      emailTextBox.Text = String.Empty;
43      messageTextBox.Text = String.Empty;
44  } // clearButton_Click
45 } // end class Guestbook

```

---

**Fig. 23.36** | Code-behind file for the guestbook app. (Part 2 of 2.)

Lines 9–36 contain `submitButton`'s event-handling code, which adds the user's information to the `Guestbook` database's `Messages` table. The `using` statement in lines 12–27 begins by creating a `GuestbookEntities` object to interact with the database. Recall that the `using` statement will call `Dispose` on this `GuestbookEntities` object when the `using` statement terminates. This is a good practice for an ASP.NET web page request, so that we don't maintain a connection to the database beyond the request.

Line 16 creates an object of the entity data model's `Message` class, which represents a row in the database's `Messages` table. Lines 19–22 set the new `Message` object's properties to the values that should be stored in the database. Line 25 calls the `Add` method of the `GuestbookEntities` object's `Messages` property, which represents the `Messages` table in the database. This adds a new record to the entity data model's representation of the table. Line 26 then saves the changes into the database.

After the data is inserted into the database, lines 30–32 clear the `TextBoxes`, and line 35 invokes `messagesGridView`'s **DataBind** method to refresh the data that the `GridView` displays. This causes `messagesEntityDataSource` (the `GridView`'s data source) to obtain the `Messages` table's updated data from the database.

## 23.9 Online Case Study: ASP.NET AJAX

In the online Chapter 29, Web App Development with ASP.NET: A Deeper Look, you learn the difference between a traditional web app and an **AJAX (Asynchronous JavaScript and XML) web app**. You also learn how to use **ASP.NET AJAX** to quickly and easily improve the user experience for your web apps, giving them responsiveness comparable to that of desktop apps. To demonstrate **ASP.NET AJAX** capabilities, you enhance the validation example by displaying the submitted form information without reloading the entire page. The only modifications to this web app appear in `Validation.aspx` file. You use **AJAX**-enabled controls to add this feature.

## 23.10 Online Case Study: Password-Protected Books Database App

In the online Chapter 29, Web App Development with ASP.NET: A Deeper Look, we include a web app case study in which a user logs into a password-protected website to view a list of publications by a selected author. The app consists of several pages and provides website registration and login capabilities. You'll learn about ASP.NET master pages, which allow you to specify a common look-and-feel for all the pages in your app. We also introduce the **Web Site Administration Tool** and use it to configure the portions of the app that can be accessed only by users who are logged into the website.

## 23.11 Wrap-Up

In this chapter, we introduced web-app development using ASP.NET and Visual Studio Express 2012 for Web. We began by discussing the simple HTTP transactions that take place when you request and receive a web page through a web browser. You then learned about the three tiers (that is, the client or top tier, the business logic or middle tier and the information or bottom tier) that comprise most web apps.

Next, we explained the role of ASPX files (that is, Web Form files) and code-behind files, and the relationship between them. We discussed how ASP.NET compiles and executes web apps so that they can be displayed in a web browser. You also learned how to build an ASP.NET web app using Visual Studio Express For Web.

The chapter demonstrated several common ASP.NET web controls used for displaying text and images on a Web Form. We also discussed validation controls, which allow you to ensure that user input on a web page satisfies certain requirements.

We discussed the benefits of maintaining a user's state information across multiple pages of a website. We then demonstrated how you can include such functionality in a web app by using session tracking with `HttpSessionState` objects.

Finally, we built a guestbook app that allows users to submit comments about a website. You learned how to save the user input in a database and how to display past submissions on the web page.

## Summary

### Section 23.1 Introduction

- ASP.NET technology is Microsoft's technology for web-app development.
- Web Form files have the file-name extension `.aspx` and contain the web page's GUI. A Web Form file represents the web page that's sent to the client browser.
- The file that contains the programming logic of a Web Form is called the code-behind file.

### Section 23.2 Web Basics

- URIs (Uniform Resource Identifiers) identify resources on the Internet. URIs that start with `http://` are called URLs (Uniform Resource Locators).
- A URL contains information that directs a browser to the resource that the user wishes to access. Computers that run web server software make such resources available.

- In a URL, the hostname is the name of the server on which the resource resides. This computer usually is referred to as the host, because it houses and maintains resources.
- A hostname is translated into a unique IP address that identifies the server. This translation is performed by a domain-name system (DNS) server.
- The remainder of a URL specifies the location and name of a requested resource. For security reasons, the location is normally a virtual directory. The server translates the virtual directory into a real location on the server.
- When given a URL, a web browser uses HTTP to retrieve the web page found at that address.

### ***Section 23.3 Multitier App Architecture***

- Multitier apps divide functionality into separate tiers—logical groupings of functionality—that commonly reside on separate computers for security and scalability.
- The information tier (also called the bottom tier) maintains data pertaining to the app. This tier typically stores data in a relational database management system.
- The middle tier implements business logic, controller logic and presentation logic to control interactions between the app's clients and the app's data. The middle tier acts as an intermediary between data in the information tier and the app's clients.
- Business logic in the middle tier enforces business rules and ensures that data is reliable before the server app updates the database or presents the data to users.
- The client tier, or top tier, is the app's user interface, which gathers input and displays output. Users interact directly with the app through the user interface (typically viewed in a web browser), keyboard and mouse. In response to user actions, the client tier interacts with the middle tier to make requests and to retrieve data from the information tier. The client tier then displays to the user the data retrieved from the middle tier.

### ***Section 23.4.1 Building the WebTime App***

- **File System** websites are created and tested on your local computer. Such websites execute in IIS Express and can be accessed only by web browsers running on the same computer. You can later “publish” your website to a production web server for access via a local network or the Internet.
- **HTTP** websites are created and tested on an IIS web server and use HTTP to allow you to put your website’s files on the server. If you own a website and have your own web server computer, you might use this to build a new website directly on that server computer.
- **FTP** websites use File Transfer Protocol (FTP) to allow you to put your website’s files on the server. The server administrator must first create the website on the server for you. FTP is commonly used by so called “hosting providers” to allow website owners to share a server computer that runs many websites.
- A Web Form represents one page in a web app and contains a web app’s GUI.
- You can view the Web Form’s properties by selecting DOCUMENT in the **Properties** window. The **Title** property specifies the title that will be displayed in the web browser’s title bar when the page is loaded.
- Controls and other elements are placed sequentially on a Web Form one after another in the order in which you drag-and-drop them onto the Web Form. The cursor indicates the insertion point in the page. This type of layout is known as relative positioning. You can also use absolute positioning in which controls are located exactly where you drop them on the Web Form.
- When a **Label** does not contain text, its name is displayed in square brackets in **Design** view as a placeholder for design and layout purposes. This text is not displayed at execution time.
- Formatting in a web page is performed with Cascading Style Sheets (CSS).

- A Web Form's `Init` event occurs when the page is requested by a web browser. The event handler for this event—named `Page_Init`—initialize the page.

#### **Section 23.4.2 Examining `WebTime.aspx`'s Code-Behind File**

- A class declaration can span multiple source-code files—the separate portions of the class declaration in each file are known as partial classes. The `partial` modifier indicates that the class in a particular file is part of a larger class.
- Every Web Form class inherits from class `Page` in namespace `System.Web.UI`. Class `Page` represents the default capabilities of each page in a web app.
- The ASP.NET controls are defined in namespace `System.Web.UI.WebControls`.

#### **Section 23.5 Standard Web Controls: Designing a Form**

- An `Image` control's `ImageUrl` property specifies the location of the image to display.
- By default, the contents of a table cell are aligned vertically in the middle of the cell. You can change this with the cell's `valign` property.
- A `TextBox` control allows you to obtain text from the user and display text to the user.
- A `DropDownList` control is similar to the Windows Forms `ComboBox` control, but doesn't allow users to type text. You can add items to the `DropDownList` using the `ListItem Collection Editor`, which you can access by clicking the ellipsis next to the `DropDownList`'s `Items` property in the `Properties` window, or by using the `DropDownList Tasks` smart-tag menu.
- A `HyperLink` control adds a hyperlink to a Web Form. The `NavigateUrl` property specifies the resource or web page that will be requested when the user clicks the `HyperLink`.
- A `RadioButtonList` control provides a series of radio buttons from which the user can select only one. The `RadioButtonList Tasks` smart-tag menu provides an `Edit Items...` link to open the `ListItem Collection Editor` so that you can create the items in the list.
- A `Button` control triggers an action when clicked.

#### **Section 23.6 Validation Controls**

- A validation control determines whether the data in another web control is in the proper format.
- When the page is sent to the client, the validator is converted into `JavaScript` that performs the validation in the client web browser.
- Some client browsers might not support scripting or the user might disable it. For this reason, you should always perform validation on the server.
- A `RequiredFieldValidator` control ensures that its `ControlToValidate` is not empty when the form is submitted. The validator's `ErrorMessage` property specifies what to display on the Web Form if the validation fails. When the validator's `Display` property is set to `Dynamic`, the validator occupies space on the Web Form only when validation fails.
- A `RegularExpressionValidator` uses a regular expression to ensure data entered by the user is in a valid format. Visual Studio Express 2012 for Web provides several predefined regular expressions that you can simply select to validate e-mail addresses, phone numbers and more. A `RegularExpressionValidator`'s `ValidationExpression` property specifies the regular expression to use for validation.
- A Web Form's `Load` event occurs each time the page loads into a web browser. The event handler for this event is `Page_Load`.
- ASP.NET pages are often designed so that the current page reloads when the user submits the form; this enables the program to receive input, process it as necessary and display the results in the same page when it's loaded the second time.

- Submitting a web form is known as a postback. Class `Page`'s `IsPostBack` property returns `true` if the page is being loaded due to a postback.
- Server-side Web Form validation must be implemented programmatically. Class `Page`'s `Validate` method validates the information in the request as specified by the Web Form's validation controls. Class `Page`'s `IsValid` property returns `true` if validation succeeded.

### ***Section 23.7 Session Tracking***

- Personalization makes it possible for e-businesses to communicate effectively with their customers and also improves users' ability to locate desired products and services.
- To provide personalized services to consumers, e-businesses must be able to recognize clients when they request information from a site.
- HTTP is a stateless protocol—it does not provide information regarding particular clients.
- Tracking individual clients is known as session tracking.

#### ***Section 23.7.1 Cookies***

- A cookie is a piece of data stored in a small text file on the user's computer. A cookie maintains information about the client during and between browser sessions.
- The expiration date of a cookie determines how long the cookie remains on the client's computer. If you do not set an expiration date for a cookie, the web browser maintains the cookie for the duration of the browsing session.

#### ***Section 23.7.2 Session Tracking with `HttpSessionState`***

- Session tracking is implemented with class `HttpSessionState`.

#### ***Section 23.7.3 `Options.aspx`: Selecting a Programming Language***

- Each radio button in a `RadioButtonList` has a `Text` property and a `Value` property. The `Text` property is displayed next to the radio button and the `Value` property represents a value that's sent to the server when the user selects that radio button and submits the form.
- Every Web Form includes a user-specific `HttpSessionState` object, which is accessible through property `Session` of class `Page`.
- `HttpSessionState` property `SessionID` contains a client's unique session ID. The first time a client connects to the web server, a unique session ID is created for that client and a temporary cookie is written to the client so the server can identify the client on subsequent requests. When the client makes additional requests, the client's session ID from that temporary cookie is compared with the session IDs stored in the web server's memory to retrieve the client's `HttpSessionState` object.
- `HttpSessionState` property `Timeout` specifies the maximum amount of time that an `HttpSessionState` object can be inactive before it's discarded. Twenty minutes is the default.
- The `HttpSessionState` object is a dictionary—a data structure that stores key–value pairs. A program uses the key to store and retrieve the associated value in the dictionary.
- The key–value pairs in an `HttpSessionState` object are often referred to as session items. They're placed in an `HttpSessionState` object by calling its `Add` method. Another common syntax for placing a session item in the `HttpSessionState` object is `Session[KeyName] = Value`.
- If an app adds a session item that has the same name as an item previously stored in the `HttpSessionState` object, the session item is replaced—session items names *must* be unique.

### **Section 23.7.4 Recommendations.aspx: Displaying Recommendations Based on Session Values**

- The Count property returns the number of session items stored in an `HttpSessionState` object.
- `HttpSessionState`'s Keys property returns a collection containing all the keys in the session.

### **Section 23.8 Case Study: Database-Driven ASP.NET Guestbook**

- A `GridView` data control displays data in tabular format. This control is located in the **Toolbox**'s **Data** section.

#### **Section 23.8.1 Building a Web Form that Displays Data from a Database**

- To use a SQL Server Express database file in an ASP.NET web app, you must first add the file to the project's `App_Data` folder. For security reasons, this folder can be accessed only by the web app on the server—clients cannot access this folder over a network. The web app interacts with the database on behalf of the client.
- An `EntityDataSource` control enables data bound Web Form controls to interact with a database via the ADO.NET Entity Framework.

#### **Section 23.8.2 Modifying the Code-Behind File for the Guestbook App**

- To insert data into a database from a web page, you create an object of your entity data model's class that represents a row in a table, set the object's properties, then use the `Add` method to add the object to the `DbContext`'s object that represents the database table. When you call `SaveChanges` on the `DbContext`, the new row is added to the database table.
- A `GridView`'s `.DataBind` method refreshes the data that the `GridView` displays.

## **Terminology**

Add method of class <code>HttpSessionState</code>	expiration date of a cookie
Add method of an entity data model class that represents a database table	<code>GridView</code> control
ASP.NET	host
ASP.NET server control	hostname
ASPX file	HTTP (HyperText Transfer Protocol)
.aspx filename extension	<code>HttpSessionState</code> class
bottom tier	<code>HyperLink</code> control
business logic	IIS (Internet Information Services)
Button control	<code>Image</code> control
client tier	<code>ImageUrl</code> property of an <code>Image</code> web control
code-behind file	information tier
controller logic	<code>Init</code> event of a Web Form
<code>ControlToValidate</code> property of a validation control	IP (Internet Protocol) address
cookie	<code>IsPostBack</code> property of <code>Page</code> class
Count property of class <code>HttpSessionState</code>	<code>IsValid</code> property of <code>Page</code> class
<code>.DataBind</code> method of a <code>GridView</code>	key-value pair
Display property of a validation control	<code>Keys</code> property of <code>HttpSessionState</code> class
DNS (domain name system) server	Load event of Web Form
DOCUMENT in the <b>Properties</b> window	middle tier
<code>DropDownList</code> control	multitier app
<code>EntityDataSource</code> control	<i>n</i> -tier app
<code>ErrorMessage</code> property of a validation control	<code>NavigateUrl</code> property of a <code>HyperLink</code> control
	<code>Page</code> class
	<code>Page_Init</code> event handler

Page_Load event handler	tier in a multitier app
partial class	Timeout property of HttpSessionState class
partial modifier	Title property of a Web Form
personalization	top tier
postback	unique session ID of an ASP.NET client
presentation logic	Validate property of Page class
RadioButtonList control	validation control
RegularExpressionValidator validation control	ValidationExpression property of a RegularExpressionValidator control
RequiredFieldValidator control	validator
session item	Visible property of an ASP.NET control
Session property of Page class	Visual Studio Express 2012 for Web
session tracking	web-app development
SessionID property of HttpSessionState class	web control
System.Web.UI namespace	Web Form
System.Web.UI.WebControls namespace	web server
Target property of a HyperLink control	Web.config ASP.NET configuration file
TextBox control	

## Self-Review Exercises

- 23.1** State whether each of the following is *true* or *false*. If *false*, explain why.
- Web Form file names end in `.aspx`.
  - `App.config` is a file that stores configuration settings for an ASP.NET web app.
  - A maximum of one validation control can be placed on a Web Form.
  - An `EntityDataSource` control enables data bound Web Form controls to interact with a database via the ADO.NET Entity Framework.
- 23.2** Fill in the blanks in each of the following statements:
- Web apps contain three basic tiers: \_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_.
  - The \_\_\_\_\_ web control is similar to the `ComboBox` Windows control.
  - A control which ensures that the data in another control is in the correct format is called a(n) \_\_\_\_\_.
  - A(n) \_\_\_\_\_ occurs when a page requests itself.
  - Every ASP.NET page inherits from class \_\_\_\_\_.
  - The \_\_\_\_\_ file contains the functionality for an ASP.NET page.

## Answers to Self-Review Exercises

- 23.1** a) True. b) False. `Web.config` is the file that stores configuration settings for an ASP.NET web app. c) False. An unlimited number of validation controls can be placed on a Web Form. d) True.
- 23.2** a) bottom (information), middle (business logic), top (client). b) `DropDownList`. c) validator. d) postback. e) `Page`. f) code-behind.

## Exercises

- 23.3** (*WebTime Modification*) Modify the `WebTime` example to contain drop-down lists that allow the user to modify such `Label` properties as `BackColor`, `ForeColor` and `Font-Size`. Configure these drop-down lists so that a postback occurs whenever the user makes a selection—to do this, set their `AutoPostBack` properties to `true`. When the page reloads, it should reflect the specified changes to the properties of the `Label` displaying the time.

**23.4** (*Page Hit Counter*) Create an ASP.NET page that uses session tracking to keep track of how many times the client computer has visited the page. Set the `HttpSessionState` object's `Timeout` property to 1440 (the number of minutes in one day) to keep the session in effect for one day into the future. Display the number of page hits every time the page loads.

**23.5** (*Guestbook App Modification*) Add validation to the guestbook app in Section 23.8. Use validation controls to ensure that the user provides a name, a valid e-mail address and a message.

**23.6** (*Project: WebControls Modification*) Modify the example of Section 23.5 to add functionality to the `Register` Button. When the user clicks the `Button`, validate all of the input fields to ensure that the user has filled out the form completely and entered a valid email address and phone number. If any of the fields are not valid, appropriate messages should be displayed by validation controls. If the fields are all valid, direct the user to another page that displays a message indicating that the registration was successful followed by the registration information that was submitted from the form.

**23.7** (*Project: Web-Based Address Book*) Using the techniques you learned in Section 23.8, create a web-based Address book with similar functionality to the `Address Book` app that you created in Section 22.9. Display the address book's contents in a `GridView`. Allow the user to search for entries with a particular last name.



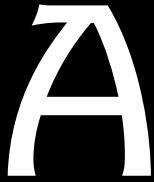
# Chapters on the Web

The following chapters are available as PDF documents from this book's Companion Website ([www.pearsonhighered.com/deitel/](http://www.pearsonhighered.com/deitel/)):

- Chapter 24, XML and LINQ to XML
- Chapter 25, Windows 8 UI and XAML
- Chapter 26, Windows 8 Graphics and Multimedia
- Chapter 27, Building a Windows Phone 8 App
- Chapter 28, Asynchronous Programming with `async` and `await`
- Chapter 29, Web App Development with ASP.NET: A Deeper Look
- Chapter 30, Web Services
- Chapter 31, Building a Windows Azure™ Cloud Computing App
- Chapter 32, GUI with Windows Presentation Foundation
- Chapter 33, WPF Graphics and Multimedia
- Chapter 34, ATM Case Study, Part 1: Object-Oriented Design with the UML
- Chapter 35, ATM Case Study, Part 2: Implementing an Object-Oriented Design

These files can be viewed in Adobe® Reader® ([get.adobe.com/reader](http://get.adobe.com/reader)).

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# Operator Precedence Chart

Operators are shown in decreasing order of precedence from top to bottom with each level of precedence separated by a horizontal line. The associativity of the operators is shown in the right column.

Operator	Type	Associativity
.	member access	left-to-right
O	method call	
[]	element access	
++	postfix increment	
--	postfix decrement	
new	object creation	
typeof	get System.Type object for a type	
sizeof	get size in bytes of a type	
checked	checked evaluation	
unchecked	unchecked evaluation	
+	unary plus	right-to-left
-	unary minus	
!	logical negation	
~	bitwise complement	
++	prefix increment	
--	prefix decrement	
( <i>type</i> )	cast	
*	multiplication	left-to-right
/	division	
%	remainder	
+	addition	left-to-right
-	subtraction	

**Fig. A.1** | Operator precedence chart (Part 1 of 2.).

Operator	Type	Associativity
>>	right shift	left-to-right
<<	left shift	
<	less than	left-to-right
>	greater than	
<=	less than or equal to	
>=	greater than or equal to	
is	type comparison	
as	type conversion	
!=	is not equal to	left-to-right
==	is equal to	
&	logical AND	left-to-right
^	logical XOR	left-to-right
	logical OR	left-to-right
&&	conditional AND	left-to-right
	conditional OR	left-to-right
??	null coalescing	right-to-left
?:	conditional	right-to-left
=	assignment	right-to-left
*=	multiplication assignment	
/=	division assignment	
%=	remainder assignment	
+=	addition assignment	
-=	subtraction assignment	
<<=	left shift assignment	
>>=	right shift assignment	
&=	logical AND assignment	
^=	logical XOR assignment	
=	logical OR assignment	

**Fig. A.1** | Operator precedence chart (Part 2 of 2.).

# B



## Simple Types

Type	Size in bits	Value range	Standard
<code>bool</code>	8	<code>true</code> or <code>false</code>	
<code>byte</code>	8	0 to 255, inclusive	
<code>sbyte</code>	8	-128 to 127, inclusive	
<code>char</code>	16	'\u0000' to '\uFFFF' (0 to 65535), inclusive	Unicode
<code>short</code>	16	-32768 to 32767, inclusive	
<code>ushort</code>	16	0 to 65535, inclusive	
<code>int</code>	32	-2,147,483,648 to 2,147,483,647, inclusive	
<code>uint</code>	32	0 to 4,294,967,295, inclusive	
<code>float</code>	32	<i>Approximate negative range:</i> -3.402823463852886E+38 to -1.40129846432481707E-45 <i>Approximate positive range:</i> 1.40129846432481707E-45 to 3.4028234663852886E+38 <i>Other supported values:</i> positive and negative zero positive and negative infinity not-a-number (NaN)	IEEE 754 IEC 60559
<code>long</code>	64	-9,223,372,036,854,775,808 to 9,223,372,036,854,775,807, inclusive	
<code>ulong</code>	64	0 to 18,446,744,073,709,551,615, inclusive	

**Fig. B.1** | Simple types. (Part I of 2.)

Type	Size in bits	Value range	Standard
<code>double</code>	64	<p><i>Approximate negative range:</i>  <math>-1.7976931348623157\text{E}+308</math> to  <math>-4.94065645841246544\text{E}-324</math></p> <p><i>Approximate positive range:</i>  <math>4.94065645841246544\text{E}-324</math> to  <math>1.7976931348623157\text{E}+308</math></p> <p><i>Other supported values:</i>  positive and negative zero  positive and negative infinity  not-a-number (NaN)</p>	IEEE 754 IEC 60559
<code>decimal</code>	128	<p><i>Negative range:</i>  <math>-79,228,162,514,264,337,593,543,950,335</math>  <math>(-7.9\text{E}+28)</math> to <math>-1.0\text{E}-28</math></p> <p><i>Positive range:</i>  <math>1.0\text{E}-28</math> to  <math>79,228,162,514,264,337,593,543,950,335</math>  <math>(7.9\text{E}+28)</math></p>	

**Fig. B.1** | Simple types. (Part 2 of 2.)

### Additional Simple Type Information

- This appendix is based on information from Sections 4.1.4–4.1.8 of Microsoft’s version of the *C# Language Specification* and Sections 11.1.4–11.1.8 of the ECMA-334 (the ECMA version of the *C# Language Specification*). These documents are available from the following websites:

[msdn.microsoft.com/en-us/vcsharp/aa336809.aspx](https://msdn.microsoft.com/en-us/vcsharp/aa336809.aspx)  
[www.ecma-international.org/publications/standards/Ecma-334.htm](http://www.ecma-international.org/publications/standards/Ecma-334.htm)

- Values of type `float` have seven digits of precision.
- Values of type `double` have 15–16 digits of precision.
- Values of type `decimal` are represented as integer values that are scaled by a power of 10. Values between –1.0 and 1.0 are represented exactly to 28 digits.
- For more information on IEEE 754 visit [grouper.ieee.org/groups/754/](http://grouper.ieee.org/groups/754/). For more information on Unicode, see Appendix F.

# C

## ASCII Character Set

	0	1	2	3	4	5	6	7	8	9
0	nu <sup>l</sup>	soh	stx	etx	eot	enq	ack	be <sup>l</sup>	bs	ht
1	n <sup>l</sup>	vt	ff	cr	so	si	dle	dc1	dc2	dc3
2	dc4	nak	syn	etb	can	em	sub	esc	fs	gs
3	rs	us	sp	!	"	#	\$	%	&	'
4	(	)	*	+	,	-	.	/	0	1
5	2	3	4	5	6	7	8	9	:	;
6	<	=	>	?	@	A	B	C	D	E
7	F	G	H	I	J	K	L	M	N	O
8	P	Q	R	S	T	U	V	W	X	Y
9	Z	[	\	]	^	-	,	a	b	c
10	d	e	f	g	h	i	j	k	l	m
11	n	o	p	q	r	s	t	u	v	w
12	x	y	z	{		}	~	de <sup>l</sup>		

**Fig. C.1** | ASCII Character Set.

The digits at the left of the table are the left digits of the decimal equivalent (0–127) of the character code, and the digits at the top of the table are the right digits of the character code. For example, the character code for “F” is 70, and the character code for “&” is 38.

Most users of this book are interested in the ASCII character set used to represent English characters on many computers. The ASCII character set is a subset of the Unicode character set used by C# to represent characters from most of the world’s languages. For more information on the Unicode character set, see Appendix F.



# Appendices on the Web

The following appendices are available as PDF documents from this book's Companion Website ([www.pearsonhighered.com/deitel/](http://www.pearsonhighered.com/deitel/)):

- Appendix D, Number Systems
- Appendix E, UML 2: Additional Diagram Types
- Appendix F, Unicode®
- Appendix G, Using the Visual Studio 2012 Debugger

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# Index

## Symbols

`&`, boolean logical exclusive OR 211, **213**  
  truth table 213  
`--`, predecrement/postdecrement 171,  
  172  
`--`, prefix/postfix decrement 171, 172  
`-`, private visibility symbol **121**  
`-`, subtraction 87, 88  
`!`, logical negation 211, **213**  
  truth table 214  
`!=`, not equals 90, 93  
`?:`, ternary conditional operator 149, 174  
.NET 4.5 16  
.NET Framework 816  
`""`, empty string **124**  
`{`, left brace 70  
`}`, right brace 70  
`@` verbatim string character 640  
`*`, multiplication 87, 88  
`*=`, multiplication compound assignment  
  operator 171  
`/`, division 87, 88  
`/* */` delimited comment 67  
`//`, single-line comment 66  
`\`, escape character 80  
`\"`, double-quote escape sequence 79  
`\=`, division compound assignment  
  operator 171  
`\n`, newline escape sequence 79  
`\r`, carriage-return escape sequence 80  
`\t`, horizontal tab escape sequence 79  
`&`, boolean logical AND 211, **213**  
`&`, menu access shortcut 571, 573  
`&&`, conditional AND **211**, 212  
  truth table 211  
`%`, remainder 87, 88  
`%=`, remainder compound assignment  
  operator 171  
`+`, addition 87, 88  
`+`, concatenation operator 650  
`+`, public visibility symbol **112**  
`++`, prefix/postfix increment 171  
`++`, preincrement/postincrement 171  
`+=`, addition compound assignment  
  operator 171  
`<`, less than 90  
`<=`, less than or equal 90  
`=`, assignment operator 84  
`-=`, subtraction compound assignment  
  operator 171  
`==`, comparison operator 643  
`==`, is equal to 90  
`>=`, lambda operator **868**  
`>`, greater than 90  
`>=`, greater than or equal to 90  
`|`, boolean logical inclusive OR 211, **213**

`||`, conditional OR 211, **212**  
  truth table **212**

## A

abbreviating assignment expressions 171  
`Abs` method of `Math` 235  
absolute positioning 908  
absolute value 235  
abstract class 443, **448**, 449, 450, 467  
abstract data type (ADT) **395**  
`abstract` keyword 423, **449**  
abstract method 449, 450, 452  
accelerometer 6  
`AcceptButton` property of class `Form`  
  522  
`AcceptsReturn` property of class  
  `TextBox` 534  
access modifier **109**, 118  
  `private` 376, 409  
  `protected` 376, **409**  
  `public` **109**, 376, 409  
access shortcut 570  
accessibility heuristic 341  
accessor **118**  
`Account` class  
  inheritance hierarchy exercise 439  
`Account` class with a constructor to  
  initialize instance variable `balance`  
  129  
Accounts Payable System Modification  
  exercise 484  
accounts-receivable file 672  
accumulator register 344, 347  
action 148, 153, 395  
action expression in the UML **145**, 147,  
  149  
action state in the UML **145**, 218  
action state symbol **145**  
action/decision model of programming  
  147  
`Activation` property of class `ListView`  
  **603**, 604  
activation record **241**  
active control **530**  
active tab **38**  
active window **521**  
`ActiveLinkColor` property of class  
  `LinkLabel` 584  
`ActiveMdiChild` property of class `Form`  
  615  
activity **145**  
activity diagram 145, 147, 218  
  `do...while` statement 201  
  `for` statement 195  
  `if` statement 147  
  `if...else` statement 148  
activity diagram (cont.)  
  in the UML 153  
  sequence statement 145  
  switch statement 208  
  while statement 153  
add a database to a project 859  
add a reference to a class library 863  
add a row to an entity collection 941  
Add method of class `ArrayList` 822,  
  **823**  
Add method of class `Dictionary` **681**  
Add method of class `Hashtable` **832**  
Add method of class  
  `HttpSessionState` **931**  
Add method of class `List<T>` **363**  
Add method of class  
  `ObjectCollection` 589  
Add Tab menu item 610  
Add User Control... option in Visual  
  Studio .NET 628  
Add Windows Form... option in Visual  
  Studio 614  
AddDay method of structure `DateTime`  
  **583**  
addition 6, 87  
AddLast method of class `LinkedList`  
  **839**  
AddYears method of structure  
  `DateTime` **583**  
“administrative” section of the computer  
  7  
ADO.NET Entity Data Model **856**  
  data source for data binding 864  
  entities 861  
ADO.NET Entity Framework **851**  
  add a row to a table 941  
  `DbContext` class 868  
  `DBExtensions` class **869**  
  entity data model **856**  
ADT (abstract data type) 395  
advertisement 925  
AfterSelected event of class  
  `TreeView` 599  
Airline Reservation System 338  
Airline Reservation System exercise 338  
AJAX (Asynchronous Javascript and  
  XML) **941**  
AJAX web app **941**  
Alarm Clock GUI exercise 63  
algebraic notation 87  
algorithm **143**, 147, 148, 154, 161  
Alphabetic icon 45  
alphabetizing 643  
`Alt` key 556  
`Alt` key shortcut 570  
`Alt` property of class `KeyEventArgs`  
  557, 559

- ALU (arithmetic and logic unit) **6**  
 anchor a control **530**  
**Anchor** property of class **Control** **532**  
 anchoring a control **530**  
 Anchoring demonstration **531**  
**Android**  
 operating system **16**  
 anonymous method **868**  
 anonymous object-creation expression **877**  
 anonymous type **361, 877**  
   **Equals** method **877**  
   **ToString** method **877**  
**Any** extension method of interface **IEnumerable<T>** **361**  
**Apache** HTTP Server **899**  
**app** **70**  
**app bar** **17**  
 app-development process **395**  
**Appearance** property of class **CheckBox**  
 539  
**Append** method of class **StringBuilder** **655**  
**AppendFormat** method of class **StringBuilder** **656, 657**  
**AppendText** method of class **File** **674**  
 application **34**  
**Application** class **578**  
 Application counts the number of occurrences of each word in a **string** and stores them in a generic sorted dictionary **834**  
 Application counts the number of occurrences of each word in a **string** and stores them in a hash table **830**  
**Application.Exit** method **591**  
**Application** class  
 Exit method **578**  
 arbitrary number of arguments **327**  
 area of a circle **280**  
**args** parameter of **Main** method **329**  
 argument promotion **242**  
 argument to a method **71, 113**  
**ArgumentException** class **832**  
**ArgumentOutOfRangeException** class **373, 382, 383, 641, 650, 657, 825**  
 arithmetic and logic unit (ALU) **6**  
 arithmetic calculation **86**  
 arithmetic mean **88**  
 arithmetic operators **86**  
 arithmetic overflow **395**  
**ARPAnet** **11**  
**ArrangeIcons** value of enumeration **MdiLayout** **616**  
**array** **286**  
 bounds checking **296**  
 ignoring element zero **298**  
**Length** property **287**  
 pass an array element to a method  
   **305**  
     pass an array to a method **305**  
 array-access expression **286**  
**ArrayList** class **331, 817, 817, 818, 820**  
**Array** class **static** methods for common array manipulations **818**  
 array-creation expression **288**  
**array initializer** **290**  
 for jagged array **318**  
 for rectangular array **317**  
 nested **317**
- Array Manipulations exercise **337**  
 array-access expression  
   for jagged arrays **318**  
   for rectangular arrays **317**  
**ArrayList** class **817, 822, 823**  
   property **Capacity** **822**  
   property **Count** **822**  
 arrays as references **307**  
 arrow **145**  
**as** operator (downcasting) **464**  
**ascending** modifier of a LINQ **orderby** clause **356**  
**ASCII** (American Standard Code for Information Interchange) character set **4, 30, 208, 349, 954**  
**ASCII character**, test for **558**  
**ASP.NET** **13, 14, 29, 898**  
   AJAX **941**  
   login **942**  
   registration **942**  
   server control **898**  
   start page **911, 914, 919, 928, 935**  
   validation control **918**  
**ASPX file** **898**  
 .aspx filename extension **898**  
**assembler** **7**  
**assembly** **863**  
 assembly (compiled code) **76**  
 assembly language **7**  
 assign a value to a variable **84**  
 Assigning base class and derived class  
   references to base class and derived class variables **446**  
 assignment operator, = **84, 90**  
 assignment operators **171**  
 assignment statement **84**  
 associate  
   left to right **174**  
   right to left **165, 174**  
 associativity of operators **88, 94, 174**  
   left to right **94**  
   right to left **88, 94**  
**async xx, 13**  
 asynchronous programming **13**  
 attribute  
   in the UML **10, 112**  
   of an object **10**  
**AuthorISBN** table of **Books** database **852, 854**  
**Authors** table of **Books** database **852, 853**  
 auto-implemented property **123**  
 auto-hide **42**  
 auto-implemented properties **685**  
 autoincremented database column **853**  
 automatic garbage collection **497**  
 automatically implemented property **123**  
**AutoPopDelay** property of class **ToolTip** **550**  
**AutoScroll** property of class **Form** **522**  
**AutoScroll** property of class **Panel** **536**  
**AutoSize** property of class **TextBox** **51**  
 average **88, 154, 157**  
**await xx, 13**
- B**
- BackColor** property of class **Control**  
 530  
 background color **49, 567**  
**BackgroundImage** property of class **Control** **530**  
 backslash, (\) **79**  
 backward reference **761**  
 bandwidth **11**  
 bar chart **228, 293, 294**  
 Bar chart printing application **293**  
 bar of asterisks **293, 294**  
**base**  
   for constructor initializers **422**  
   for invoking overridden methods **431**  
   keyword **409, 422, 431, 433**  
 base case **263**  
 base class **406**  
   constructor **413**  
   default constructor **413**  
   direct **406, 408**  
   indirect **406, 408**  
   method overridden in a derived class **431**  
**BASIC** (Beginner's All-purpose Symbolic Instruction Code) **14**  
 Big O notation **720, 726, 730, 734, 740**  
**BigInteger** **404**  
**BigInteger** struct **265**  
 binary **282**  
 binary arithmetic operators **165**  
 binary digit **670**  
 binary digit (bit) **3, 30**  
 binary integer **186**  
 binary operator **84, 86, 213**  
 binary search algorithm **721, 726**  
 binary search tree **770, 775**  
 binary tree **747, 770, 776**  
 binary tree sort **776**  
 Binary, Octal and Hexadecimal exercise **282**  
**BinaryFormatter** class **701**  
   **Deserialize** method **701**  
   **Serialize** method **703**  
**BinarySearch** method of class **Array** **820**  
**BinarySearch** method of class **ArrayList** **825**  
**BindingNavigator** class **858, 865**  
**BindingSource** class **865**  
   DataSource property **869**  
   **Edit** method **869**  
   **MoveFirst** method **873**  
 bit **670**  
 bit (binary digit) **3, 30**  
 bit manipulation **670**  
**BitArray** class **817**  
 bitwise operators **541**  
 bitwise Xor operator **579**  
 Bjarne Stroustrup **13**  
 BlackBerry OS **16**  
 blank line **68, 161**  
 block **238**  
 block of statements **151, 164**  
 BMP (Windows bitmap) **54**  
 body  
   of a class declaration **70**  
   of a loop **153**  
   of a method **71**  
   of an if statement **90**

body mass index (BMI) 32  
calculator 32  
**Books** database 852  
table relationships 855  
**bool** simple type 149, 952  
boolean expression 149  
boolean logical AND, & 211, 213  
boolean logical exclusive OR, ^ 211, 213  
truth table 213  
boolean logical inclusive OR, | 213  
**Boolean struct** 747  
**BorderStyle** property of class **Panel** 536  
bottom tier 901  
boundary of control 627  
bounds checking 296  
boxing 828, 832  
boxing conversion 748  
braces ({ and }) 151, 164, 193  
braces not required 206  
braces, { } 290  
**break keyword** 205  
**break statement** 205, 209, 229  
  exiting a **for** statement 209  
bricks-and-mortar store 925  
brittle software 427  
brute force 341, 342  
  Knight's Tour 342  
bubble sort 743, 744  
  improving performance 744  
bucket sort 744  
buffer 673  
**BufferedStream** class 673  
buffering 673  
**BUILD** menu 39  
**Build Web Site** command 913  
building block appearance 218  
Building Your Own Computer 344  
built-in array capabilities 817  
business logic 901  
business rule 901  
button 519  
**Button** ASP.NET web control 918  
**Button** class 20, 24, 520, 534  
  Click event 534  
  FlatStyle property 534  
  Text property 534  
**Button** properties and events 534  
**Button** property of class  
  MouseEventArgs 554  
**ButtonBase** class 534  
byte 4, 671  
byte simple type 952  
**Byte struct** 747

**C**

C format specifier 132  
C programming language 13  
.cs file name extension 70  
C# keywords 68  
C# Language Specification 795  
C# programming language 12  
C++ 13  
Calculating Sales exercise 228  
Calculating the Value of  $\pi$  exercise 229  
Calculating values to be placed into the elements of an array 291  
calculations 7, 95, 145

**Calculator** GUI exercise 62  
**Calendar and Appointments** GUI  
  exercise 62  
**CalendarForeColor** property of class **DateTimePicker** 581  
**CalendarMonthBackground** property of class **DateTimePicker** 581  
call stack 505  
calling method (caller) 109, 233  
**CancelButton** property of class **Form** 522  
**Canvas** class 24  
capacity of a collection 822  
**Capacity** property of class **ArrayList** 822, 825  
**Capacity** property of class **List<T>** 362, 365  
**Capacity** property of class  
  **StringBuilder** 653  
carbon footprint calculator 32  
**Card** class represents a playing card 299  
card games 299  
card shuffling  
  Fisher-Yates 302  
Card shuffling and dealing  
  application 302  
  exercise 344  
carriage return 80  
**Cascade** value of enumeration  
  **MdiLayout** 616  
cascaded window 616  
Cascading Style Sheets (CSS) 910  
case 205, 206  
  keyword 205  
case sensitive 69  
casino 245, 250  
cast  
  downcast 445  
cast expression 104  
cast operator 104, 164, 243, 254  
**catch**  
  general **catch** clause 493  
**catch all** exception types 493  
**catch an exception** 491  
**Catch block** 298  
**catch block (or handler)** 493  
**catch block with no exception type** 493  
**catch block with no identifier** 493  
**catch-related errors** 496  
**Categorized icon** 45  
**Ceil** method of **Math** 235  
Celsius  
  equivalent of a Fahrenheit temperature 280  
central processing unit (CPU) 7  
**char**  
  simple type 83  
**char** array 641  
**char** simple type 952  
**Char struct** 639  
  CompareTo method 662  
  IsDigit method 662  
  IsLetter method 662  
  IsLetterOrDigit method 662  
  IsLower method 662  
  IsPunctuation method 662  
  IsSymbol method 662  
  IsUpper method 662  
  IsWhiteSpace method 662

**Char struct** (cont.)  
  static character-testing methods  
    and case-conversion methods 660  
  **ToLower** method 662  
  **ToUpper** method 662  
**character** 4, 244, 670  
  constant 208  
  set 4, 103  
  string 71  
**character constant** 640  
**character set** 671  
**Character struct** 747  
check box 534  
**CheckBox** class 64, 520, 539  
  Appearance property 539  
  Checked property 539  
  CheckedChanged event 539  
  CheckState property 539  
  CheckStateChanged event 539  
  Text property 539  
  ThreeState property 539  
**CheckBox** properties and events 539  
**CheckBoxes** property of class **ListView** 603, 604  
**CheckBoxes** property of class **TreeView** 599  
**Checked** property of class **CheckBox** 539  
**Checked** property of class **RadioButton** 542  
**Checked** property of class  
  **ToolStripMenuItem** 574, 578  
**Checked** property of class **TreeNode** 599  
**CheckedChanged** event of class  
  **CheckBox** 539  
**CheckedChanged** event of class  
  **RadioButton** 542  
**CheckedIndices** property of class  
  **CheckedListBox** 592  
**CheckedItems** property of class  
  **CheckedListBox** 592  
**CheckedListBox** class 570, 587, 591  
  CheckedIndices property 592  
  CheckedItems property 592  
  GetItemChecked method 592  
  ItemCheck event 591, 592  
  SelectionMode property 592  
**CheckedListBox** properties and events 592  
**Checkerboard Pattern of Asterisks**  
  exercise 186  
**CheckOnClick** property of class  
  **ToolStripMenuItem** 574  
**CheckState** property of class **CheckBox** 539  
**CheckStateChanged** event of class  
  **CheckBox** 539  
child node 598, 769  
child window 614  
child window maximized 616  
child window minimized 616  
**Choose Items...** option in Visual Studio 629  
Choosing Repetition Statements exercise 182  
chromelless window 17  
Circle Area exercise 280  
circular, doubly linked list 761  
circular, singly linked list 760  
circumference 103

class **9**, 232  
 class keyword **109**  
 declaration **68**, **70**  
 declare a method **108**  
 instance variable **108**, **116**, **235**  
 instantiating an object **108**  
 name **68**, **70**, **522**, **623**  
 partial **913**  
 partial class **913**  
 user defined **68**  
 class average **154**  
 class-average problem **161**  
 class cannot extend a sealed class **466**  
 class constraint **797**  
 class hierarchy **406**, **449**  
 class keyword **109**  
 Class Library **14**  
 class library **407**, **434**, **622**  
   add a reference **863**  
   assembly **863**  
 Class View (Visual Studio .NET) **396**  
 "class-wide" information **390**  
 Classes  
   Application **578**  
   ArgumentException **832**  
   ArgumentOutOfRangeException  
     **382**, **383**, **825**  
   ArrayList **817**, **822**, **823**, **825**  
   BinaryFormatter **701**  
   BindingNavigator **865**  
   BindingSource **865**, **869**  
   BitArray **817**  
   BufferedStream **673**  
   Button **534**  
   ButtonBase **534**  
   CheckBox **539**  
   CheckedListBox **570**, **587**, **591**  
   ComboBox **570**, **594**  
   Console **71**, **78**, **80**, **672**, **673**  
   Control **529**, **530**, **532**, **627**  
   Convert **84**, **330**  
   DataContext **862**  
   DataGridView **858**  
   DateTimePicker **580**  
   DbContext **857**, **862**  
   Delegate **527**  
   Dictionary **681**, **682**, **817**  
   Directory **674**, **678**  
   DirectoryInfo **608**, **674**  
   DivideByZeroException **490**,  
     **492**, **496**  
   DropDownList **917**  
   Enumerable **857**  
   EventArgs **524**  
   Exception **496**  
   ExecutionEngineException **496**  
   File **673**, **674**, **677**, **682**  
   FileInfo **608**  
   FileStream **673**  
   Font **541**  
   Form **521**, **522**, **615**  
   FormatException **490**, **492**  
   Graphics **556**, **597**  
   GroupBox **536**  
   Hashtable **829**, **830**, **832**  
   HttpSessionState **927**, **931**, **931**,  
     **932**, **933**  
   Image **915**

Classes (cont.)  
 ImageList **599**, **603**  
 IndexOutOfRangeException **298**  
 InvalidCastException **464**,  
   **748**, **816**, **833**  
 InvalidOperationException  
   **821**, **828**, **839**  
 ItemCheckEventArgs **592**  
 KeyEventArgs **556**, **557**, **559**  
 KeyNotFoundException **836**  
 LinkedList **817**, **836**, **839**  
 LinkedListNode **836**  
 LinkLabel **570**, **583**, **584**  
 List **817**  
 List<T> **362**, **363**, **365**, **817**  
 ListBox **570**, **587**  
 ListBox.ObjectCollection **588**  
 ListView **603**  
 ListViewItem **604**  
 Match **639**, **662**  
 Math **234**, **235**  
 MemoryStream **673**  
 MenuStrip **571**  
 MonthCalendar **579**  
 MouseEventArgs **554**  
 MulticastDelegate **527**  
 NullReferenceException **496**  
 NumericUpDown **520**, **551**  
 object **410**, **434**  
 ObjectCollection **588**, **589**, **591**  
 ObservableCollection<T> **869**,  
   **873**  
 OpenFileDialog **695**, **700**  
 OutOfMemoryException **496**, **749**  
 Page **913**, **924**, **929**  
 PaintEventArgs **626**  
 Panel **536**  
 Path **603**, **681**  
 PictureBox **547**, **617**  
 Process **586**  
 Queryable **857**  
 Queue **817**  
 RadioButton **539**, **542**  
 Random **245**, **338**  
 Rational **403**  
 ResourceManager **549**  
 Resources **549**  
 SaveFileDialog **689**  
 SolidBrush **556**  
 SortedDictionary **817**, **834**, **835**  
 SortedList **817**, **817**  
 SortedSet<T> **842**  
 Stack **799**, **817**, **826**  
 StackOverflowException **496**  
 Stream **673**, **673**  
 StreamReader **673**  
 StreamWriter **673**  
 string **639**  
 StringBuilder **639**, **652**, **655**,  
   **656**, **657**  
 SystemException **496**  
 TabControl **609**  
 TabPage **609**  
 TextBox **520**  
 TextReader **673**  
 TextWriter **673**  
 Timer **628**  
 ToolStripMenuItem **571**, **573**  
 ToolTip **549**, **550**

Classes (cont.)  
 TreeNode **598**, **599**  
 TreeNodeCollection **598**  
 TreeView **570**, **598**, **599**  
 TreeViewEventArgs **599**  
 Type **435**, **464**  
 UnauthorizedAccessException  
   **603**  
 UserControl **627**  
 ValueType **660**, **748**  
 Clear method of class Array **821**  
 Clear method of class ArrayList **822**  
 Clear method of class Dictionary **682**  
 Clear method of class Graphics **597**  
 Clear method of class List<T> **362**  
 Clear method of class  
   ObjectCollection **591**  
 ClearSelected method of class  
   ListBox **588**  
 click a Button **522**, **534**  
 Click event of class Button **534**  
 Click event of class PictureBox **547**  
 Click event of class  
   ToolStripMenuItem **573**, **574**  
 Clicks property of class  
   MouseEventArgs **554**  
 client code **233**, **445**  
 client of a class **395**  
 client of a method **233**  
 client tier **901**  
 ClipRectangle property of class  
   PaintEventArgs **626**, **627**  
 clock **628**  
 cloning objects  
   shallow copy **435**  
 close a project **39**  
 close a window **522**  
 close box **56**, **57**  
 Close method of class Form **522**  
 closed tour **342**  
 cloud computing **19**  
 CLR (Common Language Runtime) **15**,  
   **497**, **511**  
 code **7**  
 code-behind file **898**  
 code reuse **406**, **815**  
 code snippets **123**  
 code snippets (IDE)  
   switch **255**  
 code walkthrough **66**  
 coin tossing **245**  
 Coin Tossing exercise **281**  
 collapse a tree **43**  
 Collapse method of class TreeNode  
   **599**  
 collapse node **598**  
 collection **362**, **790**, **815**  
 collection class **815**  
 collection initializers **366**  
 collision **829**  
 Color structure **556**  
 column **316**  
 column index **321**  
 column of a database table **851**, **852**  
 columns of a two-dimensional array **316**  
 Combining Control Statements exercise  
   **182**  
 ComboBox class **520**, **570**, **594**  
   DropDownStyle property **594**, **595**

ComboBox class (cont.)  
     Items property 594, **595**  
     MaxDropDownItems property 594  
     SelectedIndex property **595**  
     SelectedIndexChanged event  
         **595**  
     SelectedItem property **595**  
     Sorted property 595  
 ComboBox control  
     SelectedIndexChanged event  
         handler 873  
 ComboBox demonstration 594  
 ComboBox properties and an event 594  
 ComboBox used to draw a selected shape 595  
 ComboBoxStyle enumeration **595**  
     DropDown value 595  
     DropDownList value 595  
     Simple value 595  
 comma (,) 196  
 comma in an argument list 80  
 comma-separated list 196  
     of parameters 238  
     of arguments **80**, 83  
 command-line argument **236**, **329**, 330  
 Command-Line Arguments exercise 337  
**Command Prompt** 66, 329  
**comment** 66  
 commission 183, 337  
**CommissionEmployee** class represents a  
     commission employee 411, 428  
**CommissionEmployee** class that  
     extends Employee 457  
 Common Language Runtime (CLR) 15,  
     497, 511  
 Common Programming Errors overview  
     xxxiv  
**CompareTo** method  
     of **IComparable** 796  
     of interface **IComparable** 476  
**CompareTo** method of **IComparable** 777  
**CompareTo** method of **struct Char** 662  
 comparison operator 476  
 comparison operators **90**  
 compilation error **67**  
 compile 72  
 compile-time error **67**  
 compiler 8  
 compiler error **67**  
 compile-time type safety **790**  
 compiling 747  
 complex number 403  
 Complex Numbers (exercise) 403  
**ComplexNumber** class 477  
 component **520**  
 component selection drop-down list **45**  
 component tray **550**, 865  
 composite key **851**  
 composite primary key 854  
 composition **386**, 407, 409  
 compound assignment operators 171,  
     173  
     \*= 171  
     \= 171  
     %**= 171**  
     +**= 171**  
     -**= 171**  
 compound interest 197, 228  
 Compound Interest Program exercise  
     (modified) 228  
 compound-interest  
     calculating with **for** 197  
 computer-assisted instruction (CAI)  
     exercise 284  
 computer-assisted instruction (CAI)  
     exercise: Reducing Student Fatigue 284  
 computer program **2**, **27**  
 computer programmer **2**  
 computer simulator 346  
 computer simulator exercise 346  
 computer-assisted instruction (CAI)  
     exercise 284  
 Computerization of Health Records 141  
 computers in education 284  
 Concat method of class **string** 650  
 concatenate strings 392  
 concrete class **448**  
 concrete derived class 453  
 condition **90**, 200  
 conditional AND (**&&**) operator **211**,  
     212, 213, 360  
     truth table 211  
 conditional expression **149**  
 conditional operator, **? :** 149, 174  
 conditional OR, **||** 211, **212**  
     truth table **212**  
 confusing the equality operator == with  
     the assignment operator = 90  
 connect to a database 857, **859**  
 connection string 860, 864  
 console app **66**, 72  
**Console** class 672, 673  
     ReadLine method 114  
 console window 66, 78, 79  
**Console.WriteLine** method **80**  
**Console.WriteLine** method **71**, 78  
**const**  
     keyword 208, **235**, 291  
**const** keyword 393  
 constant **208**, 235, 291  
     declare 291  
     must be initialized 291  
 constant integral expression **201**, 208  
 constant run time **720**  
 constant string expression **201**, 208  
 constant variable 292  
 Constants  
     **Math.PI** 103  
     **Nan** of structure **Double** **490**, 511  
     **NegativeInfinity** of structure  
         **Double** **490**  
     **PositiveInfinity** of structure  
         **Double** **490**  
 constituent controls **627**  
 constrained version of a linked list 762  
 constructor 125  
     naming 126  
     parameter list 126  
 constructor constraint (**new()**) **798**  
 constructor initializer **382**, 422  
     with keyword **base** 422  
 container **520**, **521**  
**Contains** method of class **ArrayList** 822, **825**  
**Contains** method of class **List<T>** 362,  
     **365**

Contains method of class **Stack** **828**  
**ContainsKey** method of class  
     **Dictionary** **681**  
**ContainsKey** method of **Hashtable** 832  
 context-sensitive help **46**  
 contextual keyword 119  
 contextual keywords 68, **69**  
**continue** keyword **209**  
**continue** statement 209, 210, 229, 230  
     terminating an iteration of a **for**  
         statement 210  
 contravariance **842**  
**control** **38**, 44, 520  
 control boundary 627  
**Control** class **529**, 627  
     Anchor property 532  
     BackColor property 530  
     BackgroundImage property 530  
     Dock property 532  
     Enabled property **530**  
     Focused property 530  
     Font property 530  
     ForeColor property 530  
     Hide method 530  
     KeyDown event **556**, 557  
     KeyPress event **556**, 557  
     KeyUp event **556**, 557  
     Location property 532  
     MaximumSize property 532  
     MinimumSize property 532  
     MouseDown event 554  
     MouseEnter event 554  
     MouseHover event 554  
     MouseLeave event 554  
     MouseMove event 554  
     MouseUp event 554  
     MouseWheel event 554  
     OnPaint method **626**  
     Padding property 532  
     Select method **530**  
     Show method 530  
     Size property 532  
     TabIndex property **530**  
     TabStop property 530  
     Text property 530  
     Visible property 530  
 control layout and properties 529  
**Control** property of class  
     **KeyEventArgs** 557, 559  
 control statement 146, 147, 190  
     nesting 146, 218  
     stacking 146, 218  
 control structure 144  
 control variable **154**, **190**, 191, 192, 193  
 controller logic **901**  
**Controls** **20**, **24**  
     BindingNavigator **865**  
     Button **20**, **24**, **918**  
     Canvas 24  
     CheckBox 64  
     DataGridView **858**  
     DropDownList **917**  
     EntityDataSource **937**  
     GroupBox **20**, **24**, 63  
     HyperLink **918**  
     Image **915**  
     Label **38**, **47**, 50  
     MenuStrip 61

Controls (cont.)  
 MonthCalendar 62  
 Panel 20, 63  
 PictureBox 38, 47, 53  
 RadioButton 20, 24, 25, 63  
 RadioButtonList 918  
 RegularExpressionValidator 922  
 RequiredFieldValidator 921, 922  
 RichTextBox 61  
 TextBox 24  
 TextBox 63  
 TrackBar 64  
 Controls property of class GroupBox 536, 537  
 Controls property of class Panel 536  
 ControlToValidate property of an ASP.NET validation control 922  
 converge on a base case 263  
 convert  
     an integral value to a floating-point value 243  
 Convert class 84, 91, 330  
     ToDecimal method 133  
     ToInt32 method 330  
 Converting Grade Averages to a Four-Point Scale exercise 281  
 cookie 926, 926  
     deletion 926  
     expiration 926  
     expiration date 926  
     header 926  
 Cooking with Healthier Ingredients exercise 667  
 Copy method of class Array 820  
 Copy method of class File 674  
 copying objects  
     shallow copy 435  
 CopyTo method of class string 642  
 Cos method of Math 235  
 cosine 235  
 Count extension method of interface IEnumerable<T> 361  
 Count method (LINQ) 681  
 Count property of Hashtable 833  
 Count property of class ArrayList 822, 825  
 Count property of class  
     HttpSessionState 931, 933  
 Count property of class List<T> 364  
 counter 154, 160, 167  
 counter-controlled repetition 154, 163, 166, 167, 190, 191, 192, 346  
     with the for repetition statement 192  
     with the while repetition statement 190  
 covariance 841  
 covariant  
     interface 841  
 CPU (central processing unit) 7  
 craps (casino game) 245, 250, 281, 338  
 Craps class simulates the dice game craps 251  
 Craps game exercise 338  
 Craps Game Modification exercise 281  
 create a reusable class 622  
 create an object of a class 111  
 Create and write to a sequential-access file 685  
 Create method of class File 674  
 CreateDirectory method of class Directory 674  
 CreateInstance method of class Array 821  
 CreateText method of class File 674  
 creating a child Form to be added to an MDI Form 614  
 creating a generic method 806  
 creating and initializing an array 289  
 creating GradeBook object 157, 165  
 credit inquiry 696  
 Credit Limit Calculator exercise 183  
 credit limit on a charge account 183  
 .cs file name extension 43  
 .csproj file extension 54  
 CSS attribute 910  
 CSS class 910  
 Ctrl key 204, 556  
 Ctrl + z 204  
 Current property of IEnumarator 820  
 current time 629  
 CurrentValue property of class ItemCheckEventArgs 592  
 cursor 71, 78  
 custom control 626, 627  
     creation 627, 629  
 Custom palette 50  
 Custom tab 50  
 Custom value of enumeration DateTimePickerFormat 580  
 CustomFormat property of class DateTimePicker 581  
 customize a Form 44  
 customize Visual Studio IDE 40

**D**

D format specifier 132, 294  
 dangling else problem 150, 185  
     exercise 185  
 data 2, 27  
 data abstraction 395  
 data binding 857  
 data hierarchy 3, 671  
 data in support of actions 395  
 data representation 395  
 data source 355  
 data source (entity data model) 864  
 Data Source Configuration Wizard 864  
 Data Sources window 864, 864  
 data structure 286, 747  
 data validation 122  
 database 5, 29, 672, 850  
     add to a project 859  
     saving changes in LINQ to Entities 869  
         schema 852  
 database connection 859  
 database management system (DBMS) 672, 850  
 database schema 852, 856  
 database table 851  
 DataBind method of a GridView 941  
 DataContext class 862  
     SaveChanges method 857  
 DataGridView class 858  
 DataGridView control 858, 864  
 DataSource property  
     BindingSource class 869  
 Date property of a DateTime 580  
 DateChanged event of class MonthCalendar 579, 580  
 DateTime structure 629  
     AddDay method 583  
     AddYears method 583  
     DayOfWeek property 583  
     Now property 629, 913  
     ToLongDateString method 583  
     ToLongTimeString method 629  
 DateTimePicker class 580  
     CalendarForeColor property 581  
     CalendarMonthBackground property 581  
     CustomFormat property 581  
     Format property 580, 581  
     MaxDate property 581, 583  
     MinDate property 581, 583  
     ShowCheckBox property 581  
     ShowUpDown property 581  
     Value property 580, 581, 583  
     ValueChanged event 581  
 DateTimePickerFormat enumeration 580  
     Custom value 580  
     Long value 580  
     Short value 580  
     Time value 580  
 DayOfWeek enumeration 583  
 DayOfWeek property of structure DateTime 583  
 DB2 850  
 DbContext class 857, 868  
     SaveChanges method 869  
 DBExtensions class 869  
     Load extension method 869, 871  
 DBMS (database management system) 672, 850  
 dealing 299  
 debug a web application 912  
 DEBUG menu 40  
 Debugging 40  
 decimal 128, 129  
 decimal digit 3, 670  
 decimal point 165  
 decimal simple type 83, 128, 953  
 DecimalPlaces property of class NumericUpDown 551  
 decision 90, 147  
 decision symbol 147  
 declaration 82  
     class 68, 70  
     method 71  
 declarative programming 353  
 declare a constant 291  
 declare a method of a class 108  
 decrement 190  
 decrement operator, -- 171, 172  
 decrypt 188  
 deeply nested statement 219  
 default  
     case in a switch 205  
     keyword 205  
 default case 249  
 default constructor 385, 413  
 default event of a control 527

- default initial value of a field **120**  
 default settings **21**, **25**  
 default type constraint (*object*) of a type  
     parameter **802**  
 default value **175**  
 default value for optional parameter **260**,  
     **261**  
 deferred execution **366**  
 definite repetition **154**  
 definitely assigned **156**, **253**  
 delegate **526**  
     Delegate class **527**  
     MulticastDelegate class **527**  
     registering an event handler **526**  
 Delegate class **527**  
 delegate keyword **526**  
 Delete method of class *Directory* **674**  
 Delete method of class *File* **674**, **682**  
 deletion **751**  
 delimited comments **67**  
 dependent condition **212**  
 dequeue operation of queue **766**  
 derived class **406**  
 descending modifier of a LINQ  
     orderby clause **356**  
 deselected state **542**  
 Deserialize method of class  
     BinaryFormatter **701**  
 deserialized object **701**  
 design mode **56**  
 design process **10**, **28**  
 Design view **36**, **48**  
 destructor **390**  
 dialog **36**  
*DialogResult* enumeration **547**, **690**  
 diameter **103**  
 diamond **145**, **147**  
 diamond symbol **229**  
 dice game **250**  
 Dice Rolling exercise **338**  
 dictionary **834**, **931**  
*Dictionary*(*K*, *V*) generic class  
     **681**, **817**  
     Add method **681**  
     Clear method **682**  
     ContainsKey method **681**  
     Keys property **682**  
     Remove method **682**  
*DictionaryEntry* structure **833**  
 digit **83**  
 digits reversed **281**  
 direct base class **406**, **408**  
*Directory* class **674**, **678**  
     .CreateDirectory method **674**  
     .GetFiles method **681**  
*Directory* class methods (partial list)  
     **674**  
*DirectoryInfo* class **608**, **674**  
     Exists method **609**  
     FullName property **608**  
     GetDirectories method **608**  
     GetFiles method **608**  
     Name property **608**  
     Parent property **609**  
 disk **3**  
 display output **94**  
*Display* property of an ASP.NET  
     validation control **922**  
 Displaying a Bar Chart exercise **228**  
 Displaying a Diamond exercise **229**  
 Displaying a Square of Any Character  
     exercise **280**  
 displaying line numbers in the IDE **xlii**  
 Displaying Square of Asterisks exercise  
     **280**  
 Displaying the Decimal Equivalent of a  
     Binary Number exercise **186**  
 Displaying Triangles exercise **228**  
*Dispose* method of interface  
     `IDisposable` **477**, **504**  
 Distance Between Two Points exercise  
     **281**  
 distance between values (random  
     numbers) **250**  
*Distinct* extension method of interface  
     `IEnumerable<T>` **361**  
*Distinct* query operator (LINQ) **681**  
 divide-and-conquer approach **232**, **233**  
 divide by zero **161**, **490**, **492**  
*DivideByZeroException* class **490**,  
     **492**, **493**, **496**  
 division **6**, **87**  
 division by zero is undefined **395**  
 .d11 file **76**, **623**  
 DNS (Domain Name System) server **899**  
 do keyword **199**  
 do...while repetition statement **146**,  
     **199**, **200**, **201**, **221**  
 dock a control **531**  
*Dock* property of class *Control* **532**, **866**  
 docking demonstration **532**  
 DOCUMENT (representing a Web Form  
     Properties window) **908**  
 domain name system (DNS) server **899**  
 dotted line in the UML **145**  
*Double* **796**  
     (double) cast **164**  
     double equals, == **90**  
 double-precision floating-point number  
     **128**  
 double quote, " **71**, **79**  
 double selection **220**  
 double-selection statement **146**, **167**  
 double simple type **83**, **162**, **953**  
*Double* struct **747**  
*Double.NaN* **490**, **511**  
*Double.NegativeInfinity* **490**  
*Double.PositiveInfinity* **490**  
 doubly linked list **761**  
 down-arrow button **50**  
 downcast **463**, **833**  
 downcasting **445**  
 drag the mouse **45**  
 Draw event of class *ToolTip* **550**  
 draw on control **627**  
*DrawEllipse* method of class  
     `Graphics` **597**  
*DrawPie* method of class *Graphics* **598**  
*DrawRectangle* method of class  
     `Graphics` **598**  
 DreamSpark xxxv  
 drop-down list **520**, **594**  
*DropDown* value of enumeration  
     `ComboBoxStyle` **595**  
*DropDownList* ASP.NET web control  
     **917**  
*DropDownList* value of enumeration  
     `ComboBoxStyle` **595**
- DropDownStyle property of class  
     `ComboBox` **594**, **595**  
 dual-core processor **7**, **28**  
 dummy value **159**  
 duplicate elimination **776**  
 Duplicate Elimination exercise **337**  
 Duplicate Word Removal exercise **370**  
 dynamic binding **463**  
 dynamic data structures **747**  
 dynamic memory allocation **749**, **750**  
 dynamic resizing **352**  
 dynamic resizing of a *List* collection **363**  
 dynamically linked library **76**, **623**
- ## E
- E formatting code **132**  
 Ecofont **568**  
 EDIT menu **39**  
 editable list **595**  
 EF (ADO.NET Entity Framework) **851**  
 efficiency of  
     binary search **726**  
     bubble sort **744**  
     insertion sort **734**  
     linear search **721**  
     merge sort **740**  
     selection sort **730**  
 Eight Queens exercise **342**  
     Brute Force Approaches **342**  
 electronic mail (e-mail) **11**  
 element of an array **286**  
 element of chance **245**  
 eligible for destruction **389**, **393**  
 eligible for garbage collection **390**, **393**  
 eliminate resource leak **498**  
 ellipsis button **51**  
*else* **148**  
 e-mail (electronic mail) **11**  
 embedded systems **3**  
*Employee* abstract base class **453**, **472**  
*Employee* class with *FirstName*,  
     *LastName* and *MonthlySalary*  
     properties **357**  
*Employee* class with references to other  
     objects **388**  
*Employee* hierarchy test application **460**  
 employee identification number **5**  
 empty set **403**  
 empty statement **152**  
 empty statement (semicolon by itself) **93**,  
     **200**  
 empty string  
     "" **124**  
     `string.Empty` **124**  
*EmptyStackException* indicates a  
     stack is empty **801**  
*Enabled* property of class *Control* **530**  
 encapsulation **10**, **118**, **122**, **466**  
 encrypt **188**  
 "end of data entry" **159**  
 end-of-file (EOF)  
     indicator **204**  
 end-of-file marker **672**  
*EndEdit* method of class  
     `BindingSource` **869**  
*Endswith* method of class *string* **645**,  
     **646**

- Enforcing Privacy with Cryptography  
exercise 188
- English-like abbreviations 7
- Enhancing Class Date (exercise) 403
- enqueue operation of queue 766
- EnsureCapacity method of class  
  **StringBuilder** 653
- Enter* (or *Return*) key 48, 71
- enter data from the keyboard 520
- entities in an entity data model 861
- entity connection string 860
- Entity Data Model **856**
- entity data model 851, 868  
  create from database 858  
  data source for data binding 864  
  entities 861
- entity data model (ADO.NET Entity Framework) **856**
- EntityDataSource** ASP.NET data control **937**
- entity-relationship diagram **855**
- entry point 216
- entry point of an application **236**
- enum **253**  
  keyword 253
- Enumerable** class 857
- enumeration **253**
- enumeration constant **254**
- enumerations  
  **ComboBoxStyle** 595  
  **DateTimePickerFormat** 580  
  **DayOfWeek** 583  
  **MdiLayout** 616  
  **SelectionMode** 587
- enumerator **815**, 820  
  fail fast 821  
  of a **LinkedList** 839
- equal likelihood 247
- Equals** method of an anonymous type 877
- Equals** method of class **object** 435
- Equals** method of class **string** 643
- Error List** window 77
- Error** property of class **Console** 672
- ErrorMessage** property of an ASP.NET validation control **922**
- escape character **79**  
  escape sequence **79**, 83  
    carriage return, \r 80  
    escape character, \\\ 80  
    horizontal tab, \t 79  
    newline, \n 79, 83
- Euler 340
- Even or Odd exercise 280
- event **522**
- event driven **12**, **28**, **522**
- event handler **522**, 526
- event handling **522**
- event handling model 522
- event multicasting **527**
- event sender **526**
- EventArgs** class 524
- events **12**
- events at an interval 628
- examination-results problem 168
- exception 84, 296, **298**, 298, 487  
  **ArgumentException** 832  
  **ArgumentOutOfRangeException** 825
- exception (cont.)  
  handler **298**  
  handling 296  
  **IndexOutOfRangeException** 298  
  **InvalidOperationException** 464, 816, 833  
  **InvalidOperationException** 821, 828, 839  
  **KeyNotFoundException** 836  
  Message property **299**  
  parameter 298
- Exception Assistant **494**
- Exception class **496**
- exception handler **487**, 496
- exception handling 84
- .exe file name extension **76**
- executable **76**
- executable file 15
- execute **3**
- execute an application 72
- ExecutionEngineException** class  
  **496**
- exhausting memory 265
- Exists method of class **Directory** 674
- Exists method of class  
  **DirectoryInfo** 609
- Exit method of class **Application**  
  **578**, 591
- exit point 216  
  of a control statement 146
- Exp method of **Math** 235
- expand a tree 43
- Expand method of class **TreeNode** 600
- expand node 598
- ExpandAll method of class **TreeNode**  
  **600**
- expiration date of a cookie **926**
- explicit conversion **165**
- explicit type argument **795**
- explicitly shut down a Windows 8 UI app 27
- exponential method 235
- exponentiation 349
- Exponentiation exercise 279
- exponentiation operator 198
- expression **85**
- extend a class **406**
- extensibility 445
- extensible language **111**
- extension method 361, 857
- extension methods (Linq to Entities) 868
- F**
- F formatting code 132
- factorial 187, 228, 263
- Factorial** method 263, 264
- Factorials exercise 187, 228
- Fahrenheit equivalent of a Celsius temperature 280  
  “FairTax” 230
- false keyword **90**, 148, 149
- fatal error **152**, 349
- fault tolerant **84**
- fault-tolerant program **298**, **487**
- field **4**, **116**, **671**  
  in a database table **851**
- field of a class 5
- field width **198**
- fields **236**, 256
- FIFO (first-in, first-out) 396
- file **5**, 672  
  as a collection of bytes 672
- File** class **673**, 677  
  Delete method **682**
- File** class methods (partial list) 674
- FILE** menu 39
- File name extensions  
  .aspx **898**  
  .cs 43  
  .csproj 54
- FileName** property of a file in the Solution Explorer **73**
- FileAccess** enumeration 690
- FileInfo** class **608**  
  FullName property **608**  
  Name property **608**
- file-position pointer 695
- files **670**
- FileStream** class **673**, 690, 695, 706  
  Seek method 701
- FillEllipse** method of class  
  **Graphics** 556, 598
- FillPie** method of class **Graphics** 598
- FillRectangle** method of class  
  **Graphics** 598
- filter a collection using LINQ **352**
- final state in the UML 145, 218
- final value 191
- Finalize method  
  of class **object** 435
- finally block **493**, 498
- finally blocks always execute, even when no exception occurs 499
- Find method of class **LinkedList** **840**
- Find the Error exercise 182, 283
- Find the Largest Number exercise 184
- Find the Minimum exercise 280
- Find the Smallest Value exercise 227
- Find the Two Largest Numbers exercise 184
- Finished design of **MasterDetail** app 882
- First** extension method of interface  
  **IEnumerable<T>** **361**
- first-in, first-out (FIFO) data structure  
  **396**, **766**
- first refinement 159, 167
- FirstDayOfWeek** property of class  
  **MonthCalendar** 580
- FirstNode** property of class **TreeNode**  
  **599**
- Fisher-Yates shuffling algorithm 302
- fixed text 85  
  in a format string **81**
- flag **159**
- FlatStyle** property of class **Button** 534
- float** simple type 83, **128**, 952
- floating-point literal **128**
- floating-point number 158, 162, 163  
  division 165  
  double precision **128**  
  double simple type **128**  
  float simple type **128**  
  single precision **128**
- floating-point **128**
- floating-point literal  
  **double** by default 128
- Floor** method of **Math** 235

flow of control 153, 163  
     in the `if` statement 147  
     in the `if...else` statement 148  
     in the `while` statement 153

focus 521

Focused property of class `Control` 530

`Font` class 541  
     `Style` property 541

`Font` dialog 51

`Font` property of a `Label` 51

`Font` property of class `Control` 530

`Font` property of class `Form` 522

font size 51

font style 51, 540

`Font` window 52

`FontStyle` enumeration 541

for keyword 191

for repetition statement 146, 191, 192, 194, 195, 196, 198, 221  
     activity diagram 195  
     header 193

`foreach` statement 303, 821, 823, 828  
     on rectangular arrays 325

`ForeColor` property of class `Control` 530

foreign key 854, 856

form 38

form background color 49

`Form` class 521  
     `AcceptButton` property 522  
     `ActiveMdiChild` property 615  
     `AutoScroll` property 522  
     `CancelButton` property 522  
     `Close` method 522  
     `Font` property 522  
     `FormBorderStyle` property 522  
     `Hide` method 522  
     `IsMdiChild` property 615  
     `IsMdiContainer` property 614, 615  
     `LayoutMdi` method 615, 616  
     Load event 522  
     `MaximumSize` property 532  
     `MdiChildActivate` event 615  
     `MdiChildren` property 615  
     `MdiParent` property 614  
     `MinimumSize` property 532  
     `Padding` property 532  
     `Show` method 522  
     `Text` property 522

`Form` properties, methods and events 522

`Form1.cs` 56

formal parameter 238

format item 81

`FORMAT` menu 40

`Format` method of `String` 374

`Format` property of class  
     `DateTimePicker` 580, 581

format specifier 132  
     F for floating-point numbers 165  
     format specifier D 294  
     format specifier table 132  
     format string 81  
     `FormatException` class 490, 492, 493

`FormatString` 657

formatted output  
     field width 198  
     left justify 198  
     right justify 198

formatting  
     display formatted data 80

`FormBorderStyle` property of class  
     `Form` 522

formulating algorithms 154

forward reference 761

fragile software 427

Framework Class Library 796

from clause of a LINQ query 355

`FullName` property of class  
     `DirectoryInfo` 608

`FullName` property of class `FileInfo` 608

`FullName` property of class `Type` 435

`FullPath` property of class `TreeNode` 599

`FullStackException` indicates a stack is full 801

fully qualified class name 116, 243, 522, 523, 623

function 233

function key 559

**G**

G formatting code 132

Game of Craps exercise 338

game playing 245

garbage collection 498

garbage collector 389, 390

Gas Mileage exercise 183

Gates, Bill 14

general `catch` clause 493

general class average problem 158

generic class 362, 790, 799

Generic classes  
     `Dictionary` 817  
     `LinkedList` 817, 836  
     `LinkedListNode` 836  
     `List` 817  
     `Queue` 817  
     `SortedDictionary` 817, 834, 835  
     `SortedList` 817  
     `SortedSet<T>` 842  
     `Stack` 817

generic interface 790

Generic `List<T>` collection  
     demonstration 363

generic method 790, 793  
     creating 806  
     implementation 793

generics 790  
     class 790  
     class constraint 797  
     compile-time type safety 790  
     constructor constraint (`new()`) 798  
     default type constraint (`object`) of a  
         type parameter 802

interface 790  
     interface constraint 797

method 793  
     overloading 798

reference type constraint `class` 798

reusability 799

scope of a type parameter 802

specifying type constraints 796

`Stack` class 799

type argument 795, 802

type checking 790

generics (cont.)  
     type constraint of a type parameter 796, 797  
     type parameter 794  
     type parameter list 794  
     value type constraint `struct` 798  
     `where` clause 797

`get` accessor of a property 108, 118, 121

`get` keyword 119

`GetCreationTime` method of class  
     `Directory` 674

`GetCreationTime` method of class  
     `File` 674

`GetDirectories` method of class  
     `Directory` 603, 674

`GetDirectories` method of class  
      `DirectoryInfo` 608

`GetEnumerator` method of interface  
     `IEnumerable` 820

`GetExtension` method of class `Path` 681

`GetFiles` method of class `Directory` 674, 681

`GetFiles` method of class  
      `DirectoryInfo` 608

`GetHashCode` method of class `Object` 830

`GetItemChecked` method of class  
     `CheckedListBox` 592

`GetLastAccessTime` method of class  
     `Directory` 674

`GetLastAccessTime` method of class  
     `File` 674

`GetLastWriteTime` method of class  
     `Directory` 674

`GetLastWriteTime` method of class  
     `File` 674

`GetLength` method of an array 320

`GetNodeCount` method of class  
     `TreeNode` 600

`GetObject` method of class  
     `ResourceManager` 549

`GetSelected` method of class `ListBox` 588

`GetType` method of class `object` 435, 464

GIF (Graphic Interchange Format) 54

gigabyte 6

global namespace 116

Global Warming Facts Quiz 230

Good Programming Practices overview xxiv

`goto` elimination 144

`goto` statement 144

GPS device 6

graph 228

graph information 294

Graphic Interchange Format (GIF) 54

graphical user interface (GUI) 14, 36, 244, 519

`Graphics` class 556, 597  
     `Clear` method 597  
     `DrawEllipse` method 597  
     `DrawPie` method 598  
     `DrawRectangle` method 598  
     `FillEllipse` method 556, 598  
     `FillPie` method 598  
     `FillRectangle` method 598

- G**
- Graphics property of class
    - PaintEventArgs **626**, **627**
  - Greatest Common Divisor exercise **281**
  - GridView ASP.NET data control **934**
  - Gridview class
    - .DataBind method **941**
    - gross pay **184**
    - GroupBox class **20**
    - GroupBox control **63**, **536**
      - Controls property **537**
      - properties **536**
      - Text property **536**
      - guard condition **147**, **149**
    - Guess the Number exercise **281**
      - enhanced **281**
    - Guestbook Application Modification exercise **948**
    - guestbook on a website **933**
    - GUI (graphical user interface) **14**, **36**, **519**
    - GUI control **520**
    - GUI control, basic examples **520**
  

**H**

    - half word **349**
    - handle an event **526**
    - handle an exception **491**
    - hard drive **2**, **7**, **28**
    - hardware **2**, **7**
    - has-a relationship **386**, **406**
    - hash function **830**
    - hash table **829**
    - hashing **829**
    - Hashtable class **817**, **817**, **829**
      - ContainsKey method **832**
      - Count property **833**
      - method Add **832**
      - property Values **833**
    - head of a queue **747**, **766**
    - Height property of structure **Size** **532**
    - HELP menu **40**, **46**
    - helper method **207**, **775**
    - HelpLink property of **Exception** **506**
    - heuristic **341**
    - hexadecimal (base 16) number system **282**, **349**
    - “hidden” fields **256**
    - hide implementation details **233**, **376**, **394**, **396**
    - Hide method of class **Control** **530**
    - Hide method of class **Form** **522**
    - hiding implementation details **830**
    - hierarchical boss method/worker method
      - relationship **233**
    - high-level language **8**
    - horizontal tab **79**
    - host **899**
    - hostname **899**
    - hot key **570**
    - HourlyEmployee class that extends **Employee** **455**
    - HTML (HyperText Markup Language) **11**, **899**
    - HTTP (HyperText Transfer Protocol) **11**, **899**, **925**
    - HttpSessionState class **927**, **931**, **932**, **933**
      - Add method **932**  

**I**

    - IBM
      - DB2 **850**
    - ICollection interface **816**
    - IComparable interface **476**, **777**
    - IComparable<T> interface **796**, **842**
      - CompareTo method **796**
    - IComparer<T> interface **842**
    - IComponent interface **476**, **520**
    - icon **40**
    - IDE (Integrated Development Environment) **19**, **34**
    - identifier **69**, **82**
    - identity column in a database table **853**
    - IDictionary interface **816**
    - IDisposable interface **477**, **504**
      - Dispose method **477**
    - IE10 (Internet Explorer 10) **17**
    - IEC 60559 **952**
    - IEEE 754 **952**
    - IEnumerable interface
      - method GetEnumerator **820**
    - IEnumerable<T> interface **357**, **816**, **820**, **857**
      - Any extension method **361**
      - Count extension method **361**
      - Distinct extension method **361**
      - First extension method **361**
    - IEnumerator interface **477**, **820**
    - if single-selection statement **90**, **146**, **147**, **201**, **220**, **221**
      - activity diagram **147**
    - if...else double-selection statement **146**, **148**, **163**, **201**, **220**
      - activity diagram **148**
    - ignoring array element zero **298**
    - IIS Express **904**, **912**
    - IList interface **816**
    - Image ASP.NET web control **915**
    - Image Collection Editor **604**
    - Image property of class **PictureBox** **53**, **547**
    - image resource **549**
    - ImageIndex property of class **ListViewItem** **604**
    - ImageIndex property of class **TreeNode** **599**
    - ImageList class **599**, **603**
      - Images property **604**
    - ImageList property of class **TabControl** **611**
    - ImageList property of class **TreeView**
      - 599
    - Images property of class **ImageList** **604**
    - ImageUrl property of an Image web control **915**
    - imaginary part of a complex number **403**
    - immutable (strings) **392**
    - immutable string **642**
    - imperative programming **353**
    - implement
      - an interface **443**, **467**, **474**
      - multiple interfaces **471**
    - implementation-dependent code **376**
    - implementation of a function **453**
    - implementing a dispose method (link to MSDN article) **477**
    - Implementing a queue by inheriting from class **List** **767**
    - Implementing a stack by inheriting from class **List** **762**
    - implicit conversion **165**
    - implicit conversions between simple types **242**
    - implicitly typed local variable **355**, **356**, **362**
    - improve performance of bubble sort **744**
    - In property of class **Console** **672**
    - increment **190**, **196**
      - a control variable **191**
      - expression **210**
      - of a for statement **194**
    - increment and decrement operators **172**
    - increment operator, **++** **172**
    - Increment property of class **NumericUpDown** **551**
    - indefinite repetition **159**
    - indentation **71**, **148**, **150**
      - indent size **70**
    - independent software vendor (ISV) **434**
    - index **286**, **296**
    - Index property of class **ItemCheckEventArgs** **592**
    - index zero **286**
    - indexer **642**
      - of a Hashtable **832**
      - of an ArrayList **825**
    - IndexOf method of class **Array** **821**
    - IndexOf method of class **ArrayList** **822**, **825**
    - IndexOf method of class **List<T>** **362**
    - IndexOf method of class **string** **646**
    - IndexOfAny method of class **string** **646**
    - IndexOutOfRangeException class **296**, **298**, **496**
    - indirect base class **406**, **408**
    - infer a local variable’s type **355**
    - infinite loop **153**, **164**, **194**, **265**
    - infinite recursion **265**
    - infinite series **229**
    - Infinite Series:  $e^x$  exercise **187**
    - Infinite Series: Mathematical Constant  $e$  exercise **187**
    - infinity symbol **856**
    - information hiding **10**, **118**, **394**, **466**
    - information tier **901**
    - inherit from class **Control** **627**
    - inherit from Windows Form control **627**

- inherit interface 484  
 inheritance **10**, **406**, 410, 434
  - examples 407
  - hierarchy **407**
  - hierarchy for university **CommunityMembers** 408
  - single **406**
 Inheritance hierarchy for class **Shape** 408  
 inheritance with exceptions 496  
**Init** event of a Web Form **911**  
**Init** event of an ASP.NET web page 913  
 initial state **145**  
 initial state in the UML 218  
 initial value of control variable **190**  
**InitialDelay** property of class  
**ToolTip** 550  
 initialization phase 159  
 initializer list **290**  
 Initializing jagged and rectangular arrays  
 319  
 initializing **readonly** arrays 823  
 Initializing the elements of an array with  
 an array initializer 290  
 initializing two-dimensional arrays in  
 declarations 319  
 inlining method calls **466**  
**InnerException** property of  
**Exception** **505**, 509  
 innermost set of brackets 297  
 inorder traversal of a binary tree **770**  
 input data from the keyboard 95  
 input device **6**  
 input/output operation 345  
 input–output operations 145  
 input unit **6**  
**Insert** method of class **ArrayList** 822  
**Insert** method of class **List<T>** **363**  
**Insert Separator** option **533**  
**Insert Snippet** window 123  
 inserting separators in a menu 573  
 insertion point 750, 751  
 insertion sort algorithm **730**, 734  
 instance **9**  
 instance of a class 117  
 instance variable **108**, 116, 117, 129, 235  
 instance variables **10**  
 instantiate an object of a class **108**  
 instruction execution cycle 347  
 int simple type **83**, 162, 171, 952  
**Int16 struct** 747  
**Int32** 796  
**Int32 struct** 747  
**Int64 struct** 747  
 integer **81**
  - division **86**, **158**
  - mathematics 395
  - value **83**
 integer array 290  
**Integer Division** exercise 182  
 integer division without exception  
 handling 488  
 integer division yields an integer result  
 164  
**IntegerPower** method 279  
 Integrated Development Environment  
 (IDE) **19**, 34  
**IntelliSense** **74**, 355, 851, 856  
 interactions among objects 395  
 interest rate 197  
 interface **357**, 443, 468, 474
  - declaration **467**
 interface constraint **797**  
 interface keyword **467**, 475  
 Interfaces
  - ICollection** 816
  - IComparable** 476, 777, **796**
  - IComparable<T>** **842**
  - IComparer<T>** **842**
  - IComponent** 476, **520**
  - IDictionary** 816
  - IDisposable** 477, 504
  - IEnumerable** 816, **820**, 857
  - IEnumerable<T>** **357**, 857
  - IEnumerator** 477, **820**
  - IList** 816
  - IQueryable<T>** **857**
  - ISerializable** **702**
 internal data representation 396  
 Internet **11**  
 Internet Explorer 10 (IE10) 17  
 Internet Information Services (IIS) 899  
 interpreter **8**  
 intersection of two sets 403  
**Interval** property of class **Timer** **628**  
**InvalidOperationException** **464**, **748**  
**InvalidOperationException** class 816, 833  
**InvalidOperationException** class  
 821, 828, 839  
**Invoice** class implements **IPayable**  
 470  
 invoke a method **124**, 233  
 iOS 16  
 IP address **899**  
**IPayable** interface declaration 469  
**IPayable** interface hierarchy UML class  
 diagram 469  
**IQueryable<T>** interface **857**  
 is-a relationship **406**, 444  
 is operator **463**  
**IsDigit** method of **struct Char** 662  
**ISerializable** interface **702**  
**IsLetter** method of **struct Char** 662  
**IsLetterOrDigit** method of **struct Char**  
 662  
**IsLower** method of **struct Char** 662  
**IsMdiChild** property of class **Form** 615  
**IsMdiContainer** property of class **Form**  
 614, 615  
**IsNewSession** property of class  
**HttpSessionState** 931  
**IsPostBack** property of class **Page** **924**  
**IsPunctuation** method of **struct Char**  
 662  
**IsSymbol** method of **struct Char** 662  
**IsUpper** method of **struct Char** 662  
**IsValid** property of class **Page** **924**  
**IsWhiteSpace** method of **struct Char**  
 662  
**ItemActivate** event of class **ListView**  
 604  
**ItemCheck** event of class  
**CheckedListBox** **591**, 592  
**ItemCheckEventArgs** class 592
  - CurrentValue** property 592
  - Index** property 592
  - NewValue** property 592**Items** property of class **ComboBox** 594,  
**595**  
**Items** property of class **ListBox** 587,  
**588**  
**Items** property of class **ListView** 604  
**ItemSize** property of class **TabControl**  
 611  
 iterating (looping) **157**  
 iteration
  - of a loop **190**, 210
  - iteration (looping)
    - of a for loop 297
 iteration statement 146  
 iteration variable **303**  
 iterative 265

**J**

- jagged array **316**, 317, 319  
 Jagged Arrays exercise 337  
 Java programming language 14  
 JavaScript 918  
 JIT (just-in-time) compiler **15**  
 joining database tables **855**, 876
  - LINQ to Entities 875
 Joint Photographic Experts Group  
 (JPEG) 54  
 JPEG (Joint Photographic Experts  
 Group) 54  
 just-in-time (JIT) compiler **15**

**K**

- key code **559**  
 key data 559  
 key event **556**, 557  
 key value 559, 776  
 key-value pair **931**  
 keyboard 2, 28, 81, 520  
 keyboard shortcuts **570**  
**KeyChar** property of class  
**KeyPressEventArgs** **556**  
**KeyCode** property of class  
**KeyEventEventArgs** **557**  
**KeyData** property of class  
**KeyEventEventArgs** **557**  
**KeyDown** event of class **Control** **556**,  
 557  
**KeyEventArgs** class **556**
  - Alt** property 557, 559
  - Control** property 557, 559
  - KeyCode** property 557
  - KeyData** property 557
  - KeyValue** property 557
  - Modifiers** property 557
  - Shift** property 557, 559**KeyEventArgs** properties 557  
**KeyNotFoundException** class **836**  
**KeyPress** event of class **Control** **556**,  
 557  
**KeyPressEventArgs** class **556**
  - KeyChar** property **556**, 557**KeyPressEventArgs** properties 557  
 keys
  - function **559**
  - modifier **556****Keys** enumeration **556**  
**Keys** property of class **Dictionary** **682**  
**Keys** property of **Hashtable** **832**  
**Keys** property of **HttpSessionState**  
 class 931, **933**

KeyUp event of class Control 556, 557  
**KeyValue** property of class  
 KeyEventArgs 557  
**Keywords** 68, 146  
 abstract 423, 449  
 as 464  
 base 409, 422, 431, 433  
 bool 149  
 break 205  
 case 205  
 char 83  
 class 68, 109  
 const 208, 235, 291, 393  
 continue 209  
 decimal 83, 128  
 default 205  
 delegate 526  
 do 199  
 double 128  
 else 148  
 enum 253  
 false 149  
 float 83  
 for 191  
 get 119  
 if 90, 147, 148  
 interface 467  
 is 463  
 namespace 623  
 new 111, 125, 288, 289, 318  
 null 120, 124, 175, 288  
 operator 478  
 out 266  
 override 299, 414, 422, 423  
 params 327  
 partial 524, 913  
 private 118, 376, 409  
 protected 376, 409  
 public 70, 109, 118, 238, 376, 409  
 readonly 394  
 ref 266, 305  
 return 119, 233, 241  
 sealed 466  
 set 119  
 static 198  
 struct 660  
 switch 205  
 this 377, 393  
 true 149  
 value (contextual) 119  
 var 355  
 virtual 423  
 void 71, 109  
 while 152, 199  
 Knight's Tour exercise 340  
 Brute Force Approach 341  
 Closed Tour Test 342  
 Koenig, Andrew 487

**L**

Label 51  
 label 533  
 Label class 38, 47, 50  
 Label control 520, 533  
 label in a switch 205, 206  
 lambda expression 868, 873, 874  
 lambda operator 868  
 lambda operator 868

language independence 15  
 Language Integrated Query (LINQ) 352  
 language interoperability 15  
 LargeImageList property of class  
 ListView 604  
 last-in first-out (LIFO) order 805  
 Last property of class LinkedList 840  
 last-in, first-out (LIFO) data structure  
 762  
 LastIndexOf method of class Array  
 821  
 LastIndexOf method of class string  
 646, 648  
 LastIndexOfAny method of class  
 string 646  
 last-in-first-out (LIFO) 241  
 last-in-first-out (LIFO) data structure  
 395  
 LastNode property of class TreeNode  
 599  
 late binding 463  
 layout, control 529  
 LayoutMdi method of class Form 615,  
 616  
 leading 0 294  
 leaf node in a binary search tree 769, 775  
 left brace, { 70, 71, 82  
 left child 769  
 left justify output 198  
 left subtree 769, 775  
 left-to-right evaluation 89  
 Length property of an array 287  
 Length property of class string 642,  
 643  
 Length property of class  
 StringBuilder 653  
 let clause of a LINQ query 366  
 letter 670  
 level of indentation 148  
 level-order binary tree traversal 777  
 LIFO (last-in-first-out) order 241, 395,  
 805  
 line numbers xlii  
 linear collection 749  
 linear data structure 769  
 linear run time 720  
 linear search algorithm 717, 726  
 link 750, 769  
 link for a self-referential class 748  
 LinkArea property of class LinkLabel  
 584  
 LinkBehavior property of class  
 LinkLabel 584  
 LinkClicked event of class LinkLabel  
 583, 584  
 LinkColor property of class LinkLabel  
 584  
 linked list 747, 749, 758  
 linked list data structure 747  
 linked list in sorted order 750  
 LinkedList generic class 817, 836  
 AddFirst method 839  
 AddLast method 839  
 method Find 840  
 method Remove 840  
 property First 840  
 property Last 840  
 LinkedListNode class  
 property Next 836  
 LinkedListNode diagram (cont.)  
 property Previous 836  
 property Value 836  
 LinkedListNode generic class 836  
 LinkLabel class 570, 583  
 ActiveLinkColor property 584  
 LinkArea property 584  
 LinkBehavior property 584  
 LinkClicked event 583, 584  
 LinkColor property 584  
 LinkVisited property 584  
 Text property 584  
 UseMnemonic property 584  
 VisitedLinkColor property 584  
 LinkLabel properties and an event 584  
 LinkVisited property of class  
 LinkLabel 584  
 LINQ (Language Integrated Query) 352,  
 677  
 anonymous type 361  
 ascending modifier 356  
 Count method 681  
 deferred execution 366  
 descending modifier 356  
 Distinct query operator 681  
 from clause 355  
 let clause 366  
 LINQ to Entities 353, 851  
 LINQ to Objects 352, 851  
 LINQ to XML 353  
 orderby clause 356  
 provider 353  
 query expression 352  
 range variable 355  
 Resource Center 889  
 select clause 356  
 where clause 356  
 LINQ provider 353  
 LINQ query syntax 857  
 LINQ to Entities 353, 851, 852, 868  
 data binding 857  
 DbContext class 857, 862  
 Object data source 864  
 primary keys 851  
 saving changes back to a database 869  
 Linq to Entities  
 extension methods 868  
 LINQ to Objects 352, 678, 851, 857  
 using a List<T> 365  
 using an array of Employee objects  
 358  
 using an int array 353  
 LINQ to SQL 851  
 LINQ to XML 353  
 LINQ usage throughout the book 352  
 LINQPad ([www.linqpad.net](http://www.linqpad.net)) 889  
 Linux 16  
 list, editable 595  
 List<T> generic class 362, 817  
 Add method 363  
 Capacity property 362, 365  
 Clear method 362  
 Contains method 362, 365  
 Count property 364  
 IndexOf method 362  
 Insert method 363  
 Remove method 362, 364  
 RemoveAt method 363, 364  
 RemoveRange method 363

- List<T>** generic class (cont.)  
     Sort method 363  
     TrimExcess method 363  
**List<T>** methods 362  
**ListBox** control 520, 570, **587**  
     ClearSelected method 588  
     GetSelected method **588**  
     Items property **588**  
     MultiColumn property 587  
     SelectedIndex property **588**  
     SelectedIndexChanged event  
         **587**  
     SelectedIndices property **588**  
     SelectedItem property **588**  
     SelectedItems property **588**  
     SelectionMode property **587**  
     Sorted property 588  
**ListBox** properties, method and event  
     587  
**ListBox.ObjectCollection** class  
     588  
**ListNode**, **List** and  
     EmptyListException class  
     declarations 751  
**ListView** control **603**  
     Activation property **603**  
     Checkboxes property **603**  
     ItemActivate event 604  
     Items property 604  
     LargeImageList property **604**  
     MultiSelect property **603**  
     SelectedItems property 604  
     SmallImageList property **604**  
     View property **603**  
**ListView** displaying files and folders  
     605  
**ListView** properties and events 604  
**ListViewItem** class **604**  
     ImageIndex property **604**  
literal 71  
literals  
     decimal **128**  
     floating point **128**  
     int **128**  
live-code approach xxxiii  
Load event 923  
Load event of an ASP.NET web page **923**  
Load event of class **Form** 522  
Load extension method of class  
     DBExtensions **869**, 871  
load factor **829**  
load/store operations 345  
local variable **116**, 156, 255, 256, 257,  
     379  
local variable “goes out of scope” 670  
location in computer’s memory 85  
**Location** property of class **Control** 1532  
**Log** method of **Math** 235  
logarithm 235  
logarithmic run time **726**  
logic error 84, **152**, 192  
logical decision 3  
logical negation, ! 213, 214  
     operator truth table 214  
logical operators 211, 213, 214  
logical output operation **673**  
logical unit **6**  
logical XOR, ^ **213**  
login (ASP.NET) 942  
Logo language 339  
long simple type 952  
long-term retention of data 670  
Long value of enumeration  
     DateTimePickerFormat **580**  
loop 146, 153, 157  
     body 199  
     continuation condition **146**  
     counter 190  
     infinite **153**, 164  
     nested within a loop **167**  
loop-continuation condition **190**, 191,  
     192, 194, 196, 199, 200, 210  
lower camel casing **83**  
lowercase letter 4, 68
- M**
- m-by-n* array **317**  
Mac OS X 16  
machine language 7  
machine language programming exercise  
     344  
magic numbers **292**  
magnetic disk 670  
magnetic tape 670  
Main method 70, 72, 82, 111  
maintainability 747  
make your point (game of craps) 250  
making decisions 95  
managed code 15  
“manufacturing” section of the computer  
     6  
many-to-many relationship **856**, 861  
mask the user input 533  
master pages 942  
master/detail view **879**  
Match class 639, 662  
**Math** class 234, 235  
     Abs method 235  
     Ceiling method 235  
     Cos method 235  
     E constant **235**  
     Exp method 235  
     Floor method 235  
     Log method 235  
     Max method 235  
     Min method 235  
     PI constant **235**, **275**  
     Pow method 198, 199, 234, 235, 275  
     Sin method 235  
     Sqrt method 234, 235, 242, 511  
     Tan method 235  
**Math.PI** constant 103  
Max method of **Math** 235  
**MaxDate** property of class  
     DateTimePicker **581**, **583**  
**MaxDate** property of class  
     MonthCalendar 580  
**MaxDropDownItems** property of class  
     ComboBox **594**  
maximum 184  
Maximum method 236  
Maximum property of class  
     NumericUpDown **551**  
**MaximumSize** property of class **Control**  
     532  
**MaximumSize** property of class **Form**  
     532
- MaxSelectionCount** property of class  
     MonthCalendar 580  
.mdf file extension 852  
**MDI** (Multiple Document Interface) **614**  
**MDI** (Multiple Document Interface)  
     window **520**  
**MDI** child 621  
**MDI** parent and **MDI** child properties,  
     method and event 615  
**MDI** parent window class 618  
**MDI** title bar 616  
**MdiChildActivate** event of class **Form**  
     615  
**MdiChildren** property of class **Form** 615  
**MdiLayout** enumeration **616**  
     ArrangeIcons value 616  
     Cascade value 616  
     TileHorizontal value 616  
     TileVertical value 616  
**MdiParent** property of class **Form** **614**  
**MdiWindowListItem** property of class  
     MenuStrip **616**  
mean 88  
member access (.) operator 198, 234, 391  
member access operator **112**  
**MemberwiseClone** method of class  
     object 435  
memory 3, 6  
memory consumption 815  
memory dump 348  
memory leak **390**, **497**  
memory location **85**  
memory unit 6  
**MemoryStream** class **673**  
menu 39, 519, 570  
     BUILD 39  
     DEBUG 40  
     EDIT 39  
     FILE 39  
     FORMAT 40  
     HELP 40, **46**  
     PROJECT 39  
     TEAM 40  
     TEST menu 40  
     TOOLS 40  
     VIEW 39, 41  
     WINDOW 40  
menu access shortcut 570  
menu access shortcut, create 571  
menu bar **39**, 519  
     in Visual Studio IDE 39  
menu item 39, 570  
menu, ellipsis convention 573  
menu, expanded and checked 571  
MenuItem property  
     MdiWindowListItem example 617  
MenuStrip class **61**, **571**  
     MdiWindowListItem property **616**  
     RightToLeft property 574  
MenuStrip properties and events 574  
merge sort algorithm **734**, 740  
merge symbol in the UML 153  
merge two arrays 735  
message **71**  
message (sent to an object) **108**  
Message property of an exception object  
     299  
Message property of **Exception** 502,  
     505

method **8, 70, 113**  
 call **108**  
 header **110**  
 in the UML **10**  
 parameter **115**  
 parameter list **114**  
 return type **109**  
 static **198**  
 method call **9, 233, 238**  
 method call stack **241, 505, 762**  
 method declaration **238**  
 method overloading **232, 258**  
 method parameter list **327**  
 methods implicitly sealed **466**  
 methods of class *List<T>* **362**  
 Metro **17**  
 Microsoft  
   SQL Server **850**  
   SQL Server Express **850**  
 Microsoft Developer Network (MSDN) **35**  
 Microsoft Intermediate Language (MSIL) **15, 76**  
 middle tier **901**  
 mileage obtained by automobiles **183**  
 Min method of *Math* **235**  
 MinDate property of class  
   **DatePicker** **581, 583**  
 MinDate property of class  
   **MonthCalendar** **580**  
 minimized and maximized child window **616**  
 Minimum property of class  
   **NumericUpDown** **551**  
 MinimumSize property of class *Control* **532**  
 MinimumSize property of class *Form* **532**  
 modal dialog **690**  
 model **858**  
 model designer **861**  
 Modified Compound Interest Program  
   exercise **228**  
 Modified Diamond Program exercise **229**  
 Modified Triangle Program exercise **229**  
 modifier key **556**  
 Modifiers property of class  
   **KeyEventArg** **557**  
 Modifying the Internal Data  
   Representation of a Class (exercise) **402**  
 modularizing a program with methods **233**  
 modulus operator (%) **86**  
 monetary calculations **199**  
*MonthCalendar* class **62, 579**  
   **DateChanged** event **579**  
   **FirstDayOfWeek** property **580**  
   **MaxDate** property **580**  
   **MaxSelectionCount** property **580**  
   **MinDate** property **580**  
   **MonthlyBoldedDates** property  
     **580**  
   **SelectionEnd** property **580**  
   **SelectionRange** property **580**  
   **SelectionStart** property **580**  
*MonthlyBoldedDates* property of class  
*MonthCalendar* **580**  
*Moore's Law* **3**  
**More Windows...** option in Visual Studio  
   .NET **616**  
 motion information **6**  
 mouse **2, 28, 520**  
   pointer **41**  
 mouse click **553**  
 mouse event **553, 554**  
 mouse move **553**  
*MouseDown* event of class *Control* **554**  
*MouseEnter* event of class *Control* **554**  
*MouseEventArgs* class **554**  
   **Button** property **554**  
   **Clicks** property **554**  
   **X** property **554**  
   **Y** property **554**  
*MouseEventArgs* properties **554**  
*MouseEventHandler* delegate **554**  
*MouseHover* event of class *Control* **554**  
*MouseLeave* event of class *Control* **554**  
*MouseMove* event of class *Control* **554**  
*MouseUp* event of class *Control* **554**  
*MouseWheel* event of class *Control* **554**  
 Move method of class *Directory* **674**  
 Move method of class *File* **674**  
*MoveFirst* method of class  
   **BindingSource** **873**  
*MoveNext* method of *IEnumerator* **820**  
 MSDN (Microsoft Developer Network)  
   **68, 233**  
 MSDN (Microsoft Developers Network) **35**  
 MSIL (Microsoft Intermediate Language) **15**  
 multi-core processor **7**  
 multicast delegate **527**  
 multicast event **527**  
*MulticastDelegate* class **527**  
*MultiColumn* property of class *ListBox* **587**  
 multidimensional array **316**  
*MultiExtended* value of enumeration  
   **SelectionMode** **587**  
*Multiline* property of class  
   **TabControl** **611**  
*Multiline* property of class *TextBox* **534**  
 multiple document interface (MDI) **520, 614**  
 multiple-selection statement **146**  
 Multiples exercise **279**  
 Multiples of 2 exercise **187**  
 multiplication, \* **86**  
 multiplicative operators: \*, / and % **165**  
*MultiSelect* property of class  
   **ListView** **603**  
*MultiSimple* value of enumeration  
   **SelectionMode** **587**  
 multitier app **900**  
 mutual exclusion **542**  
 mutually exclusive options **542**  
*MySQL* **850**

**N**

N format specifier **132**  
*n-tier* app **900**  
 name **85**  
 name collision **523, 623**  
 name conflict **523, 623**  
 Name property of class  *DirectoryInfo* **608**  
 Name property of class  *FileInfo* **608**  
 named constant **292**  
 named parameter **262**  
 namespace **67, 232, 243**  
   **System.Web.UI** **913**  
   **System.Web.UI.WebControls** **913**  
 namespace **623**  
   declaration **622**  
   keyword **623**  
 namespace declaration **522**  
 Namespaces  
   of the FCL **244**  
   **System** **245**  
   **System.Collections** **244, 762, 796, 815**  
   **System.Collections.Concurrent** **815**  
   **System.Collections.Generic** **244, 362, 681, 815, 835**  
   **System.Collections.Specialized** **815**  
   **System.Data.Entity** **244, 857**  
   **System.Data.Linq** **244**  
   **System.Diagnostics** **586**  
   **System.Drawing** **541**  
   **System.IO** **244, 673**  
   **System.Linq** **244, 353, 857**  
   **System.Runtime.Serialization.Formatters.Binary** **701**  
   **System.Text** **244, 639**  
   **System.Text.RegularExpressions** **639**  
   **System.Web** **244**  
   **System.Windows.Controls** **244**  
   **System.Windows.Forms** **244, 521**  
   **System.Windows.Input** **244**  
   **System.Windows.Media** **244**  
   **System.Windows.Shapes** **244**  
   **System.Xml** **244**  
   **System.Xml.Linq** **244**  
 NaN constant of structure *Double* **490, 511**  
 natural logarithm **235**  
*NavigateUrl* property of a *HyperLink* control **918**  
 navigation property **856, 857, 864, 865**  
*NegativeInfinity* constant of structure *Double* **490**  
*NegativeNumberException* represents exceptions caused by illegal operations performed on negative numbers **510**  
 nested array initializer **317**  
 nested building block **221**  
 nested control statements **166, 218, 221, 249**  
 nested *for* statement **294, 319, 320, 321**  
 nested *foreach* statement **321**  
 nested *if...else* selection statement **149, 150, 151**  
 nested parentheses **87**  
 nesting **147, 148**  
 nesting rule **218**

.NET  
 Framework 14, 790  
 Framework Class Library 67, 232,  
 243, 476  
 Framework Class Library (FCL) 12,  
 14, 16  
 Framework documentation 68  
 initiative 14  
 .NET for Windows Store Apps 16  
 New keyword 877  
 new keyword 288, 289, 318  
 new operator 111, 125, 749  
 New Project dialog 36, 38, 48  
 new project in Visual Studio 39  
 new() (constructor constraint) 798  
 newline character 79  
 newline escape sequence, \n 79, 83, 349  
 NewValue property of class  
 ItemCheckEventArgs 592  
 Next method of class Random 245, 246,  
 249  
 Next property of class LinkedListNode  
 836  
 NextNode property of class TreeNode  
 599  
 Nginx web server 899  
 node 598  
 child 598  
 expand and collapse 598  
 parent 598  
 root 598  
 sibling 598  
 nodes in a linked list 749  
 Nodes property of a TreeView 598  
 Nodes property of class TreeNode 599  
 Nodes property of class TreeView 599  
 non-static class member 393  
 None value of enumeration  
 SelectionMode 587  
 nonfatal logic error 152  
 nonlinear data structures 750  
 not selected state 542  
 note (in the UML) 145  
 Notepad 584  
 Notepad GUI exercise 61  
 Now property of structure DateTime 629  
 null keyword 120, 124, 175, 288  
 null reference 749, 760  
 NullReferenceException class 496  
 NumericUpDown control 520, 551  
 DecimalPlaces property 551  
 Increment property 551  
 Maximum property 551  
 Minimum property 551  
 ReadOnly property 553  
 UpDownAlign property 552  
 Value property 552  
 ValueChanged event 552  
 NumericUpDown properties and events  
 551

**O**

*O(1)* time 720  
*O(log n)* time 726  
*O(n log n)* time 740  
*O(n)* time 720  
*O(n<sup>2</sup>)* time 720

object 2, 8, 29  
 send a message 124  
 object (or instance) 10  
 Object Browser (Visual Studio .NET)  
 396  
**object class** 406, 410, 434  
 Equals method 435  
 Finalize method 435  
 GetHashCode method 435  
 GetType method 435, 464  
 MemberwiseClone method 435  
 ReferenceEquals method 435  
 ToString method 413, 435  
 object creation expression 111, 126  
**Object** data source 864  
 object initializer 398  
 object initializer list 398  
 object methods that are inherited  
 directly or indirectly by all classes 435  
 object of a class 108  
 object of a derived class 445  
 object of a derived class is instantiated 433  
 object-oriented analysis and design  
 (OOAD) 10  
 object-oriented language 10  
 object-oriented programming (OOP) 2,  
 10, 406  
 object serialization 701  
**ObjectCollection** collection  
 Add method 589  
 Clear method 591  
 RemoveAt method 591  
**ObservableCollection<T>** class 869,  
 873  
 octal number system (base 8) 282  
 off-by-one error 192  
 one statement per line 94  
 one-to-many relationship 855, 856  
 One value of enumeration  
 SelectionMode 587  
 OnPaint method of class Control 626  
 OOAD (object-oriented analysis and  
 design) 10  
 OOP (object-oriented programming) 10,  
 406  
 Open method of class File 674  
 OpenFileDialog class 695, 700  
 opening a project 39  
 OpenRead method of class File 674  
 OpenText method of class File 674  
 OpenWrite method of class File 674  
 operand 165, 344  
 operands of a binary operator 85  
 operating system 16  
 operation code 344  
 operation in the UML 112  
 operation parameter in the UML 115  
 operations of an abstract data type 395  
 operator 86  
 operator keyword 478  
 operator overloading 477  
 operator precedence 87  
 operator precedence chart 165  
 rules 87  
**Operators** 868  
 ^, boolean logical exclusive OR 211,  
 213  
 --, prefix decrement/postfix decre-  
 ment 172

Operators diagram (cont.)  
 -, subtraction 87, 88  
 !=, logical negation 211, 213  
 !=, not equals 90, 93  
 ?:, ternary conditional operator 149,  
 174  
 \*, multiplication 87, 88  
 \*=, multiplication compound assign-  
 ment 171  
 /, division 87, 88  
 /=, division compound assignment  
 171  
&, boolean logical AND 211, 213  
&&, conditional AND 211, 212  
%, remainder 87, 88  
%-, remainder compound assign-  
 ment 171  
+, addition 87, 88  
++, prefix increment/postfix incre-  
 ment 172  
+=, addition assignment operator  
 171  
<, less than 90  
<=, less than or equal 90  
=, assignment operator 84  
-=, subtraction compound assign-  
 ment 171  
==, is equal to 90  
>, greater than 90  
>=, greater than or equal to 90  
|, boolean logical inclusive OR 211,  
 213  
||, conditional OR 211, 212  
arithmetic 86  
as 464  
binary 84, 86  
boolean logical AND, & 211, 213  
boolean logical exclusive OR, | 211,  
 213  
boolean logical inclusive OR, || 213  
cast 164, 254  
compound assignment operators  
 171, 173  
conditional AND, && 211, 212, 213,  
 360  
conditional operator, ?: 149, 174  
conditional OR, || 211, 212, 213  
decrement operator, -- 171, 172  
increment and decrement 172  
increment operator, ++ 172  
is 463  
logical negation, != 214  
logical operators 211, 213  
logical XOR, ^ 213  
member access (.) 198, 391  
multiplicative: \*, / and % 165  
new 111, 125  
postfix decrement 172  
postfix increment 172  
precedence chart 950  
prefix decrement 172  
prefix increment 172  
remainder operator 186  
remainder, % 86  
optical disk 670  
optimizing compiler 199  
optional parameter 260, 262  
 default value 260, 261  
Oracle Corporation 850

order in which actions should execute 143  
**orderby** clause of a LINQ query 356  
  ascending modifier 356  
  descending modifier 356  
**OrderBy** extension method of class *Queryable* 868, 873  
orientation information 6  
**out** keyword 266  
out-of-range array index 496  
**Out** property of class *Console* 672  
outer set of brackets 297  
**OutOfMemoryException** class 496, 749  
output 79  
output device 6  
output parameter 266  
output uni 6  
overflow error 349  
overloaded constructors 379  
overloaded generic methods 798  
overloaded methods 75, 258, 791  
  with identical signatures 260  
overloaded operators for complex numbers 479  
override a base class method 409, 413  
**override** keyword 299, 414, 422, 423

**P**

**π** calculation exercise 229  
**Padding** property of class *Control* 532  
**Padding** property of class *Form* 532  
**Page** class 913, 924, 929  
  Session property 929  
Page Hit Counter exercise 948  
page layout software 639  
**Page\_Init** event handler 911, 913  
**Page\_Load** event handler 923  
**PaintEventArgs** class 626  
  **ClipRectangle** property 626  
  **Graphics** property 626  
**PaintEventArgs** properties 627  
palette 50  
palindrome 186  
Palindromes exercise 186  
**Panel** class 20, 63  
Panel control 520, 536  
  AutoScroll property 536  
  BorderStyle property 536  
  Controls property 536  
**Panel** properties 536  
Panel with scrollbars 537  
parameter 113, 115  
  output 266  
parameter in the UML 115  
**Parameter Info** window 75  
parameter list 114, 126  
parameterless constructor 382, 385, 798  
**params** keyword 327  
parent menu 570  
parent node 598, 770  
**Parent** property of class *DirectoryInfo* 609  
parent window 614  
parentheses 70, 87  
  nested 87  
  redundant 90  
  unnecessary 90  
Parking Charges exercise 278  
partial class 913  
**partial** class 521  
**partial** keyword 524  
**partial** modifier 913  
partition step in quicksort 745  
pass an array element to a method 305  
pass an array to a method 305  
pass-by-reference 266  
pass-by-value 266, 305  
Passing an array reference by value and by reference 308  
Passing arrays and individual array elements to methods 305  
passing options to a program with command-line arguments 329  
password *TextBox* 533  
Path class 603, 681  
  **GetExtension** method 681  
pattern of 0s and 1s 671  
pattern of 1s and 0s 4  
payroll fil 672  
payroll system 671  
Payroll System Modification exercise 484  
**Peek** method of class *Stack* 828  
Perfect Numbers exercise 281  
perform a calculation 95  
perform a task 110  
perform an action 71  
permission setting 604  
persistent 7  
persistent data 670  
personalization 925  
phases of an application 159  
Phishing Scanner 714  
physical output operation 673  
“pick off” each digit 104  
**PictureBox** class 38, 47, 53  
**PictureBox** control 547, 617  
  Click event 547  
  Image property 547  
  SizeMode property 547  
**PictureBox** properties and event 547  
Pig Latin 667  
pin icon 42  
platform 17, 31  
platform independence 15, 28  
PNG (Portable Network Graphics) 54  
poker 344  
Poll analysis application 296  
Polymorphic banking program exercise using *Account* hierarchy 485  
polymorphic screen manager 444  
polymorphically process *Invoices* and *Employees* 474  
polymorphism 209, 436, 442  
polynomial 89  
pop data off a stack 241  
Pop method of class *Stack* 827, 828  
pop stack operation 762  
portability 15  
Portability Tips overview xxxiv  
Portable Network Graphics (PNG) 54  
porting 15  
position number 286  
**PositiveInfinity** constant of *structure Double* 490  
postback event of an ASP.NET page 924  
postfix decrement operator 172  
postfix increment operator 172, 194  
PostgreSQL 850  
postorder traversal of a binary tree 770  
**Pow** method of *Math* 198, 199, 234, 235, 275  
power (exponent) 235  
**Power** method 282  
power of 3 larger than 100 152  
precedence 94, 174  
  arithmetic operators 88  
  char 88  
precedence chart 165  
precedence chart appendix 950  
precision  
  formatting a floating-point number 165  
  of **double** values 953  
  of **float** values 953  
precision of a floating-point value 128  
**predicate** 356  
**predicate** method 755  
prefix decrement operator 172  
prefix increment operator 172  
Prefix vs. Postfix Increment Operators exercise 182  
preorder traversal of a binary tree 770  
prepackaged data structures 815  
presentation logic 901  
**Previous** property of class *LinkedListNode* 836  
**PrevNode** property of class *TreeNode* 599  
primary key 851, 856  
  in LINQ to Entities 851  
primary memory 6  
prime 281  
prime number 342, 848  
Prime Numbers exercise 281  
principal 197  
principle of least privilege 393  
print spooling 766  
privacy protection 925  
**private**  
  access modifier 377  
  **static** class member 391  
**private** access modifier 118, 409  
probability 245  
procedure 143, 233  
**Process** class 586  
  Start method 586  
processing phase 159  
processing unit 2, 28  
Product of Odd Integers exercise 227  
program 2  
program control 144  
program execution stack 241  
program in the general 442, 484  
program in the specific 442  
programming languages  
  BASIC 14  
  C# 12  
  Visual Basic 14  
project 36  
**PROJECT** menu 39  
projection 361  
promotion 165, 197, 925  
promotion rules 242  
prompt 84  
properties 116  
**Properties** window 44, 45, 48, 52, 908  
property 108

property declaration 118  
 property for a form or control 44  
 proprietary class 434  
**protected**  
 access modifier 376  
**protected** access modifier 409  
 pseudocode 144, 148, 154, 166, 168  
   first refinement 159, 167  
   second refinement 160, 168  
 pseudocode algorithm 161  
 pseudorandom number 245, 250  
**public**  
 access modifier 109, 118, 238  
 class 70  
 interface 372  
 keyword 70, 118  
 member of a derived class 409  
 method 373, 376  
 method encapsulated in an object 376  
 service 372  
 static class members 391  
 static method 391  
**public** access modifier 409  
**public** default constructor 125  
 push date onto a stack 241  
**Push** method of class Stack 827  
 push stack operation 762  
 Pythagorean Triples exercise 229

## Q

quad-core processor 7, 28  
 quadratic run time 720  
**query** 352, 850, 852  
 query expression (LINQ) 352  
**Queryable** class 857  
   **OrderBy** extension method 868, 873  
   **ThenBy** extension method 868  
   **Where** extension method 873  
 Querying an Array of **Invoice** Objects  
   exercise 370  
 queue 396, 747, 766  
**Queue** class 817  
 queue data structure 747  
 Queue generic class 817  
 quicksort algorithm 745

## R

radians 235  
 radio button 534, 542  
 radio button group 542  
 radio buttons, using with TabPage 613  
**Radio** GUI exercise 64  
**RadioButton** control 20, 24, 25, 63, 539, 542  
   Checked property 542  
   CheckedChanged event 542  
   Text property 542  
**RadioButton** properties and events 542  
**RadioButtonList** ASP.NET web control 918  
 radius of a circle 280  
**Random** class 245, 338  
   Next method 245, 246, 249  
 random number generation 299, 666  
 random numbers 250  
   in a range 250

random numbers (cont.)  
   scaling factor 246, 249, 250  
   seed value 245, 250  
   shifting value 249, 250  
 range variable of a LINQ query 355  
**Rational** class 403  
 Rational Numbers (exercise) 403  
**Read** method of class Console 673  
 readability 66, 168  
 Reading sequential-access files 691  
**ReadLine** method of class Console 84, 114, 205, 673  
**readonly**  
   keyword 394  
**ReadOnly** property of class NumericUpDown 553  
**ReadOnly** property of class TextBox 534  
 real number 162  
 real part of a complex number 403  
 realization in the UML 469  
 “receiving” section of the computer 6  
 reclaim memory 393  
 recognizing clients 925  
 record 4, 671, 851  
 Record for sequential-access file-processing applications 684  
 record key 672  
 rectangle 402  
**Rectangle** Class (exercise) 402  
 rectangular array 316, 318  
   with three rows and four columns 317, 318  
 recursion 603  
 recursion exercises  
   binary search 744  
   linear search 744  
 recursion step 263  
 recursive binary search algorithm 744  
 recursive call 263  
 recursive evaluation 264  
   of 5! 264  
 recursive factorial 263  
 recursive linear search algorithm 744  
 recursive method 263  
 Recursive Power Calculation exercise 282  
 recursive Power method 282  
 recursive step 745  
 redundant parentheses 90  
**ref** keyword 266, 305  
 refer to an object 124  
 reference 124  
 reference manipulation 747  
 reference type 123, 286  
 reference type constraint class 798  
 Reference, output and value parameters 267  
**ReferenceEquals** method of object 435  
 refinement process 159  
**Regex** class 639  
 registration (ASP.NET) 942  
 regular expression 662  
**RegularExpressionValidator**  
   ASP.NET validation control 922  
 reinventing the wheel 67  
 relational database 850, 851  
 relational database management system (RDBMS) 901  
 relational database table 851  
 relational operators 90  
 relative positioning 908  
 release resource 498  
 release unmanaged resources 477  
 remainder 86  
 remainder operator, % 86, 87, 186  
**Remove** method of class **ArrayList** 823, 825  
**Remove** method of class **Dictionary** 682  
**Remove** method of class **LinkedList** 840  
**Remove** method of class **List**<T> 362, 364  
**Remove** method of class **StringBuilder** 657  
**RemoveAt** method of class **ArrayList** 823  
**RemoveAt** method of class **List**<T> 363, 364  
**RemoveAt** method of class **ObjectCollection** 591  
**RemoveRange** method of class **ArrayList** 823  
**RemoveRange** method of class **List**<T> 363  
 repetition 219, 221  
   counter controlled 154, 163, 166, 167  
   definite 154  
   sentinel controlled 158, 160, 161, 163, 164  
 repetition statement 144, 146, 152, 160  
   **do...while** 146, 199, 201, 221, 201, 221  
   **for** 146, 195, 221  
   **foreach** 146  
   **while** 146, 152, 153, 157, 163, 221  
 repetition terminates 153  
**Replace** method of class **String** 651, 652  
**Replace** method of class **StringBuilder** 659  
**RequiredFieldValidator** ASP.NET validation control 921, 922  
 requirements 10  
 reservations system 338  
 reserved word 68, 146  
**Reset** method of interface **IEnumerator** 820  
**ReshowDelay** property of class **ToolTip** 550  
**Resize** method of class **Array** 352, 362  
 resource 549  
 resource leak 389, 497  
**ResourceManager** class 549  
   GetObject method 549  
**Resources** class 549  
 responses to a survey 296, 298  
 result of an uncaught exception 494  
 resumption model of exception handling 495  
 rethrow an exception 503  
**return** keyword 119, 233, 241  
**return** statement 119, 263  
 return type of a method 109  
 reusability 747, 799  
 reusable component 407  
 reusable software components 244  
 reuse 67

- Reverse method of class **Array** **821**  
 Reversing Digits exercise **281**  
**RichTextBox** control **61**  
 right brace, { **71**, **82**, **156**, **164**  
 right child **769**  
 right justify output **198**  
 right subtree **769**, **775**  
**RightToLeft** property of class  
**MenuStrip** **574**  
 rise-and-shine algorithm **143**  
 Ritchie, Dennis **13**  
 robust **84**  
 robust application **487**  
 Roll a six-sided die **6,000,000** times **295**  
 Roll a six-sided die **6000** times **247**  
 rolling two dice **253**  
 root node **598**, **769**  
 root node, create **600**  
 round a floating-point number for display purposes **165**  
 rounding a number **86**, **158**, **199**, **235**, **278**  
 Rounding to a Specific Decimal Place exercise **278**  
 Rounding to Nearest Integer exercise **278**  
**row objects** **856**  
 row of a database table **851**  
 rows of a two-dimensional array **316**  
 rules for forming structured applications **218**  
 rules of operator precedence **87**  
**Run** command in Windows **586**  
 run mode **56**  
 run-time logic error **84**  
 running an app **586**  
 running total **160**  
 runtime system **799**
- S**
- SalariedEmployee** class that extends **Employee** **454**, **473**  
**Salary Calculator** exercise **184**  
**Sales Commission Calculator** exercise **183**  
**Sales Commissions** exercise **337**  
**SaveChanges** method of a LINQ to Entities **DbContext** **857**, **869**  
**SaveFileDialog** class **689**  
 saving changes back to a database in LINQ to Entities **869**  
 savings account **197**  
**SavingsAccount** Class (exercise) **402**  
**sbyte** simple type **952**  
**SByte** struct **747**  
 scaling factor (random numbers) **246**, **249**, **250**  
 scanning images **6**  
 schema (database) **852**  
 scope **193**
  - static** variable **391****Scope** class demonstrates instance and local variable scopes **256**  
 scope of a declaration **255**  
 scope of a type parameter **802**  
 screen 2, **6**, **28**, **30**  
 screen cursor **71**, **78**, **79**  
 screen-manager program **444**  
**scrollbar** **45**
- ScrollBars** property of class **TextBox** **534**  
**scrollbox** **45**  
**SDI** (Single Document Interface) **614**  
**sealed**
  - class **466**
  - keyword **466**
  - method **466****Search Algorithms**
  - binary search **721**
  - linear search **717**
  - recursive binary search **744**
  - recursive linear search **744****search key** **716**  
**searching** **747**  
**Searching Algorithms**
  - binary search **721**
  - linear search **717**
  - recursive binary search **744**
  - recursive linear search **744****searching data** **716**  
**Searching for characters and substrings in strings** **647**  
 second-degree polynomial **89**  
 second refinement **160**, **168**  
 secondary storage **3**  
 secondary storage device **670**  
 secondary storage unit **7**  
 seed value (random numbers) **245**, **250**  
**Seek** method of class **FileStream** **701**  
**SeekOrigin** enumeration **701**  
**select** clause of a LINQ query **356**  
**Select** method of class **Control** **530**  
**Select Resource** dialog **54**  
 selected state **542**  
**SelectedImageIndex** property of class **TreeNode** **599**  
**SelectedIndex** property of class **ComboBox** **595**  
**SelectedIndex** property of class **ListBox** **588**  
**SelectedIndex** property of class **TabControl** **611**  
**SelectedIndexChanged** event handler **ComboBox** class **873**  
**SelectedIndexChanged** event of class **ComboBox** **595**  
**SelectedIndexChanged** event of class **ListBox** **587**  
**SelectedIndexChanged** event of class **TabControl** **611**  
**SelectedIndices** property of class **ListBox** **588**  
**SelectedItem** property of class **ComboBox** **595**  
**SelectedItem** property of class **ListBox** **588**  
**SelectedItems** property of class **ListBox** **604**  
**SelectedItems** property of class **TreeView** **599**  
**SelectedTab** property of class **TabControl** **611**  
 selecting an item from a menu **522**  
 selecting data from a table **852**  
 selection **146**, **218**, **219**  
 selection sort algorithm **726**, **727**, **730**  
 selection statement **144**, **146**
  - if** **146**, **147**, **201**, **220**, **221**
  - if...else** **146**, **148**, **163**, **201**, **220**
  - switch** **146**, **201**, **207**, **220****SelectionEnd** property of class **MonthCalendar** **580**  
**SelectionMode** enumeration **587**
  - MultiExtended** value **587**
  - MultiSimple** value **587**
  - None** value **587**
  - One** value **587****SelectionMode** property of class **CheckedListBox** **592**  
**SelectionMode** property of class **ListBox** **587**, **588**  
**SelectionRange** property of class **MonthCalendar** **580**  
**SelectionStart** property of class **MonthCalendar** **580**  
**self-documenting code** **83**  
**self-referential class** **748**, **749**  
**Self-referential Node** class declaration **748**  
**self-referential object** **749**  
**semicolon** ; **71**, **82**, **93**  
 send a message to an object **124**  
 sentinel-controlled repetition **158**, **160**, **161**, **228**, **163**, **164**, **346**  
 sentinel value **159**, **160**, **164**  
**Separating Digits** exercise **280**  
**separator bar** **573**  
**sequence** **218**, **219**, **769**  
**sequence of items** **749**  
**sequence statement** **144**  
**sequence structure** **145**  
**sequence-structure activity diagram** **145**  
**sequential-access file** **685**  
**sequential execution** **144**  
**sequential file** **672**
  - created using serialization **703**
  - read using deserialization **707****[Serializable]** attribute **702**  
**SerializationException** class **703**  
**Serialize** method of class **BinaryFormatter** **701**, **703**  
**serialized object** **701**, **702**  
 service of a class **376**  
 session **926**  
**session item** **931**  
**Session** property of **Page** class **929**  
**session tracking** **926**, **927**  
**SessionID** property of **HttpSessionState** class **931**  
**set** accessor of a property **108**, **118**, **121**  
**Set at Startup** Project **863**  
**set** keyword **119**  
**Set of Integers** (exercise) **403**  
**set-theoretic intersection** **403**  
**set-theoretic union** **403**  
**shallow copy** **435**  
**Shape** class hierarchy **408**, **439**  
**Shape Hierarchy** exercise **484**  
**shift** **246**  
**Shift** key **556**  
**Shift** property of class **KeyEventArgs** **557**, **559**  
**Shifted and scaled random integers** **246**  
**shifting value (random numbers)** **246**, **249**, **250**  
**"shipping"** section of the computer **6**  
**shopping list** **152**

- short-circuit evaluation **212**  
**short** simple type **952**  
**Short** value of enumeration  
  **DateTimePickerFormat** **580**  
**shortcut key** **570**  
**ShortcutKeyDisplayString** property  
  of class **ToolStripMenuItem** **571**,  
  **574**  
**ShortcutKeys** property of class  
  **ToolStripMenuItem** **571**, **574**  
shortcuts with the & symbol **573**  
**Show All Files** icon **43**  
**Show** method of class **Control** **530**  
**Show** method of class **Form** **522**, **614**, **620**  
**ShowCheckBox** property of class  
  **DateTimePicker** **581**  
**ShowDialog** method of class  
  **OpenFileDialog** **695**, **701**  
**ShowDialog** method of class  
  **SaveFileDialog** **690**  
**ShowShortcutKeys** property of class  
  **ToolStripMenuItem** **571**, **574**  
**ShowUpDown** property of class  
  **DateTimePicker** **581**  
**shuffling** **299**  
  Fisher-Yates **302**  
**sibling** **769**  
**sibling node** **598**  
**side effect** **213**, **266**  
**Sides of a Right Triangle** exercise **187**  
**Sides of a Triangle** exercise **187**  
**Sieve of Eratosthenes** **342**  
**Sieve of Eratosthenes** exercise **342**  
**signal value** **159**  
**signature of a method** **259**  
**simple condition** **211**  
**simple name** **522**, **623**  
**simple type** **83**, **174**, **242**  
**Simple Types**  
  **bool** **952**  
  **byte** **952**  
  **char** **83**, **952**  
  **decimal** **83**, **128**, **953**  
  **double** **83**, **128**, **162**, **953**  
  **float** **83**, **128**, **952**  
  **int** **82**, **83**, **162**, **171**, **952**  
  **long** **952**  
  names are keywords **83**  
  **sbyte** **952**  
  **short** **952**  
  table of **952**  
  **uint** **952**  
  **ulong** **952**  
  **ushort** **952**  
**Simple value of enumeration**  
  **ComboBoxStyle** **595**  
**simplest activity diagram** **218**  
**Simpletron Machine Language (SML)**  
  **344**  
**Simpletron simulator** **347**, **349**  
**Simpletron Simulator Modifications**  
  exercise **349**  
**simulation**  
  coin tossing **281**  
**Simulation: Tortoise and the Hare**  
  exercise **343**  
**simulator** **344**  
  terminate a running app **22**, **27**  
**Sin** method of **Math** **235**
- sine **235**  
**Single Document Interface (SDI)** **614**  
**single entry point** **216**  
**single-entry/single-exit control statements**  
  **146**, **218**  
**single exit point** **216**  
**single inheritance** **406**  
**single-precision floating-point number**  
  **128**  
**single-selection statement** **146**, **147**, **220**  
**Single struct** **747**  
**single-line comment** **66**  
**single-selection statement**  
  **if** **147**  
**singly linked list** **760**  
**size** **85**  
**Size** property of class **Control** **532**  
**Size structure** **532**  
  **Height** property **532**  
  **Width** property **532**  
**SizeMode** property of class **PictureBox**  
  **54**, **547**  
**sizing handle** **48**  
**sizing handle, enabled** **48**  
**.sln** file extension **54**  
**smallest of several integers** **227**  
**SmallImageList** property of class  
  **ListView** **604**  
**smart tag menu** **871**, **917**  
**SMS Language** **668**  
**snap lines** **533**  
**software** **2**  
  software engineering  
    encapsulation **122**  
  Software Engineering Observations  
    overview **xxxiv**  
  software model **346**  
  software reuse **233**, **406**, **623**  
  software simulation **344**  
**solid circle** **145**  
**solid circle surrounded by a hollow circle**  
  **145**  
**SolidBrush** class **556**  
**solution** **20**, **23**, **36**  
**Solution Explorer** window **43**  
**Some methods of class** **ArrayList** **822**  
**Sort Algorithms**  
  bubble sort **743**, **744**  
  bucket sort **744**  
  insertion sort **730**  
  merge sort **734**  
  quicksort **745**  
  selection sort **726**  
**sort key** **716**  
**Sort** method of **Array** **722**  
**Sort** method of class **Array** **820**  
**Sort** method of class **ArrayList** **823**  
**Sort** method of class **List<T>** **363**  
**sorted array** **751**  
**Sorted** property of class **ComboBox** **595**  
**Sorted** property of class **ListBox** **588**  
**SortedDictionary** generic class **817**,  
  **834**, **835**  
**SortedSet** generic class **817**  
**SortedSet<T>** class **842**  
**sorting** **747**  
**Sorting Algorithms**  
  bubble sort **743**, **744**  
  bucket sort **744**
- Sorting Algorithms (cont.)**  
  insertion sort **730**  
  merge sort **734**  
  quicksort **745**  
  selection sort **726**  
**sorting data** **716**, **726**  
**Sorting Letters and Removing Duplicates**  
  exercise **370**  
**source code** **434**  
**Source** property of **Exception** **506**  
**space character** **68**  
**space/time trade-off** **829**  
**spacing convention** **70**  
**Spam Scanner** **668**  
**speaking to a computer** **6**  
**special character** **83**, **640**  
**Special Section: Building Your Own Computer** **344**  
**special symbol** **3**, **670**  
**sphere** **275**  
**Split** method of class **Regex** **832**  
**Split** method of class **String** **370**, **695**  
**split the array in merge sort** **734**  
**spooler** **766**  
**spooling** **766**  
**SQL** **352**, **850**  
**SQL Server** **850**  
**SQL Server Express** **859**  
**SQL Server Express 2012 LocalDB** **850**  
**Sqr** method of class **Math** **511**  
**Sqr** method of **Math** **234**, **235**, **242**  
**square brackets**, **[]** **286**  
**Square of Asterisks** exercise **186**  
**square root** **235**  
**stack** **241**, **282**, **394**, **762**, **799**  
**Stack** class **817**, **826**  
**stack data structure** **747**  
**stack frame** **241**  
**Stack** generic class **799**, **817**  
  **Stack<double>** **808**  
  **Stack<int>** **808**  
**stack overflow** **242**  
**stack trace** **490**  
**stack unwinding** **506**  
**Stack** unwinding and **Exception** class  
  properties **506**  
**StackComposition** class encapsulates  
  functionality of class **List** **765**  
**stacked building block** **221**  
**stacking control statements** **147**, **221**  
**stacking rule** **218**  
**StackOverflowException** class **496**  
**StackTrace** property of **Exception**  
  **505**, **506**, **509**  
**standard error stream object** **673**  
**standard input stream object** **672**  
**standard input/output object** **71**  
**standard output stream object** **673**  
**standard reusable component** **407**  
**standard time format** **374**  
**“warehouse” section of the computer** **7**  
**Start** method of class **Process** **586**  
**Start Page** **34**  
**start page for a web application** **911**, **914**,  
  **919**, **928**, **935**  
**StartsWith** and **EndsWith** methods  
  **646**  
**StartsWith** method of class **string**  
  **366**, **645**

startup project 43  
 state button 539  
 stateless protocol 925  
 statement 71, 110  
   empty 93  
   if 90  
 statements 160  
   break 205, 209, 229  
   continue 209, 229, 230  
   control statements 144, 146  
   control-statement nesting 146  
   control-statement stacking 146  
   do...while 146, 199, 201, 221  
   double selection 146, 167  
   empty statement 152  
   for 146, 191, 192, 194, 195, 196,  
     198, 221  
   if 146, 147, 201, 220, 221  
   if...else 146, 148, 163, 201, 220  
   iteration 146  
   multiple selection 146  
   nested 166  
   nested if...else 149, 150, 151  
   repetition 144, 146, 152  
   return 233, 241  
   selection 144, 146  
   single selection 146  
   switch 146, 201, 207, 220  
   switch multiple-selection statement  
     249  
   throw 373, 502  
   try 298, 495  
   using 504  
   while 146, 152, 153, 157, 163, 221

**static**  
   class member 390  
   method 111, 198  
   variable 390, 391

static binding 466  
 Static member demonstration 392  
**static** method cannot access non-  
   static class members 393  
**static** method Concat 650  
**static** variable scope 391  
 Static variable used to maintain a count of  
   the number of Employee objects in  
   memory 391

stereotype in the UML 121  
 straight-line form 87  
 stream  
   standard error 673  
   standard input 672  
   standard output 673

**Stream** class 673  
 stream of bytes 672  
**StreamReader** class 673  
**StreamWriter** class 673  
 StretchImage value 54

**string** 71, 244  
   literal 71  
   of characters 71  
   verbatim 640

**string**  
   verbatim 586  
**String** array 288  
**String** class  
   Split method 370, 695  
**string** class 639  
   Concat method 650  
   constructors 641

**string** class (cont.)  
   CopyTo method 642  
   EndsWith method 645, 646  
   Equals method 643  
   Format method 374  
   immutable 642  
   IndexOf method 646  
   IndexOfAny method 646  
   LastIndexOf method 646, 648  
   LastIndexOfAny method 646, 649  
   Length property 642, 643  
   method ToCharArray 404  
   method ToLower 832  
   method ToUpper 840  
   Replace method 651, 652  
   StartsWith method 366, 645  
   Substring method 649  
   ToLower method 651, 652  
   ToUpper method 366, 651, 652  
   Trim method 651, 652  
   verbatim string literal 240

**String Collection Editor** in Visual Studio .NET 589  
 string concatenation 239, 392  
 string constant 640  
 string constructors 641  
 string format specifiers 132  
 string indexer 643  
 string indexer, Length property and  
   CopyTo method 642  
 string literal 640  
**string.Empty** 124  
**StringBuilder** class 639, 652  
   Append method 655  
   AppendFormat method 656  
   Capacity property 653  
   constructors 653  
   EnsureCapacity method 653  
   Length property 653  
   Remove method 657  
   Replace method 659  
   ToString method 653

**StringBuilder** constructors 652  
**StringBuilder** size manipulation 653  
**StringBuilder** text replacement 659  
 strongly typed languages 174  
 Stroustrup, Bjarne 487  
 struct 748  
**struct** 747  
   Boolean 747  
   Byte 747  
   Character 747  
   DateTime 629  
   Decimal 747  
   Double 747  
   Int16 747  
   Int32 747  
   Int64 747  
   Single 747  
   UInt16 747  
   UInt64 747

**struct** keyword 660  
 Structs  
   UInt32 747

Structured Equivalent of break  
 Statement exercise 229

Structured Equivalent of continue  
 Statement exercise 230

structured programming 143, 144, 210,  
   218  
   summary 216

Structured Query Language (SQL) 850  
 Structures  
   BigInteger 404

Student Poll exercise 714  
**Style** property of class **Font** 541  
 subarray 721  
 submenu 570  
**Substring** method of class **string** 649  
 substrings generated from **strings** 649  
 subtraction 6, 87  
 summarizing responses to a survey 296  
 summing integers with the **for** statement  
   196

suspended app 27, 29  
 swapping values 726, 730  
**switch** code snippet (IDE) 255  
**switch** expression 205  
**switch** keyword 205  
**switch** logic 209  
**switch** multiple-selection statement  
   146, 201, 207, 220, 249  
   activity diagram with **break** statements 208  
   **case** label 205, 206  
   controlling expression 205  
   default label 205, 249

Sybase 850  
 synchronous programming 13  
 syntax 67  
 syntax error 67, 71, 76  
 syntax error underlining 77  
 syntax-color highlighting 73  
 System namespace 68, 245, 639  
**System.Collections** namespace 244,  
   762, 796, 815  
**System.Collections.Concurrent**  
   namespace 815  
**System.Collections.Generic**  
   namespace 244, 362, 681, 815, 835  
**System.Collections.Specialized**  
   namespace 815  
**System.Data.Entity** namespace 244,  
   857  
**System.Diagnostics** namespace 586  
**System.Drawing** namespace 541  
**System.IO** namespace 244, 673  
**System.Linq** namespace 244, 353, 857  
**System.Runtime.Serialization.F**  
   ormatters.Binary namespace 701  
**System.Text** namespace 244, 639  
**System.Text.RegularExpressions**  
   namespace 639  
**System.Web** namespace 244  
**System.Web.UI** namespace 913  
**System.Web.UI.WebControls**  
   namespace 913  
**System.Windows.Controls**  
   namespace 244  
**System.Windows.Forms** namespace  
   244, 521  
**System.Windows.Input** namespace  
   244  
**System.Windows.Media** namespace  
   244  
**System.Windows.Shapes** namespace  
   244

**S**  
 System.Xml namespace 244  
 System.Xml.Linq namespace 244  
 SystemException class 496, 511

**T**  
 tab 520  
 tab character, \t 68, 79  
 Tab key 70  
 tab stops 70, 79  
 Tabbed pages in Visual Studio .NET 610  
 tabbed window 38  
 TabControl class 609  
   ImageList property 611  
   ItemSize property 611  
   Multiline property 611  
   SelectedIndex property 611  
   SelectedIndexChanged event 611  
   SelectedTab property 611  
   TabCount property 611  
   TabPages property 610, 611  
 TabControl with TabPages example 610  
 TabControl1, adding a TabPage 611  
 TabCount property of class TabControl 611  
 TabIndex property of class Control 530  
 TabPage class 609  
   Text property 610  
 TabPage, add to TabControl 610  
 TabPage, using radio buttons 613  
 TabPages added to a TabControl 611  
 TabPages property of class TabControl 610, 611  
 TabStop property of class Control 530  
 tabular format 290  
 Tabular Output exercise 184  
 tail of a queue 747, 766  
 Tan method of Math 235  
 tangent 235  
 Target property of a HyperLink control 918  
 Target-Heart-Rate Calculator 141  
 TargetSite property of Exception 506  
 Tax Plan Alternatives 230  
 TCP (Transmission Control Protocol) 11  
 TCP/IP 11  
 TEAM menu 40  
 Telephone-Number Word Generator exercise 713  
 template 36  
 temporary 164  
 temporary data storage 670  
 terabyte 7  
 terminate a loop 160  
 terminate an app running in the simulator 22, 27  
 termination housekeeping 390  
 termination model of exception handling 495  
 termination phase 159  
 ternary operator 149

test harness 316  
 Testing class  
   BasePlusCommissionEmployee 419, 426, 432  
 Testing class CommissionEmployee 414  
 Testing class List 755  
 Testing class QueueInheritance 768  
 Testing class StackInheritance 763  
 Testing class Tree with a binary tree 773  
 Testing class Tree with IComparable objects 780  
 Testing generic class Stack 802, 806  
 Testing the insertion sort class 733  
 Testing the merge sort class 738  
 Testing the selection sort class 729  
 Tests interface IPayable with disparate classes 475  
 text editor 71, 639  
 Text property 48, 52  
 Text property of class Button 534  
 Text property of class CheckBox 539  
 Text property of class Control 530  
 Text property of class Form 522  
 Text property of class GroupBox 536  
 Text property of class LinkLabel 584  
 Text property of class RadioButton 542  
 Text property of class TabPage 610  
 Text property of class TextBox 534  
 Text property of class  
   ToolStripMenuItem 574  
 Text property of class TreeNode 599  
 TextAlign property of a Label 53  
 TextBlock control 24  
 textbox 533  
 TextBox ASP.NET web control 916  
 TextBox control 63, 520, 533  
   AcceptsReturn property 534  
   Multiline property 534  
   ReadOnly property 534  
   ScrollBars property 534  
   Text property 534  
   TextChanged event 534  
   UseSystemPasswordChar property 533  
 TextChanged event of class TextBox 534  
 Text-displaying application 67  
 TextReader class 673  
 TextWriter class 673  
 ThenBy extension method of class Queryable 868  
 this  
   keyword 377, 393  
   reference 377  
   to call another constructor of the same class 382  
 this used implicitly and explicitly to refer to members of an object 378  
 ThreeDimensionalShape 439  
 ThreeState property of class CheckBox 539  
 throw an exception 298, 298, 373, 382, 488, 493  
 throw point 490, 495  
 throw statement 502  
 throws an exception 373  
 Tick event of class Timer 628  
 TicTacToe 404  
   exercise 404

tier in a multitier application 900  
 tightly packed binary tree 776  
 tile 17  
 tiled window 616  
 TileHorizontal value of enumeration MdiLayout 616  
 TileVertical value of enumeration MdiLayout 616  
 time and date 629  
 Time value of enumeration  
   DateTimePickerFormat 580  
 Time1 class declaration maintains the time in 24-hour format 372  
 Time1 object used in an app 375  
 Time2 class declaration with overloaded constructors 380  
 TimeOfDay property of DateTime 580  
 Timeout property of  
   HttpSessionState class 931  
 Timer class 628  
   Interval property 628  
   Tick event 628  
 title bar 48  
 title bar, MDI parent and child 616  
 Title property of a Web Form 908  
 Titles table of Books database 852, 853  
 ToCharArray method of class string 404  
 ToDecimal method of class Convert 133  
 ToInt32 method of class Convert 84, 91, 330  
 tokenize a string 695  
 ToLongDateString method of structure DateTime 583  
 ToLongTimeString method of structure DateTime 629  
 ToLower method of class string 651, 652, 832  
 ToLower method of struct Char 662  
 tool bar 519  
 tool tip 41  
 toolbar 40  
 toolbar icon 40  
 Toolbox 44, 908  
 TOOLS menu 40  
 ToolStripMenuItem class 571  
   Checked property 574, 578  
   CheckOnClick property 574  
   Click event 573, 574  
   ShortcutKeyDisplayStyle property 571, 574  
   Text property 574  
 ToolStripMenuItem properties and an event 574  
 ToolTip class 549  
   AutoPopDelay property 550  
   Draw event 550  
   InitialDelay property 550  
   ReshowDelay property 550  
 ToolTip properties and events 550  
 top 159  
 top-down, stepwise refinement 159, 160, 161, 167, 168  
 top of a stack 747  
 top tier 901

- Tortoise and the Hare exercise 343  
 Tortoise and the Hare simulation 343  
**ToString** method of an anonymous type 877  
**ToString** method of class **Exception** 509  
**ToString** method of class **object** 413, 435  
**ToString** method of class **StringBuilder** 653, 655  
**total** 154, 160  
 Total Sales exercise 338  
**ToUpper** method of class **string** 366, 651, 652, **840**  
**ToUpper** method of struct **Char** 662  
 Towers of Hanoi exercise 282  
**trace** 805  
 TrackBar control 64  
 tracking customers 925  
 transfer of control 144, 346, 347, 348  
 transition 145  
 transition arrow 145, 147, 153  
 translation 7  
 translator program 7  
 Transmission Control Protocol (TCP) 11  
 traversals forwards and backwards 761  
 traverse a tree 775  
 traverse an array 319  
**tree** 598, **769**  
**TreeNode** class 598, 599  
 Checked property 599  
 Collapse method 599  
 Expand method 600  
 ExpandAll method 600  
**FirstNode** property 599  
**FullPath** property 599  
**GetNodeCount** method 600  
**ImageIndex** property 599  
**LastNode** property 599  
**NextNode** property 599  
**Nodes** property 599  
**PrevNode** property 599  
**SelectedImageIndex** property 599  
 Text property 599  
**TreeNode Editor** 600  
**TreeNode** properties and methods 599  
**TreeNodeCollection** class 598  
**TreeView** class 570, **598**  
 AfterSelected event 599  
 CheckBoxes property 599  
 ImageList property 599  
 Nodes property 599  
 SelectedNode property 599  
**TreeView** displaying a sample tree 598  
**TreeView** properties and an event 599  
**TreeView** used to display directories 601  
**TreeViewEventArgs** class 599  
 trigger an event 520  
 trigonometric cosine 235  
 trigonometric sine 235  
 trigonometric tangent 235  
**Trim** method of class **string** 651  
**TrimExcess** method of class **List<T>** 363  
**TrimToSize** method of class **ArrayList** 822, 823  
**true** 90, 148, 149  
**truncate** 86, **158**
- truth table 211  
 truth tables  
   for operator **&** 213  
   for operator **!** 214  
   for operator **&&** 211  
   for operator **||** 212  
**try block** 298, **493**  
**try statement** 298, **495**  
**TryParse** method of structure **Int32** 493  
 Turing Machine 144  
 Turtle Graphics exercise 339  
 24-hour clock format 372  
 two-dimensional array 316  
 two-dimensional data structure 769  
 two largest values 184  
**TwoDimensionalShape** class 439  
 type 82, 83, 85  
 type argument 794, **795**, 802  
 type checking 790  
 Type class 435, **464**  
   **FullName** property 435  
 type constraint 796  
   specifying 796  
 type inference 795  
 type parameter 794, 799, 808  
   scope 802  
 type parameter list 794, 799  
 typesetting system 639  
 typing in a **TextBox** 522  
 Typing Tutor: Tuning a Crucial Skill in the Computer Age exercise 568
- U**
- uint** simple type 952  
**UInt16** struct 747  
**UInt32** struct 747  
**UInt64** struct 747  
**ulong** simple type 952  
 UML  
   activity diagram 145, 147, 153, 200  
   arrow 145  
   class diagram 112  
   diamond 147  
   dotted line 145  
   final state 145  
   guard condition 147  
   merge symbol 153  
   modeling properties 121  
   note 145  
   solid circle 145  
   solid circle surrounded by a hollow circle 145  
   stereotype 121  
 UML (Unified Modeling Language) 10  
 UML class diagram 407  
 unary cast operator 164  
 unary operator 165, 213  
**UnauthorizedAccessException** class 603  
 unboxing conversion 748  
 uncaught exception 494  
 uneditable text or icons 520  
 unhandled exception 490, **494**  
 Unicode® character set 4, 175, 208, **640**, 671  
 Unified Modeling Language (UML) 10  
 Uniform Resource Identifier (URI) 899
- Uniform Resource Locator (URL) 899  
 union of two sets 403  
 unique session ID of an ASP.NET client 931  
 universal-time format 372, 373, 374  
 unmanaged resource 477  
 unnecessary parentheses 90  
 unobtrusive validation 924  
 unqualified name 243, 255, 522, 623  
 unwind a method from the call stack 508  
**UpDownAlign** property of class **NumericUpDown** 552  
 upper camel casing 69  
 uppercase letter 69, 83  
 URI (Uniform Resource Identifier) 899  
 URL (Uniform Resource Locator) 899  
**UseMnemonic** property of class **LinkLabel** 584  
 user-defined classes 68  
 user interface 901  
**UserControl** control 627  
**UserControl** defined clock 628  
 user-defined exception class 509  
 user-defined method 233  
 user-defined method **Maximum** 237  
**UseSystemPasswordChar** property of class **TextBox** 533  
**ushort** simple type 952  
**using** directive 67, 116, 243  
 utility method 207
- V**
- valid identifier 82  
**Validate** property of **Page** class 924  
 Validating User Input exercise 184  
 validation 130  
 validation control 918  
**ValidationExpression** property of a **RegularExpressionValidator** control 922  
 validator 918  
 validity checking 130  
 value 85  
 value contextual keyword 119  
 Value property of class **DateTimePicker** 580, 581, **583**  
 Value property of class **LinkedListNode** 836  
 Value property of class **NumericUpDown** 552  
 value to the nearest integer 278  
 value type 123, 286  
 value type constraint struct 798  
**ValueChanged** event of class **DateTimePicker** 581  
**ValueChanged** event of class **NumericUpDown** 552  
 Values property of class **Hashtable** 833  
**ValueType** class 660, **748**  
 var keyword 355  
 variable 81, 82  
   declaration statement 82  
   name 82, 85  
 variable is not modifiable 394  
 variable-length argument list 327  
 Variable-Length Argument List exercise 337

variable scope 193  
**verbatim string** **586**  
 verbatim string **640**  
 verbatim string literal 240  
 verbatim string syntax(@) 640  
**VIEW** menu 39, 41  
 View property of class **ListView** **603**,  
 604  
**virtual**  
 keyword **423**  
 virtual directory 900  
 virtual goods 18  
 virtual machine (VM) **15**, **30**  
 visibility symbols in the UML **112**, **121**  
**Visible** property of an ASP.NET web  
 control **921**  
**Visible** property of class **Control** **530**  
**VisitedLinkColor** property of class  
**LinkLabel** **584**  
 visual app development **34**  
 Visual Basic **14**  
 visual programming 521  
 Visual Studio **19**  
 component tray **550**  
 IDE (integrated development envi-  
 ronment) 19  
 Visual Studio .NET Class View 396  
 Visual Studio .NET Object Browser 396  
 Visual Studio Express 2012 for Web **898**  
 Visual Studio® 2012 **34**  
**void** keyword 71, 109  
 volatile information 6  
 volume of a sphere 275, 277

**W**

W3C (World Wide Web Consortium)  
**11**  
 waiting line 747  
 walk the list 760  
 Web app development **898**  
 web control **898**

Web Form **898**, **905**, 926, 932  
**Init** event **911**  
**Load** event 923  
 web server **899**  
**Web.config** ASP.NET configuration  
 file **912**  
**WebTime** Modification exercise 947  
 What Does This Code Do? exercise 227,  
 230, 283  
 What Does This Program Do? exercise  
 182, 184, 185  
 What's Wrong with This Code? exercise  
 187  
**where** clause **797**  
**where** clause of a LINQ query **356**  
**Where** extension method of class  
**Queryable** **873**  
**while** keyword 199  
**while** repetition statement 146, 152,  
 153, 157, 163, 221  
 activity diagram in the UML 153  
 whitespace **68**, 71, 93  
 characters **68**  
 whitespace character (regular expressions)  
 652  
 widget **520**  
**Width** property of structure **Size** **532**  
 window auto hide **42**  
 window gadget **520**  
**WINDOW** menu 40  
 window tab 38  
 Windows  
**Font** 52  
**Properties** **44**, 45, 48, 52  
**Solution Explorer** **43**  
 Windows 8 **17**  
 Windows 8 UI 16, 17, 23  
 Windows Azure **19**, **30**  
 Windows bitmap (BMP) 54  
 Windows Explorer 586  
 Windows Form **520**  
 Windows Forms app **36**

Windows operating system **16**  
 Windows Phone **7** **16**  
 Windows Phone 8 operating system **17**,  
**29**  
 Windows Phone Dev Center 18  
 Windows Phone Emulator **18**, **28**  
 Windows Phone Marketplace **18**  
 Windows Phone operating system **17**, **28**  
 Windows Store 17  
 Windows Store developer 17  
 word processor 639, 646  
 workflow **145**  
 World Population Growth 187  
 World Wide Web **11**  
 World Wide Web Consortium (W3C)  
**11**  
 worst-case run time for an algorithm 720  
**Write** method of class **Console** **78**, **673**  
**WriteLine** method of class **Console** **71**,  
 78, 673  
**WriteLine** method of class  
**StreamWriter** **690**  
[www.deitel.com/LINQ/](http://www.deitel.com/LINQ/) 367  
[www.unicode.org](http://www.unicode.org) 671

**X**

X format specifier 132  
**X** property of class **MouseEventArgs** 554  
 XOR bitwise operator 579

**Y**

**Y** property of class **MouseEventArgs** 554

**Z**

zero-based counting 192  
 zeroth element **287**