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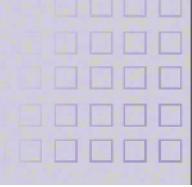
PROGRAMMING LOGIC AND DESIGN

SIXTH EDITION



TONY GADDIS





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Edition

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Programming Logic & Design

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Starting Out with

Programming Logic & Design

Tony Gaddis
Haywood Community College



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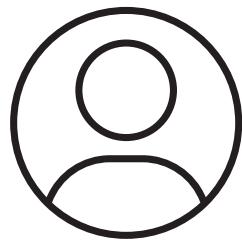
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Preface

Welcome to *Starting Out with Programming Logic and Design*, Sixth Edition. This book uses a language-independent approach to teach programming concepts and problem-solving skills, without assuming any previous programming experience. By using easy-to-understand pseudocode, flowcharts, and other tools, the student learns how to design the logic of programs without the complication of language syntax.

Fundamental topics such as data types, variables, input, output, control structures, modules, functions, arrays, and files are covered as well as object-oriented concepts, GUI development, and event-driven programming. As with all the books in the *Starting Out with . . .* series, this text is written in clear, easy-to-understand language that students find friendly and inviting.

Each chapter presents a multitude of program design examples. Short examples that highlight specific programming topics are provided, as well as more involved examples that focus on problem solving. Each chapter includes at least one *In the Spotlight* section that provides step-by-step analysis of a specific problem and demonstrates a solution to that problem.

This book is ideal for a programming logic course that is taught as a precursor to a language-specific introductory programming course, or for the first part of an introductory programming course in which a specific language is taught.

Changes in the Sixth Edition

Previous editions of this book introduced modules, which are procedures that do not return a value, in Chapter 3. Feedback from adopters and reviewers indicate that students sometimes have trouble learning about modules before they have been exposed to control structures, such as If statements and loops. In this edition, the chapter on modules has been moved to Chapter 5. Now, the students will learn about control structures, then modules, and then value-returning functions. This improved pedagogy gradually introduces the students to the different ways a program's flow of execution can be directed.

Brief Overview of Each Chapter

Chapter 1: Introduction to Computers and Programming

This chapter begins by giving a concise and easy-to-understand explanation of how computers work, how data is stored and manipulated, and why we write programs in high-level languages.

Chapter 2: Input, Processing, and Output

This chapter introduces the program development cycle, data types, variables, and sequence structures. The student learns to use pseudocode and flowcharts to design simple programs that read input, perform mathematical operations, and produce screen output.

Chapter 3: Decision Structures and Boolean Logic

In this chapter students explore relational operators and Boolean expressions and are shown how to control the flow of a program with decision structures. The If-Then, If-Then-Else, and If-Then-Else If statements are covered. Nested decision structures, logical operators, and the case structure are also discussed.

Chapter 4: Repetition Structures

This chapter shows the student how to use loops to create repetition structures. The While, Do-While, Do-Until, and For loops are presented. Counters, accumulators, running totals, and sentinels are also discussed.

Chapter 5: Modules

This chapter demonstrates the benefits of modularizing programs and using the top-down design approach. The student learns to define and call modules, pass arguments to modules, and use local variables. Hierarchy charts are introduced as a design tool.

Chapter 6: Functions

This chapter begins by discussing common library functions, such as those for generating random numbers. After learning how to call library functions and how to use values returned by functions, the student learns how to define and call his or her own functions.

Chapter 7: Input Validation

This chapter discusses the importance of validating user input. The student learns to write input validation loops that serve as error traps. Defensive programming and the importance of anticipating obvious as well as unobvious errors is discussed.

Chapter 8: Arrays

In this chapter the student learns to create and work with one- and two-dimensional arrays. Many examples of array processing are provided including examples illustrating how to find the sum, average, and highest and lowest values in an array, and how to sum the rows, columns, and all elements of a two-dimensional array. Programming techniques using parallel arrays are also demonstrated.

Chapter 9: Sorting and Searching Arrays

In this chapter the student learns the basics of sorting arrays and searching for data stored in them. The chapter covers the bubble sort, selection sort, insertion sort, and binary search algorithms.

Chapter 10: Files

This chapter introduces sequential file input and output. The student learns to read and write large sets of data, store data as fields and records, and design programs that work with both files and arrays. The chapter concludes by discussing control break processing.

Chapter 11: Menu-Driven Programs

In this chapter the student learns to design programs that display menus and execute tasks according to the user's menu selection. The importance of modularizing a menu-driven program is also discussed.

Chapter 12: Text Processing

This chapter discusses text processing at a detailed level. Algorithms that step through the individual characters in a string are discussed, and several common library functions for character and text processing are introduced.

Chapter 13: Recursion

This chapter discusses recursion and its use in problem solving. A visual trace of recursive calls is provided, and recursive applications are discussed. Recursive algorithms for many tasks are presented, such as finding factorials, finding a greatest common denominator (GCD), summing a range of values in an array, and performing a binary search. The classic Towers of Hanoi example is also presented.

Chapter 14: Object-Oriented Programming

This chapter compares procedural and object-oriented programming practices. It covers the fundamental concepts of classes and objects. Fields, methods, access specification, constructors, accessors, and mutators are discussed. The student learns how to model classes with UML and how to find the classes in a particular problem.

Chapter 15: GUI Applications and Event-Driven Programming

This chapter discusses the basic aspects of designing a GUI application. Building graphical user interfaces with visual design tools (such as Visual Studio® or NetBeans™) is discussed. The student learns how events work in a GUI application and how to write event handlers.

Appendix A: ASCII/Unicode Characters

This appendix lists the ASCII character set, which is the same as the first 127 Unicode character codes.

Appendix B: Flowchart Symbols

This appendix shows the flowchart symbols that are used in this book.

Appendix C: Pseudocode Reference

This appendix provides a quick reference for the pseudocode language that is used in the book.

Appendix D: Converting Decimal Numbers to Binary

This appendix uses a simple tutorial to demonstrate how to convert a decimal number to binary.

Appendix E: Answers to Checkpoint Questions

This appendix provides answers to the Checkpoint questions that appear throughout the text.

Organization of the Text

The text teaches programming logic and design in a step-by-step manner. Each chapter covers a major set of topics and builds knowledge as students progress through the book. Although the chapters can be easily taught in their existing sequence, there is some flexibility. Figure P-1 shows chapter dependencies. Each box represents a chapter or a group of chapters. A chapter to which an arrow points must be covered before the chapter from which the arrow originates. The dotted line indicates that only a portion of Chapter 10 depends on information presented in Chapter 8.

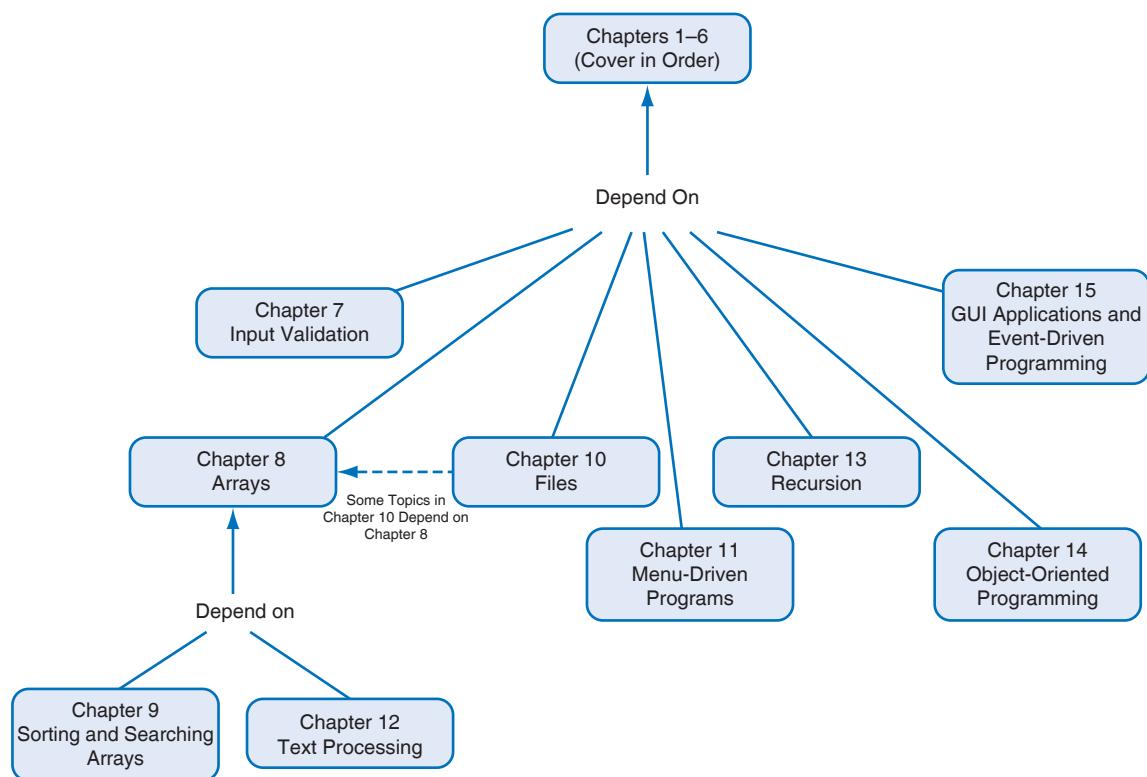
Features of the Text

Concept Statements. Each major section of the text starts with a concept statement. This statement concisely summarizes the main point of the section.

Example Programs. Each chapter has an abundant number of complete and partial example programs, each designed to highlight the current topic. Pseudocode, flowcharts, and other design tools are used in the example programs.

In the Spotlight. Each chapter has one or more *In the Spotlight* case studies that provide detailed, step-by-step analysis of problems, and show the student how to solve them.



Figure P-1 Chapter dependencies

VideoNotes. A series of online videos, developed specifically for this book, are available for viewing at www.pearson.com/cs-resources. Icons appear throughout the text alerting the student to videos about specific topics.



NOTE: Notes appear at several places throughout the text. They are short explanations of interesting or often misunderstood points relevant to the topic at hand.



TIP: Tips advise the student on the best techniques for approaching different programming or animation problems.



WARNING! Warnings caution students about programming techniques or practices that can lead to malfunctioning programs or lost data.



Programming Language Companions. Many of the pseudocode programs shown in this book have also been written in Java, Python, and C++. These programs appear in the programming language companions that are available at www.pearson.com/cs-resources. Icons appear next to each pseudocode program that also appears in the language companions.



Checkpoints. Checkpoints are questions placed at intervals throughout each chapter. They are designed to query the student's knowledge quickly after learning a new topic.

Review Questions. Each chapter presents a thorough and diverse set of Review Questions and exercises. They include Multiple Choice, True/False, Short Answer, and Algorithm Workbench.

Debugging Exercises. Most chapters provide a set of Debugging Exercises in which the student examines a set of pseudocode algorithms and identifies logical errors.

Programming Exercises. Each chapter offers a pool of Programming Exercises designed to solidify the student's knowledge of the topics currently being studied.

Supplements

Student Online Resources

Many student resources are available for this book from the publisher. The following items are available on the Gaddis Series resource page at www.pearson.com/cs-resources:

- **Access to the book's companion VideoNotes**

An extensive series of online VideoNotes have been developed to accompany this text. Throughout the book, VideoNote icons alert the student to videos covering specific topics. Additionally, one programming exercise at the end of each chapter has an accompanying VideoNote explaining how to develop the problem's solution.

- **Access to the Language Companions for Python, Java, and C++**

Programming language companions specifically designed to accompany this textbook are available for download. The companions introduce the Java™, Python®, and C++ programming languages, and correspond on a chapter-by-chapter basis with the textbook. Many of the pseudocode programs that appear in the textbook also appear in the companions, implemented in a specific programming language.

- **A link to download the Flowgorithm flowcharting application**

Flowgorithm is a free application, developed by Devin Cook at Sacramento State University, which allows you to create programs using simple flowcharts. It supports the flowcharting conventions used in this textbook, as well as several other standard conventions. When you create a flowchart with Flowgorithm, you can execute the program and generate Gaddis Pseudocode. You can also generate source code in Java, Python, Visual Basic, C#, Ruby, JavaScript, and several other languages. For more information, see www.flowgorithm.org.

- **A link to download the RAPTOR flowcharting environment**

RAPTOR is a flowchart-based programming environment developed by the US Air Force Academy Department of Computer Science. For more information, see <https://raptor.martincarlisle.com>.

Instructor Resources

The following supplements are available to qualified instructors only:

- Answers to all of the Review Questions
- Solutions for the Programming Exercises
- PowerPoint® presentation slides for each chapter
- Test bank

Visit the Pearson Instructor Resource Center www.pearson.com or contact your local Pearson representative for information on how to access them.

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About the Author

Tony Gaddis is the principal author of the *Starting Out with . . .* series of textbooks. Tony has twenty years of experience teaching computer science courses at Haywood Community College. He is a highly acclaimed instructor who was previously selected as the North Carolina Community College “Teacher of the Year” and has received the Teaching Excellence award from the National Institute for Staff and Organizational Development. The *Starting Out with . . .* series includes introductory books covering Programming Logic and Design, C++, Java, Microsoft® Visual Basic, C#®, Python, App Inventor, and Alice, all published by Pearson.

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Introduction to Computers and Programming

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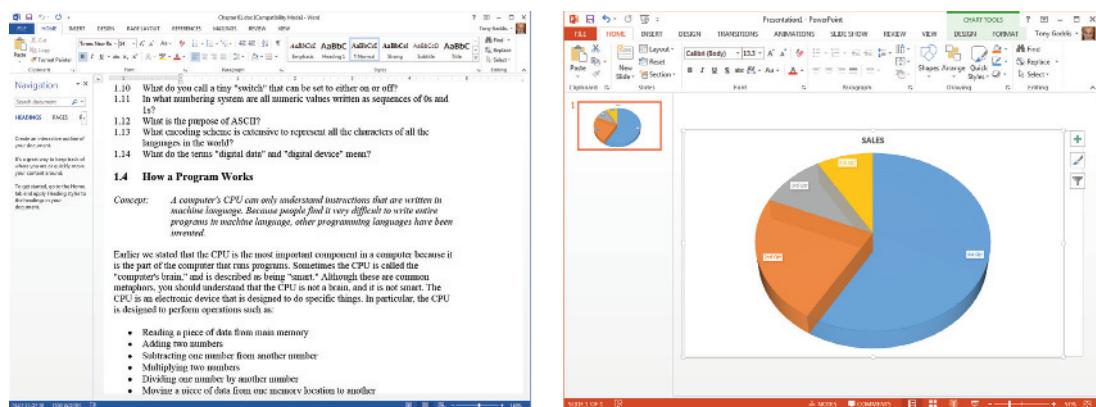
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|------------------------------|-------------------------|
| 1.1 Introduction | 1.4 How a Program Works |
| 1.2 Hardware | 1.5 Types of Software |
| 1.3 How Computers Store Data | |

1.1

Introduction

Think about some of the different ways that people use computers. In school, students use computers for tasks such as writing papers, searching for articles, sending email, and participating in online classes. At work, people use computers to analyze data, make presentations, conduct business transactions, communicate with customers and coworkers, control machines in manufacturing facilities, and many other things. At home, people use computers for tasks such as paying bills, shopping online, communicating with friends and family, and playing computer games. And don't forget that smart phones, tablets, home automation devices, car navigation systems, and many other devices are computers too. The uses of computers are almost limitless in our everyday lives.

Computers can do such a wide variety of things because they can be programmed. This means that computers are not designed to do just one job, but to do any job that their programs tell them to do. A *program* is a set of instructions that a computer follows to perform a task. For example, Figure 1-1 shows screens from two commonly used programs: Microsoft Word and PowerPoint.

Figure 1-1 Commonly used programs (courtesy of Microsoft Corporation)

Programs are commonly referred to as *software*. Software is essential to a computer because without software, a computer can do nothing. All of the software that we use to make our computers useful is created by individuals known as programmers or software developers. A *programmer*, or *software developer*, is a person with the training and skills necessary to design, create, and test computer programs. Computer programming is an exciting and rewarding career. Today, you will find programmers working in business, medicine, government, law enforcement, agriculture, academics, entertainment, and almost every other field.

This book introduces you to the fundamental concepts of computer programming. Before we begin exploring those concepts, you need to understand a few basic things about computers and how they work. This chapter will build a solid foundation of knowledge that you will continually rely on as you study computer science. First, we will discuss the physical components that computers are commonly made of. Next, we will look at how computers store data and execute programs. Finally, we will discuss the major types of software that computers use.

1.2

Hardware

CONCEPT: The physical devices that a computer is made of are referred to as the computer's hardware. Most computer systems are made of similar hardware devices.

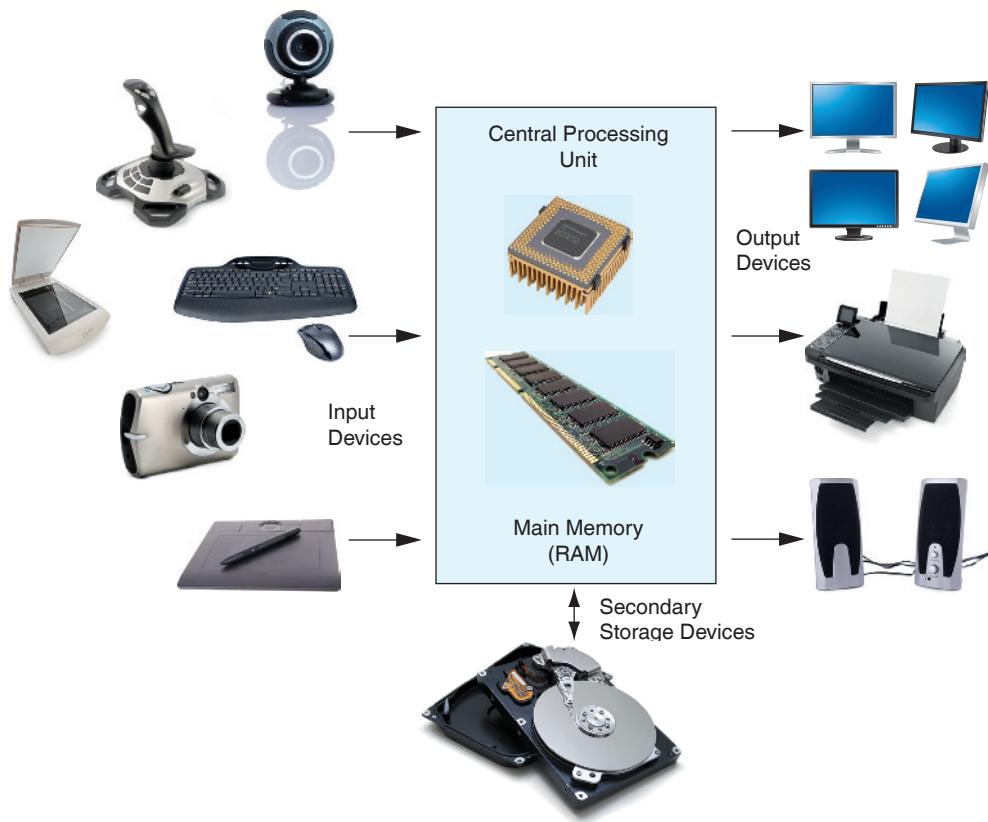
The term *hardware* refers to all of the physical devices, or *components*, that a computer is made of. A computer is not one single device, but a system of devices that all work together. Like the different instruments in a symphony orchestra, each device in a computer plays its own part.

If you have ever shopped for a computer, you've probably seen sales literature listing components such as microprocessors, memory, disk drives, video displays, graphics cards, and so on. Unless you already know a lot about computers, or at least have a friend who

does, understanding what these different components do can be confusing. As shown in Figure 1-2, a typical computer system consists of the following major components:

- The central processing unit (CPU)
- Main memory
- Secondary storage devices
- Input devices
- Output devices

Figure 1-2 Typical components of a computer system



(Photo credits: Webcam Iko/Shutterstock, Joystick Nikita Rogul/Shutterstock, Scanner Feng Yu/Shutterstock, Keyboard Chiyacat/Shutterstock, Camera Elkostas/Shutterstock, Tablet Tkemot/Shutterstock, Hard disk Vitaly Korovin/Shutterstock, Speakers StockPhotosArt/Shutterstock, Printer Jocic/Shutterstock, Monitors Art gallery/Shutterstock, RAM Peter Guess/Shutterstock, Chip Aquila/Shutterstock).

Let's take a closer look at each of these components.

The CPU

When a computer is performing the tasks that a program tells it to do, we say that the computer is *running* or *executing* the program. The *central processing unit*, or *CPU*, is the part of a computer that actually runs programs. (The CPU is often referred to as the *processor*.) The CPU is the most important component in a computer because without it, the computer could not run software.

In the earliest computers, CPUs were huge devices made of electrical and mechanical components such as vacuum tubes and switches. Figure 1-3 shows such a device. The two women in the photo are working with the historic ENIAC computer. The *ENIAC*, considered by many to be the world's first programmable electronic computer, was built in 1945 to calculate artillery ballistic tables for the U.S. Army. This machine, which was primarily one big CPU, was 8 feet tall, 100 feet long, and weighed 30 tons.

Today, CPUs are small chips known as *microprocessors*. Figure 1-4 shows a photo of a lab technician holding a modern-day microprocessor. In addition to being much

Figure 1-3 The ENIAC computer (courtesy of US Army Center of Military History)

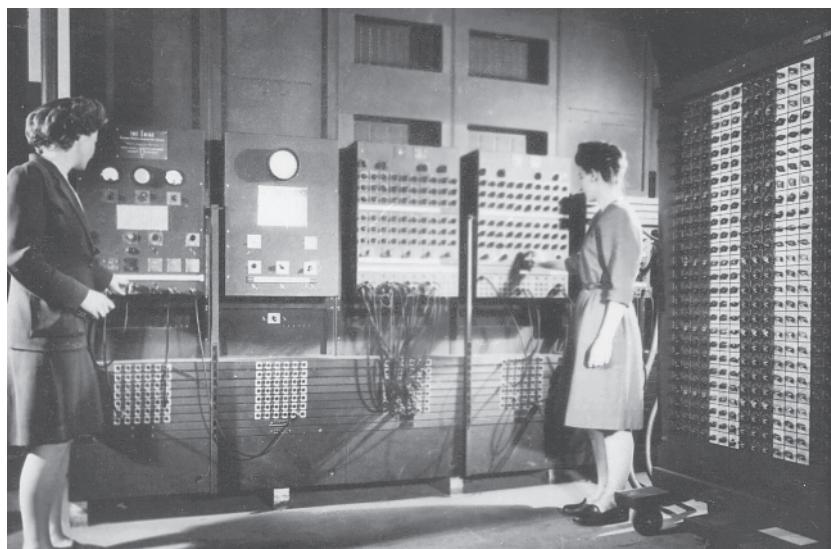


Figure 1-4 A lab technician holds a modern microprocessor (courtesy of Chris Ryan/OJO Images/Getty Images)



smaller than the old electro-mechanical CPUs in early computers, microprocessors are also much more powerful.

Main Memory

You can think of *main memory* as the computer's work area. This is where the computer stores a program while the program is running, as well as the data that the program is working with. For example, suppose you are using a word processing program to write an essay for one of your classes. While you do this, both the word processing program and the essay are stored in main memory.

Main memory is commonly known as *random-access memory*, or *RAM*. It is called this because the CPU is able to quickly access data stored at any random location in RAM. RAM is usually a *volatile* type of memory that is used only for temporary storage while a program is running. When the computer is turned off, the contents of RAM are erased. Inside your computer, RAM is stored in chips, similar to the ones shown in Figure 1-5.

Figure 1-5 Memory chips (photo © Garsya/Shutterstock)



NOTE: Another type of memory that is stored in chips inside the computer is *read-only memory*, or *ROM*. A computer can read the contents of ROM, but it cannot change its contents, or store additional data there. ROM is *nonvolatile*, which means that it does not lose its contents, even when the computer's power is turned off. ROM is typically used to store programs that are important for the system's operation. One example is the computer's startup program, which is executed each time the computer is started.

Secondary Storage Devices

Secondary storage is a type of memory that can hold data for long periods of time, even when there is no power to the computer. Programs are normally stored in secondary memory and loaded into main memory as needed. Important data, such as word processing documents, payroll data, and inventory records, is saved to secondary storage as well.

The most common type of secondary storage device is the disk drive. A traditional *disk drive* stores data by magnetically encoding it onto a circular disk. *Solid state drives*, which store data in solid-state memory, are increasingly becoming popular. A solid state drive has no moving parts, and operates faster than a traditional disk drive. Most computers have some sort of secondary storage device, either a traditional disk drive or a solid state drive, mounted inside their case. External disk drives, which connect to one of the computer's communication ports, are also available. External disk drives can be used to create backup copies of important data or to move data to another computer.

In addition to external disk drives, many types of devices have been created for copying data, and for moving it to other computers. *Universal Serial Bus drives*, or *USB drives*, are small devices that plug into the computer's USB port, and appear to the system as a disk drive. These drives do not actually contain a disk, however. They store data in a special type of memory known as *flash memory*. USB drives, which are also known as *memory sticks* and *flash drives*, are inexpensive, reliable, and small enough to be carried in your pocket.



NOTE: In recent years, *cloud storage* has become a popular way to store data. When you store data in the cloud, you are storing it on a remote server via the Internet, or via a company's private network. When your data is stored in the cloud, you can access it from many different devices, and from any location where you have a network connection. Cloud storage can also be used to back up important data that is stored on a computer's disk.

Input Devices

Input is any data the computer collects from people and from other devices. The component that collects the data and sends it to the computer is called an *input device*. Common input devices are the keyboard, mouse, touchscreen, scanner, microphone, and digital camera. Disk drives and optical drives can also be considered input devices because programs and data are retrieved from them and loaded into the computer's memory.

Output Devices

Output is any data the computer produces for people or for other devices. It might be a sales report, a list of names, or a graphic image. The data is sent to an *output device*, which formats and presents it. Common output devices are video displays and printers. Disk drives can also be considered output devices because the system sends data to them in order to be saved.



Checkpoint

- 1.1 What is a program?
- 1.2 What is hardware?
- 1.3 List the five major components of a computer system.
- 1.4 What part of the computer actually runs programs?
- 1.5 What part of the computer serves as a work area to store a program and its data while the program is running?
- 1.6 What part of the computer holds data for long periods of time, even when there is no power to the computer?
- 1.7 What part of the computer collects data from people and from other devices?
- 1.8 What part of the computer formats and presents data for people or other devices?

1.3

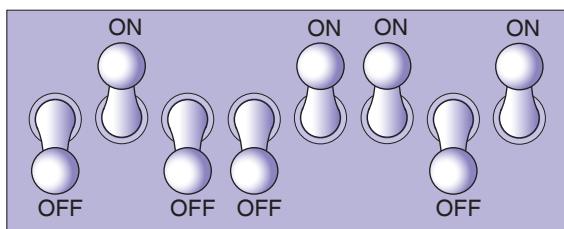
How Computers Store Data

CONCEPT: All data that is stored in a computer is converted to sequences of 0s and 1s.

A computer's memory is divided into tiny storage locations known as *bytes*. One byte is only enough memory to store a letter of the alphabet or a small number. In order to do anything meaningful, a computer has to have lots of bytes. Most computers today have millions, or even billions, of bytes of memory.

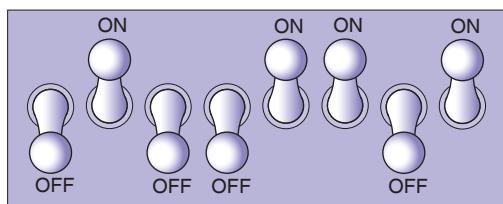
Each byte is divided into eight smaller storage locations known as bits. The term *bit* stands for *binary digit*. Computer scientists usually think of bits as tiny switches that can be either on or off. Bits aren't actual "switches," however, at least not in the conventional sense. In most computer systems, bits are tiny electrical components that can hold either a positive or a negative charge. Computer scientists think of a positive charge as a switch in the *on* position, and a negative charge as a switch in the *off* position. Figure 1-6 shows the way that a computer scientist might think of a byte of memory: as a collection of switches that are each flipped to either the on or off position.

Figure 1-6 Think of a byte as eight switches

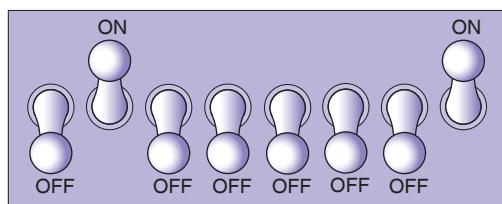


When a piece of data is stored in a byte, the computer sets the eight bits to an on/off pattern that represents the data. For example, the pattern shown on the left in Figure 1-7 shows how the number 77 would be stored in a byte, and the pattern on the right shows how the letter A would be stored in a byte. In a moment you will see how these patterns are determined.

Figure 1-7 Bit patterns for the number 77 and the letter A



The number 77 stored in a byte.



The letter A stored in a byte.

Storing Numbers

A bit can be used in a very limited way to represent numbers. Depending on whether the bit is turned on or off, it can represent one of two different values. In computer systems, a bit that is turned off represents the number 0 and a bit that is turned on represents the number 1. This corresponds perfectly to the *binary numbering system*. In the binary numbering system (or *binary*, as it is usually called) all numeric values are written as sequences of 0s and 1s. Here is an example of a number that is written in binary:

10011101

The position of each digit in a binary number has a value assigned to it. Starting with the rightmost digit and moving left, the position values are 2^0 , 2^1 , 2^2 , 2^3 , and so forth, as shown in Figure 1-8. Figure 1-9 shows the same diagram with the position values calculated. Starting with the rightmost digit and moving left, the position values are 1, 2, 4, 8, and so forth.

Figure 1-8 The values of binary digits as powers of 2

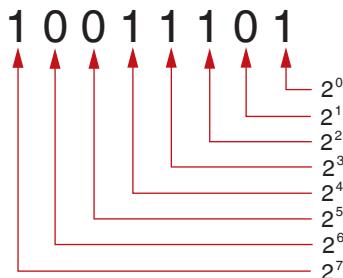
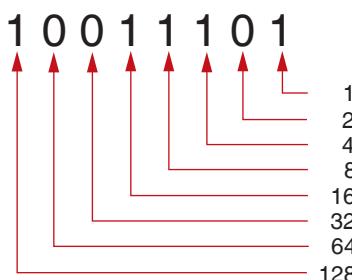


Figure 1-9 The values of binary digits



To determine the value of a binary number you simply add up the position values of all the 1s. For example, in the binary number 10011101, the position values of the 1s are 1, 4, 8, 16, and 128. This is shown in Figure 1-10. The sum of all of these position values is 157. So, the value of the binary number 10011101 is 157.

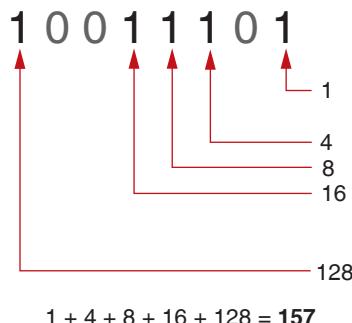
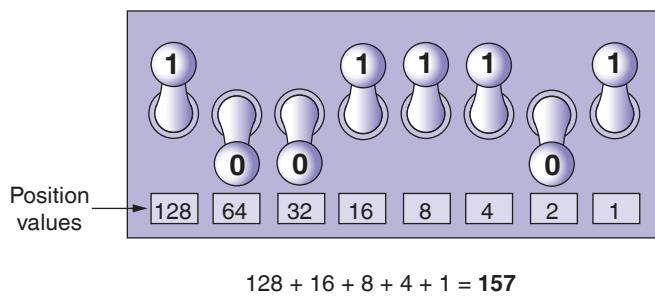
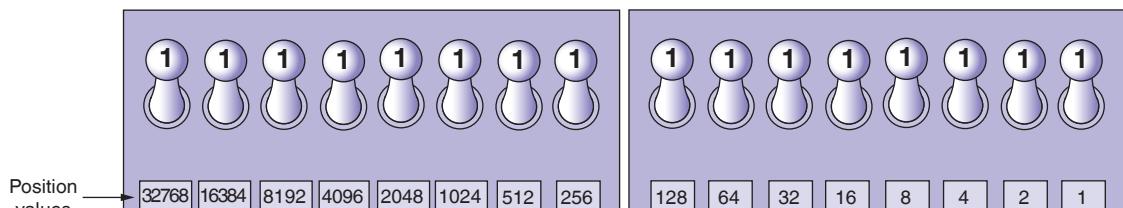
Figure 1-10 Determining the value of 10011101

Figure 1-11 shows how you can picture the number 157 stored in a byte of memory. Each 1 is represented by a bit in the on position, and each 0 is represented by a bit in the off position.

Figure 1-11 The bit pattern for 157

When all of the bits in a byte are set to 0 (turned off), then the value of the byte is 0. When all of the bits in a byte are set to 1 (turned on), then the byte holds the largest value that can be stored in it. The largest value that can be stored in a byte is $1 + 2 + 4 + 8 + 16 + 32 + 64 + 128 = 255$. This limit exists because there are only eight bits in a byte.

What if you need to store a number larger than 255? The answer is simple: use more than one byte. For example, suppose we put two bytes together. That gives us 16 bits. The position values of those 16 bits would be $2^0, 2^1, 2^2, 2^3$, and so forth, up through 2^{15} . As shown in Figure 1-12, the maximum value that can be stored in two bytes is 65,535. If you need to store a number larger than this, then more bytes are necessary.

Figure 1-12 Two bytes used for a large number



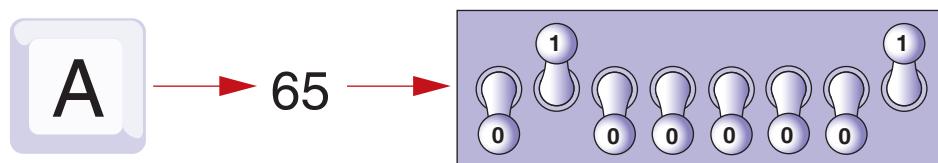
TIP: In case you’re feeling overwhelmed by all this, relax! You will not have to actually convert numbers to binary while programming. Knowing that this process is taking place inside the computer will help you as you learn, and in the long term this knowledge will make you a better programmer.

Storing Characters

Any piece of data that is stored in a computer’s memory must be stored as a binary number. That includes characters, such as letters and punctuation marks. When a character is stored in memory, it is first converted to a numeric code. The numeric code is then stored in memory as a binary number.

Over the years, different coding schemes have been developed to represent characters in computer memory. Historically, the most important of these coding schemes is *ASCII*, which stands for the *American Standard Code for Information Interchange*. ASCII is a set of 128 numeric codes that represent the English letters, various punctuation marks, and other characters. For example, the ASCII code for the uppercase letter A is 65. When you type an uppercase A on your computer keyboard, the number 65 is stored in memory (as a binary number, of course). This is shown in Figure 1-13.

Figure 1-13 The letter A is stored in memory as the number 65



TIP: The acronym ASCII is pronounced “askee.”

In case you are curious, the ASCII code for uppercase B is 66, for uppercase C is 67, and so forth. Appendix A shows all of the ASCII codes and the characters they represent.

The ASCII character set was developed in the early 1960s, and was eventually adopted by most of all computer manufacturers. ASCII is limited, however, because it defines codes for only 128 characters. To remedy this, the Unicode character set was developed in the early 1990s. *Unicode* is an extensive encoding scheme that is compatible with ASCII, and can also represent the characters of many of the world’s languages. Today, Unicode is quickly becoming the standard character set used in the computer industry.

Advanced Number Storage

Earlier you read about numbers and how they are stored in memory. While reading that section, perhaps it occurred to you that the binary numbering system can be used to represent only integer numbers, beginning with 0. Negative numbers and real numbers (such as 3.14159) cannot be represented using the simple binary numbering technique we discussed.

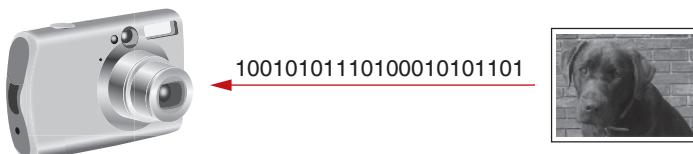
Computers are able to store negative numbers and real numbers in memory, but to do so they use encoding schemes along with the binary numbering system. Negative numbers are encoded using a technique known as *two's complement*, and real numbers are encoded in *floating-point notation*. You don't need to know how these encoding schemes work, only that they are used to convert negative numbers and real numbers to binary format.

Other Types of Data

Computers are often referred to as digital devices. The term *digital* can be used to describe anything that uses binary numbers. *Digital data* is data that is stored in binary, and a *digital device* is any device that works with binary data. In this section, we have discussed how numbers and characters are stored in binary, but computers also work with many other types of digital data.

For example, consider the pictures that you take with your digital camera. These images are composed of tiny dots of color known as *pixels*. (The term pixel stands for *picture element*.) As shown in Figure 1-14, each pixel in an image is converted to a numeric code that represents the pixel's color. The numeric code is stored in memory as a binary number.

Figure 1-14 A digital image is stored in binary format (photo on the right courtesy of Tony Gaddis)



The music that you stream from an online source, or play on an MP3 player is also digital. A digital song is broken into small pieces known as *samples*. Each sample is converted to a binary number, which can be stored in memory. The more samples that a song is divided into, the more it sounds like the original music when it is played back. A CD-quality song is divided into more than 44,000 samples per second!



Checkpoint

- 1.9 What amount of memory is enough to store a letter of the alphabet or a small number?
- 1.10 What do you call a tiny “switch” that can be set to either on or off?

- 1.11 In what numbering system are all numeric values written as sequences of 0s and 1s?
- 1.12 What is the purpose of ASCII?
- 1.13 What encoding scheme is extensive to represent all the characters of all the languages in the world?
- 1.14 What do the terms “digital data” and “digital device” mean?

1.4

How a Program Works

CONCEPT: A computer’s CPU can only understand instructions that are written in machine language. Because people find it very difficult to write entire programs in machine language, other programming languages have been invented.

Earlier, we stated that the CPU is the most important component in a computer because it is the part of the computer that runs programs. Sometimes the CPU is called the “computer’s brain,” and is described as being “smart.” Although these are common metaphors, you should understand that the CPU is not a brain, and it is not smart. The CPU is an electronic device that is designed to do specific things. In particular, the CPU is designed to perform operations such as the following:

- Reading a piece of data from main memory
- Adding two numbers
- Subtracting one number from another number
- Multiplying two numbers
- Dividing one number by another number
- Moving a piece of data from one memory location to another
- Determining whether one value is equal to another value
- And so forth . . .

As you can see from this list, the CPU performs simple operations on pieces of data. The CPU does nothing on its own, however. It has to be told what to do, and that’s the purpose of a program. A program is nothing more than a list of instructions that cause the CPU to perform operations.

Each instruction in a program is a command that tells the CPU to perform a specific operation. Here’s an example of an instruction that might appear in a program:

10110000

To you and me, this is only a series of 0s and 1s. To a CPU, however, this is an instruction to perform an operation.¹ It is written in 0s and 1s because CPUs only understand instructions that are written in *machine language*, and machine language instructions are always written in binary.

¹ The example shown is an actual instruction for an Intel microprocessor. It tells the microprocessor to move a value into the CPU.

A machine language instruction exists for each operation that a CPU is capable of performing. For example, there is an instruction for adding numbers; there is an instruction for subtracting one number from another; and so forth. The entire set of instructions that a CPU can execute is known as the CPU's *instruction set*.



NOTE: There are several microprocessor companies today that manufacture CPUs. Some of the more well-known microprocessor companies are Intel, AMD, and Motorola. If you look carefully at your computer, you might find a tag showing a logo for its microprocessor.

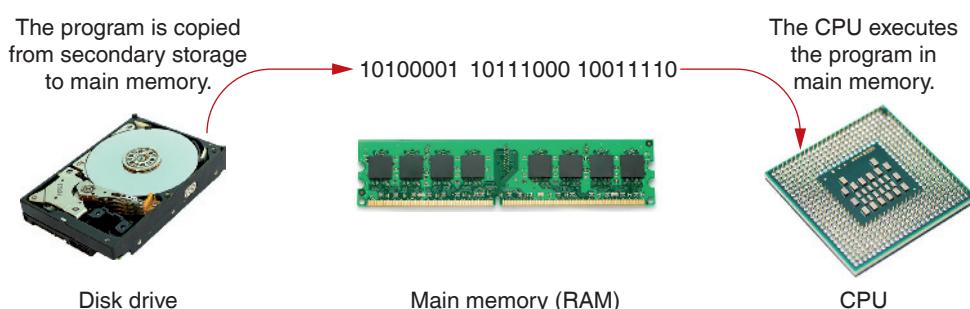
Each brand of microprocessor has its own unique instruction set, which is typically understood only by microprocessors of the same brand. For example, Intel microprocessors understand the same instructions, but they do not understand instructions for Motorola microprocessors.

The machine language instruction that was previously shown is an example of only one instruction. It takes a lot more than one instruction, however, for the computer to do anything meaningful. Because the operations that a CPU knows how to perform are so basic in nature, a meaningful task can be accomplished only if the CPU performs many operations. For example, if you want your computer to calculate the amount of interest that you will earn from your savings account this year, the CPU will have to perform a large number of instructions, carried out in the proper sequence. It is not unusual for a program to contain thousands, or even a million or more machine language instructions.

Programs are usually stored on a secondary storage device such as a disk drive. When you install a program on your computer, the program is typically downloaded from a Web site, or installed from an online app store.

Although a program can be stored on a secondary storage device such as a disk drive, it has to be copied into main memory, or RAM, each time the CPU executes it. For example, suppose you have a word processing program on your computer's disk. To execute the program you use the mouse to double-click the program's icon. This causes the program to be copied from the disk into main memory. Then, the computer's CPU executes the copy of the program that is in main memory. This process is illustrated in Figure 1-15.

Figure 1-15 A program is copied into main memory and then executed (courtesy of Lefteris Papaulakis/Shutterstock, Garsya/Shutterstock and marpan/Shutterstock)

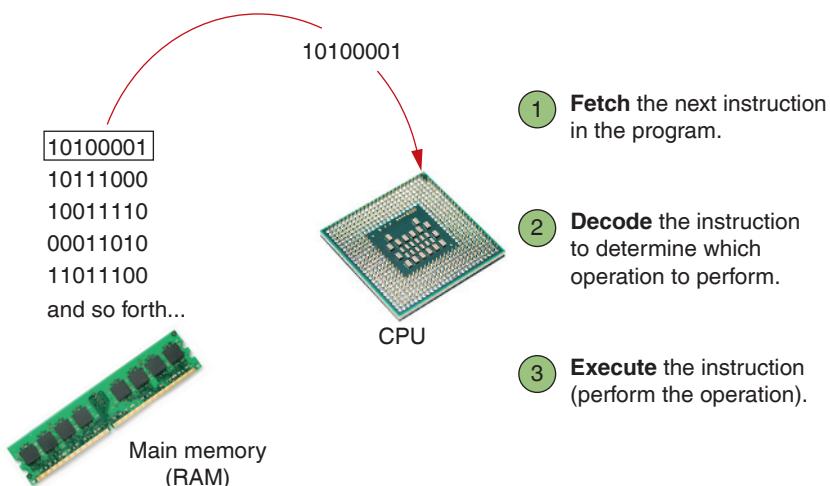


When a CPU executes the instructions in a program, it is engaged in a process that is known as the *fetch-decode-execute cycle*. This cycle, which consists of three steps, is repeated for each instruction in the program. The steps are:

1. **Fetch.** A program is a long sequence of machine language instructions. The first step of the cycle is to fetch, or read, the next instruction from memory into the CPU.
2. **Decode.** A machine language instruction is a binary number that represents a command that tells the CPU to perform an operation. In this step the CPU decodes the instruction that was just fetched from memory, to determine which operation it should perform.
3. **Execute.** The last step in the cycle is to execute, or perform, the operation.

Figure 1-16 illustrates these steps.

Figure 1-16 The fetch-decode-execute cycle (courtesy of Garsya/Shutterstock, marpan/Shutterstock)



From Machine Language to Assembly Language

Computers can only execute programs that are written in machine language. As previously mentioned, a program can have thousands, or even a million or more binary instructions, and writing such a program would be very tedious and time consuming. Programming in machine language would also be very difficult because putting a 0 or a 1 in the wrong place will cause an error.

Although a computer's CPU only understands machine language, it is impractical for people to write programs in machine language. For this reason, *assembly language* was created in the early days of computing² as an alternative to machine language. Instead of using binary numbers for instructions, assembly language uses short words that are known as *mnemonics*. For example, in assembly language, the mnemonic `add` typically means to add numbers, `mul` typically means to multiply numbers, and `mov` typically means to move a value to a location in memory. When programmers use assembly language to write programs, they can write short mnemonics instead of binary numbers.

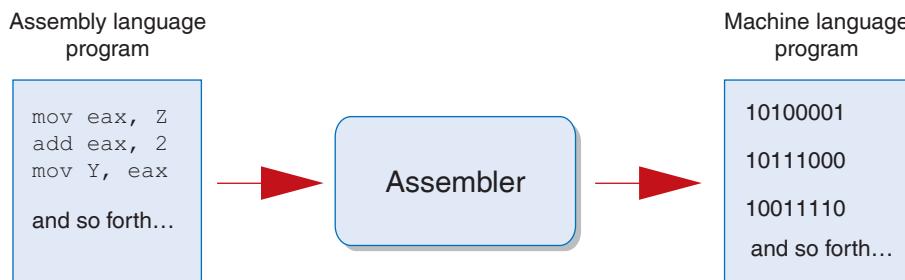
² The first assembly language was most likely developed in the 1940s at Cambridge University for use with a historical computer known as the EDSAC.



NOTE: There are many different versions of assembly language. It was mentioned earlier that each brand of CPU has its own machine language instruction set. Each brand of CPU typically has its own assembly language as well.

Assembly language programs cannot be executed by the CPU, however. The CPU only understands machine language, so a special program known as an *assembler* is used to translate an assembly language program to a machine language program. This process is shown in Figure 1-17. The machine language program that is created by the assembler can then be executed by the CPU.

Figure 1-17 An assembler translates an assembly language program to a machine language program



High-Level Languages

Although assembly language makes it unnecessary to write binary machine language instructions, it is not without difficulties. Assembly language is primarily a direct substitute for machine language, and like machine language, it requires that you know a lot about the CPU. Assembly language also requires that you write a large number of instructions for even the simplest program. Because assembly language is so close in nature to machine language, it is referred to as a *low-level language*.

In the 1950s, a new generation of programming languages known as *high-level languages* began to appear. A high-level language allows you to create powerful and complex programs without knowing how the CPU works, and without writing large numbers of low-level instructions. In addition, most high-level languages use words that are easy to understand. For example, if a programmer were using COBOL (which was one of the early high-level languages created in the 1950s), the programmer would write the following instruction to display the message “Hello world” on the computer screen:

Display "Hello world"

Doing the same thing in assembly language would require several instructions, and an intimate knowledge of how the CPU interacts with the computer’s video circuitry. As you can see from this example, high-level languages allow programmers to concentrate on the tasks they want to perform with their programs rather than the details of how the CPU will execute those programs.

Since the 1950s, thousands of high-level languages have been created. Table 1-1 lists several of the more well-known languages. If you are working toward a degree in computer science or a related field, you are likely to study one or more of these languages.

Each high-level language has its own set of words that the programmer must learn in order to use the language. The words that make up a high-level programming language

Table 1-1 Programming languages

Language	Description
Ada	Ada was created in the 1970s, primarily for applications used by the U.S. Department of Defense. The language is named in honor of Ada Lovelace, a 19th century mathematician who published an algorithm that is considered by many to be the first computer program.
BASIC	Beginners All-purpose Symbolic Instruction Code is a general-purpose language that was originally designed in the early 1960s to be simple enough for beginners to learn. Today, there are many different versions of BASIC.
FORTRAN	FORmula TRANslator was the first high-level programming language. It was designed in the 1950s for performing complex mathematical calculations.
COBOL	Common Business-Oriented Language was created in the 1950s, and was designed for business applications.
Pascal	Pascal was created in 1970, and was originally designed for teaching programming. The language was named in honor of the mathematician, physicist, and philosopher Blaise Pascal.
C and C++	C and C++ (pronounced “c plus plus”) are powerful, general-purpose languages developed at Bell Laboratories. The C language was created in 1972 and the C++ language was created in 1983.
C#	Pronounced “c sharp.” This language was created by Microsoft around the year 2000 for developing applications based on the Microsoft .NET platform.
Java	Java was created by Sun Microsystems (a company that is now owned by Oracle) in the early 1990s. It can be used to develop programs that run on a single computer or over the Internet from a Web server.
JavaScript™	JavaScript, created in the 1990s, can be used in Web pages. Despite its name, JavaScript is not related to Java.
Python	Python is a general-purpose language created in the early 1990s. It has become popular in business and academic applications.
Ruby	Ruby is a general-purpose language that was created in the 1990s. It is increasingly becoming a popular language for programs that run on Web servers.
Rust	The Rust programming language is designed for high performance, memory safety, and concurrent execution. It was announced in 2010 by Mozilla Research.
Visual Basic	Visual Basic (commonly known as VB) is a Microsoft programming language and software development environment that allows programmers to create Windows®-based applications quickly. VB was originally created in the early 1990s.

are known as *key words* or *reserved words*. Each key word has a specific meaning, and cannot be used for any other purpose. You previously saw an example of a COBOL statement that uses the key word *display* to print a message on the screen. In the Python language the word *print* serves the same purpose.

In addition to key words, programming languages have *operators* that perform various operations on data. For example, all programming languages have math operators that perform arithmetic. In Java, as well as most other languages, the + sign is an operator that adds two numbers. The following adds 12 and 75:

In addition to key words and operators, each language also has its own *syntax*, which is a set of rules that must be strictly followed when writing a program. The syntax rules dictate how key words, operators, and various punctuation characters must be used in a program. When you are learning a programming language, you must learn the syntax rules for that particular language.

The individual instructions that you use to write a program in a high-level programming language are called *statements*. A programming statement can consist of key words, operators, punctuation, and other allowable programming elements, arranged in the proper sequence to perform an operation.



NOTE: Human languages also have syntax rules. Do you remember when you took your first English class, and you learned all those rules about infinitives, indirect objects, clauses, and so forth? You were learning the syntax of the English language.

Although people commonly violate the syntax rules of their native language when speaking and writing, other people usually understand what they mean. Unfortunately, computers do not have this ability. If even a single syntax error appears in a program, the program cannot be executed.



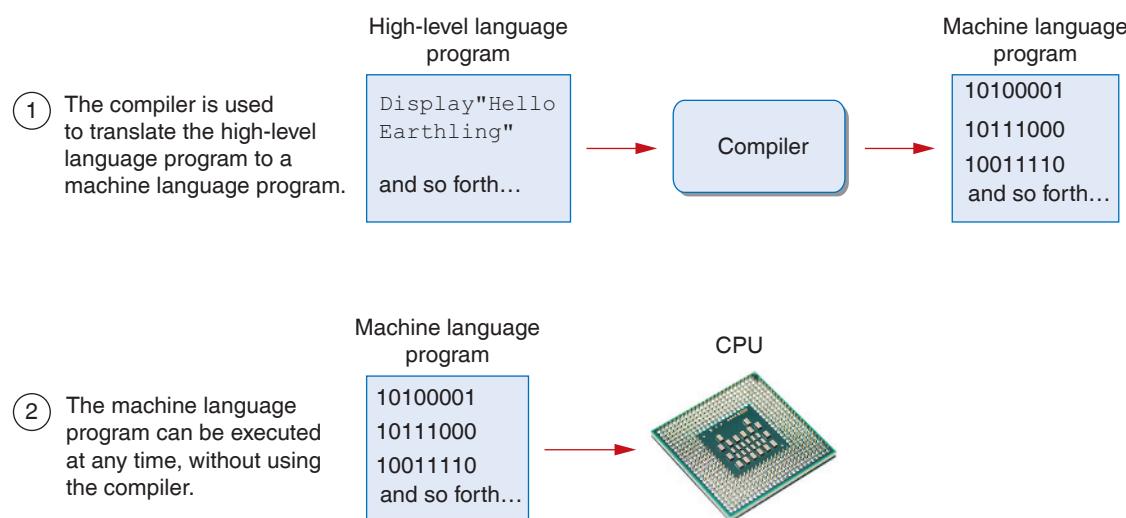
VideoNote
Compiling and
Executing a
Program

Compilers and Interpreters

Because the CPU understands only machine language instructions, programs that are written in a high-level language must be translated into machine language. Once a program has been written in a high-level language, the programmer will use a compiler or an interpreter to make the translation.

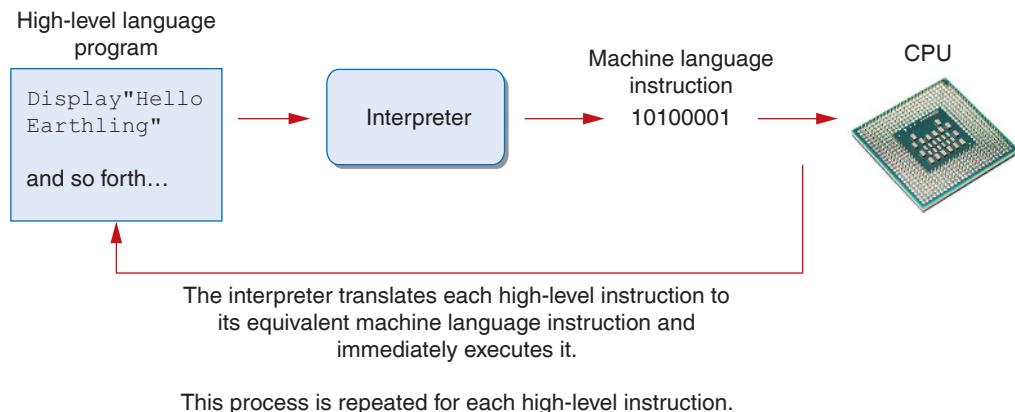
A *compiler* is a program that translates a high-level language program into a separate machine language program. The machine language program can then be executed any time it is needed. This is shown in Figure 1-18. As shown in the figure, compiling and executing are two different processes.

Figure 1-18 Compiling a high-level program and executing it (courtesy of marpan/Shutterstock)



An *interpreter* is a program that both translates and executes the instructions in a high-level language program. As the interpreter reads each individual instruction in the program, it converts it to a machine language instruction and then immediately executes it. This process repeats for every instruction in the program. This process is illustrated in Figure 1-19. Because interpreters combine translation and execution, they typically do not create separate machine language programs.

Figure 1-19 Executing a high-level program with an interpreter (courtesy of marpan/Shutterstock)



NOTE: Programs that are compiled generally execute faster than programs that are interpreted because a compiled program is already translated entirely to machine language when it is executed. A program that is interpreted must be translated at the time it is executed.

The statements that a programmer writes in a high-level language are called *source code*, or simply *code*. Typically, the programmer types a program's code into a text editor and then saves the code in a file on the computer's disk. Next, the programmer uses a compiler to translate the code into a machine language program, or an interpreter to translate and execute the code. If the code contains a syntax error, however, it cannot be translated. A *syntax error* is a mistake such as a misspelled key word, a missing punctuation character, or the incorrect use of an operator. When this happens the compiler or interpreter displays an error message indicating that the program contains a syntax error. The programmer corrects the error and then attempts once again to translate the program.

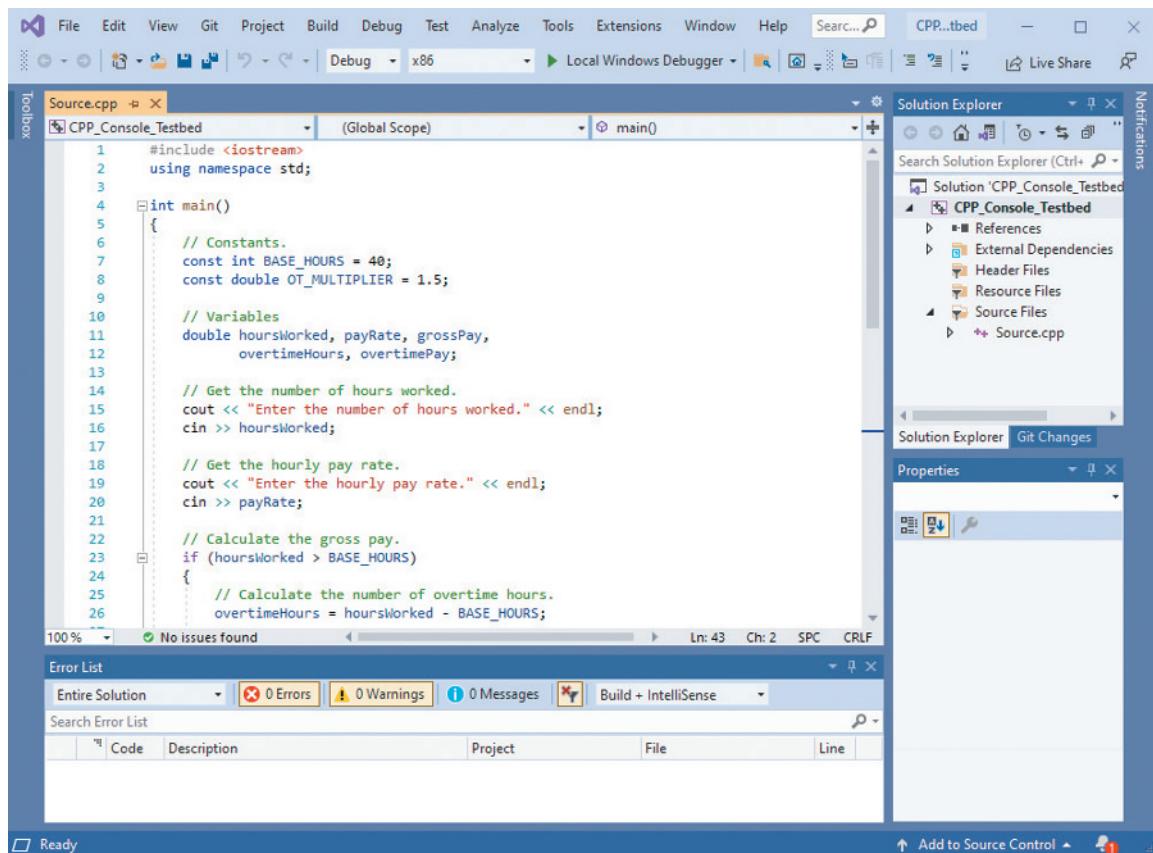
Integrated Development Environments

Although you can use a simple text editor such as Notepad (which is part of the Windows operating system) to write a program, most programmers use specialized software packages called *integrated development environments* or *IDEs*. Most IDEs combine the following programs into one software package:

- A text editor that has specialized features for writing statements in a high-level programming language
- A compiler or interpreter
- Useful tools for testing programs and locating errors

Figure 1-20 shows a screen from Microsoft Visual Studio, a popular IDE for developing programs in the C++, Visual Basic, and C# languages. EclipseTM, NetBeans, Dev-C++, and jGRASPTM are a few other popular IDEs.

Figure 1-20 An integrated development environment (photo courtesy of Microsoft Corporation)



Checkpoint

- 1.15 A CPU understands instructions that are written only in what language?
- 1.16 A program has to be copied into what type of memory each time the CPU executes it?
- 1.17 When a CPU executes the instructions in a program, it is engaged in what process?
- 1.18 What is assembly language?
- 1.19 What type of programming language allows you to create powerful and complex programs without knowing how the CPU works?

- 1.20 Each language has a set of rules that must be strictly followed when writing a program. What is this set of rules called?
- 1.21 What do you call a program that translates a high-level language program into a separate machine language program?
- 1.22 What do you call a program that both translates and executes the instructions in a high-level language program?
- 1.23 What type of mistake is usually caused by a misspelled key word, a missing punctuation character, or the incorrect use of an operator?

1.5

Types of Software

CONCEPT: Programs generally fall into one of two categories: system software or application software. System software is the set of programs that control or enhance the operation of a computer. Application software makes a computer useful for everyday tasks.

If a computer is to function, software is not optional. Everything that a computer does, from the time you turn the power switch on until you shut the system down, is under the control of software. There are two general categories of software: system software and application software. Most computer programs clearly fit into one of these two categories. Let's take a closer look at each.

System Software

The programs that control and manage the basic operations of a computer are generally referred to as *system software*. System software typically includes the following types of programs:

Operating Systems. An *operating system* is the most fundamental set of programs on a computer. The operating system controls the internal operations of the computer's hardware, manages all of the devices connected to the computer, allows data to be saved to and retrieved from storage devices, and allows other programs to run on the computer. Examples of operating systems that are widely used today are Windows, macOS, iOS, Android, and Linux.

Utility Programs. A *utility program* performs a specialized task that enhances the computer's operation or safeguards data. Examples of utility programs are virus scanners, file compression programs, and data backup programs.

Software Development Tools. *Software development tools* are the programs that programmers use to create, modify, and test software. Assemblers, compilers, and interpreters are examples of programs that fall into this category.

Application Software

Programs that make a computer useful for everyday tasks are known as *application software*. These are the programs that people normally spend most of their time running on their computers. Figure 1-1, at the beginning of this chapter, shows screens from two

commonly used applications—Microsoft Word, a word processing program, and Microsoft PowerPoint, a presentation program. Some other examples of application software are spreadsheet programs, email programs, Web browsers, and game programs.



Checkpoint

- 1.24 What fundamental set of programs controls the internal operations of the computer's hardware?
- 1.25 What do you call a program that performs a specialized task, such as a virus scanner, a file compression program, or a data backup program?
- 1.26 Word processing programs, spreadsheet programs, email programs, Web browsers, and game programs belong to what category of software?

Review Questions

Multiple Choice

1. A(n) _____ is a set of instructions that a computer follows to perform a task.
 - a. compiler
 - b. program
 - c. interpreter
 - d. programming language
2. The physical devices that a computer is made of are referred to as _____.
 - a. hardware
 - b. software
 - c. the operating system
 - d. tools
3. The part of a computer that runs programs is called _____.
 - a. RAM
 - b. secondary storage
 - c. main memory
 - d. the CPU
4. Today, CPUs are small chips known as _____.
 - a. ENIACs
 - b. microprocessors
 - c. memory chips
 - d. operating systems
5. The computer stores a program while the program is running, as well as the data that the program is working with, in _____.
 - a. secondary storage
 - b. the CPU
 - c. main memory
 - d. the microprocessor

6. This is a volatile type of memory that is used only for temporary storage while a program is running.
 - a. RAM
 - b. Secondary storage
 - c. The disk drive
 - d. The USB drive
7. A type of memory that can hold data for long periods of time—even when there is no power to the computer—is called _____.
 - a. RAM
 - b. main memory
 - c. secondary storage
 - d. CPU storage
8. A component that collects data from people or other devices and sends it to the computer is called _____.
 - a. an output device
 - b. an input device
 - c. a secondary storage device
 - d. main memory
9. A video display is a(n) _____.
 - a. output device
 - b. input device
 - c. secondary storage device
 - d. main memory
10. A _____ is enough memory to store a letter of the alphabet or a small number.
 - a. byte
 - b. bit
 - c. switch
 - d. transistor
11. A byte is made up of eight _____.
 - a. CPUs
 - b. instructions
 - c. variables
 - d. bits
12. In a(n) _____ numbering system, all numeric values are written as sequences of 0s and 1s.
 - a. hexadecimal
 - b. binary
 - c. octal
 - d. decimal
13. A bit that is turned off represents the following value: _____.
 - a. 1
 - b. -1
 - c. 0
 - d. “no”

14. A set of 128 numeric codes that represent the English letters, various punctuation marks, and other characters is ____.
 - a. binary numbering
 - b. ASCII
 - c. Unicode
 - d. ENIAC
15. An extensive encoding scheme that can represent the characters of many of the languages in the world is ____.
 - a. binary numbering
 - b. ASCII
 - c. Unicode
 - d. ENIAC
16. Negative numbers are encoded using the ____ technique.
 - a. two's complement
 - b. floating-point
 - c. ASCII
 - d. Unicode
17. Real numbers are encoded using the ____ technique.
 - a. two's complement
 - b. floating-point
 - c. ASCII
 - d. Unicode
18. The tiny dots of color that digital images are composed of are called ____.
 - a. bits
 - b. bytes
 - c. color packets
 - d. pixels
19. If you were to look at a machine language program, you would see ____.
 - a. Java code
 - b. a stream of binary numbers
 - c. English words
 - d. circuits
20. In the ____ part of the fetch-decode-execute cycle, the CPU determines which operation it should perform.
 - a. fetch
 - b. decode
 - c. execute
 - d. immediately after the instruction is executed
21. Computers can only execute programs that are written in ____.
 - a. Java
 - b. assembly language
 - c. machine language
 - d. C++

22. The _____ translates an assembly language program to a machine language program.
 - a. assembler
 - b. compiler
 - c. translator
 - d. interpreter
23. The words that make up a high-level programming language are called _____.
 - a. binary instructions
 - b. mnemonics
 - c. commands
 - d. key words
24. The rules that must be followed when writing a program are called _____.
 - a. syntax
 - b. punctuation
 - c. key words
 - d. operators
25. A(n) _____ program translates a high-level language program into a separate machine language program.
 - a. assembler
 - b. compiler
 - c. translator
 - d. utility

True or False

1. Today, CPUs are huge devices made of electrical and mechanical components such as vacuum tubes and switches.
2. Main memory is also known as RAM.
3. Any piece of data that is stored in a computer's memory must be stored as a binary number.
4. Images, like the ones you make with your digital camera, cannot be stored as binary numbers.
5. Machine language is the only language that a CPU understands.
6. Assembly language is considered a high-level language.
7. An interpreter is a program that both translates and executes the instructions in a high-level language program.
8. A syntax error does not prevent a program from being compiled and executed.
9. Windows, macOS, iOS, Android, and Linux are all examples of application software.
10. Word processing programs, spreadsheet programs, email programs, Web browsers, and games are all examples of utility programs.

Short Answer

1. Why is the CPU the most important component in a computer?
2. What number does a bit that is turned on represent? What number does a bit that is turned off represent?
3. What would you call a device that works with binary data?
4. What are the words that make up a high-level programming language called?
5. What are the short words that are used in assembly language called?
6. What is the difference between a compiler and an interpreter?
7. What type of software controls the internal operations of the computer's hardware?

Exercises

1. Appendix D shows how to convert a decimal number to binary. Use the technique shown in Appendix D to convert the following decimal numbers to binary:

11

65

100

255

2. Use what you've learned about the binary numbering system in this chapter to convert the following binary numbers to decimal:

1101

1000

101011

3. Look at the ASCII chart in Appendix A and determine the codes for each letter of your first name.

4. Use the Web to research the history of the BASIC, C++, Java, and Python programming languages, and answer the following questions:

- Who was the creator of each of these languages?
- When was each of these languages created?
- Was there a specific motivation behind the creation of these languages? If so, what was it?



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Input, Processing, and Output

TOPICS

- | | |
|--|--|
| 2.1 Designing a Program | 2.6 Hand Tracing a Program |
| 2.2 Output, Input, and Variables | 2.7 Documenting a Program |
| 2.3 Variable Assignment and Calculations | 2.8 Designing Your First Program |
| 2.4 Variable Declarations and Data Types | 2.9 Focus on Languages: Java, Python,
and C++ |
| 2.5 Named Constants | |

2.1

Designing a Program

CONCEPT: Programs must be carefully designed before they are written. During the design process, programmers use tools such as pseudocode and flowcharts to create models of programs.

In Chapter 1 you learned that programmers typically use high-level languages to write programs. However, all professional programmers will tell you that a program should be carefully designed before the code is actually written. When programmers begin a new project, they never jump right in and start writing code as the first step. They begin by creating a design of the program.

After designing the program, the programmer begins writing code in a high-level language. Recall from Chapter 1 that each language has its own rules, known as syntax, that must be followed when writing a program. A language's syntax rules dictate things such as how key words, operators, and punctuation characters can be used. A syntax error occurs if the programmer violates any of these rules.

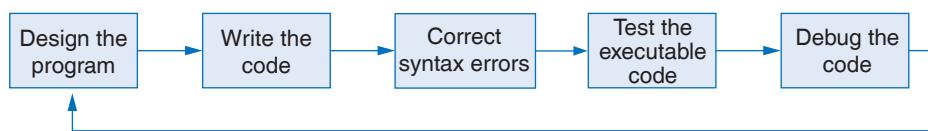
If the program contains a syntax error, or even a simple mistake such as a misspelled key word, the compiler or interpreter will display an error message indicating what the error is. Virtually all code contains syntax errors when it is first written, so the programmer will typically spend some time correcting these. Once all of the syntax errors and simple

typing mistakes have been corrected, the program can be compiled and translated into a machine language program (or executed by an interpreter, depending on the language being used).

Once the code is in an executable form, it is then tested to determine whether any logic errors exist. A *logic error* is a mistake that does not prevent the program from running, but causes it to produce incorrect results. (Mathematical mistakes are common causes of logic errors.)

If there are logic errors, the programmer *debugs* the code. This means that the programmer finds and corrects the code that is causing the error. Sometimes during this process, the programmer discovers that the original design must be changed. This entire process, which is known as the *program development cycle*, is repeated until no errors can be found in the program. Figure 2-1 shows the steps in the process.

Figure 2-1 The program development cycle



This book focuses primarily on the first step of the program development cycle: designing the program. The process of designing a program is arguably the most important part of the cycle. You can think of a program's design as its foundation. If you build a house on a poorly constructed foundation, eventually you will find yourself doing a lot of work to fix the house! A program's design should be viewed no differently. If your program is designed poorly, eventually you will find yourself doing a lot of work to fix the program.

Designing a Program

The process of designing a program can be summarized in the following two steps:

1. Understand the task that the program is to perform.
2. Determine the steps that must be taken to perform the task.

Let's take a closer look at each of these steps.

Understand the Task That the Program Is to Perform

It is essential that you understand what a program is supposed to do before you can determine the steps that the program will perform. Typically, a professional programmer gains this understanding by working directly with the customer. We use the term *customer* to describe the person, group, or organization that is asking you to write a program. This could be a customer in the traditional sense of the word, meaning someone who is paying you to write a program. It could also be your boss, or the manager of a department within your company. Regardless of who it is, the customer will be relying on your program to perform an important task.

To get a sense of what a program is supposed to do, the programmer usually interviews the customer. During the interview, the customer will describe the task that the program

should perform, and the programmer will ask questions to uncover as many details as possible about the task. A follow-up interview is usually needed because customers rarely mention everything they want during the initial meeting, and programmers often think of additional questions.

The programmer studies the information that was gathered from the customer during the interviews and creates a list of different software requirements. A *software requirement* is simply a single function that the program must perform in order to satisfy the customer. Once the customer agrees that the list of requirements is complete, the programmer can move to the next phase.



TIP: If you choose to become a professional software developer, your customer will be anyone who asks you to write programs as part of your job. As long as you are a student, however, your customer is your instructor! In every programming class that you will take, it's practically guaranteed that your instructor will assign programming problems for you to complete. For your academic success, make sure that you understand your instructor's requirements for those assignments and write your programs accordingly.

Determine the Steps That Must Be Taken to Perform the Task

Once you understand the task that the program will perform, you begin by breaking down the task into a series of steps. This is similar to the way you would break down a task into a series of steps that another person can follow. For example, suppose your little sister asks you how to boil water. Assuming she is old enough to be trusted around the stove, you might break down that task into a series of steps as follows:

1. Pour the desired amount of water into a pot.
2. Put the pot on a stove burner.
3. Turn the burner to high.
4. Watch the water until you see large bubbles rapidly rising. When this happens, the water is boiling.

This is an example of an *algorithm*, which is a set of well-defined logical steps that must be taken to perform a task. Notice that the steps in this algorithm are sequentially ordered. Step 1 should be performed before Step 2, and so on. If your little sister follows these steps exactly as they appear, and in the correct order, she should be able to boil water successfully.

A programmer breaks down the task that a program must perform in a similar way. An algorithm is created, which lists all of the logical steps that must be taken. For example, suppose you have been asked to write a program to calculate and display the gross pay for an hourly paid employee. Here are the steps that you would take:

1. Get the number of hours worked.
2. Get the hourly pay rate.
3. Multiply the number of hours worked by the hourly pay rate.
4. Display the result of the calculation that was performed in Step 3.

Of course, this algorithm isn't ready to be executed on the computer. The steps in this list have to be translated into code. Programmers commonly use two tools to help them accomplish this: pseudocode and flowcharts. Let's look at each of these in more detail.

Pseudocode

Recall from Chapter 1 that each programming language has strict rules, known as **syntax**, that the programmer must follow when writing a program. If the programmer writes code that violates these rules, a syntax error will result and the program cannot be compiled or executed. When this happens, the programmer has to locate the error and correct it.

Because small mistakes like misspelled words and forgotten punctuation characters can cause syntax errors, programmers have to be mindful of such small details when writing code. For this reason, programmers find it helpful to write their programs in pseudocode (pronounced “sue doe code”) before they write it in the actual code of a programming language.

The word *pseudo* means fake, so *pseudocode* is fake code. It is an informal language that has no syntax rules, and is not meant to be compiled or executed. Instead, programmers use pseudocode to create models, or “mock-ups” of programs. Because programmers don’t have to worry about syntax errors while writing pseudocode, they can focus all of their attention on the program’s design. Once a satisfactory design has been created with pseudocode, the pseudocode can be translated directly to actual code.

Here is an example of how you might write pseudocode for the pay calculating program that we discussed earlier:

```
Display "Enter the number of hours the employee worked."
Input hours
Display "Enter the employee's hourly pay rate."
Input payRate
Set grossPay = hours * payRate
Display "The employee's gross pay is $", grossPay
```

Each statement in the pseudocode represents an operation that can be performed in any high-level language. For example, all languages provide a way to display messages on the screen, read input that is typed on the keyboard, and perform mathematical calculations. For now, don’t worry about the details of this particular pseudocode program. As you progress through this chapter you will learn more about each of the statements that you see here.

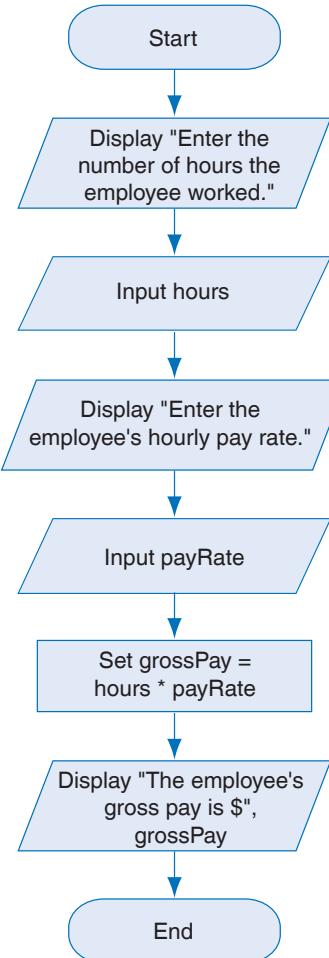


NOTE: As you read the examples in this book, keep in mind that pseudocode is not an actual programming language. It is a generic way to write the statements of an algorithm, without worrying about syntax rules. If you mistakenly write pseudocode into an editor for an actual programming language, such as Python or Visual Basic, errors will result.

Flowcharts

Flowcharting is another tool that programmers use to design programs. A *flowchart* is a diagram that graphically depicts the steps that take place in a program. Figure 2-2 shows how you might create a flowchart for the pay calculating program.

Notice that there are three types of symbols in the flowchart: ovals, parallelograms, and rectangles. The ovals, which appear at the top and bottom of the flowchart, are called

Figure 2-2 Flowchart for the pay calculating program

terminal symbols. The *Start* terminal symbol marks the program’s starting point and the *End* terminal symbol marks the program’s ending point.

Between the terminal symbols are parallelograms, which are used for both *input symbols* and *output symbols*, and rectangles, which are called *processing symbols*. Each of these symbols represents a step in the program. The symbols are connected by arrows that represent the “flow” of the program. To step through the symbols in the proper order, you begin at the *Start* terminal and follow the arrows until you reach the *End* terminal. Throughout this chapter we will look at each of these symbols in greater detail. For your reference, Appendix B summarizes all of the flowchart symbols that we use in this book.

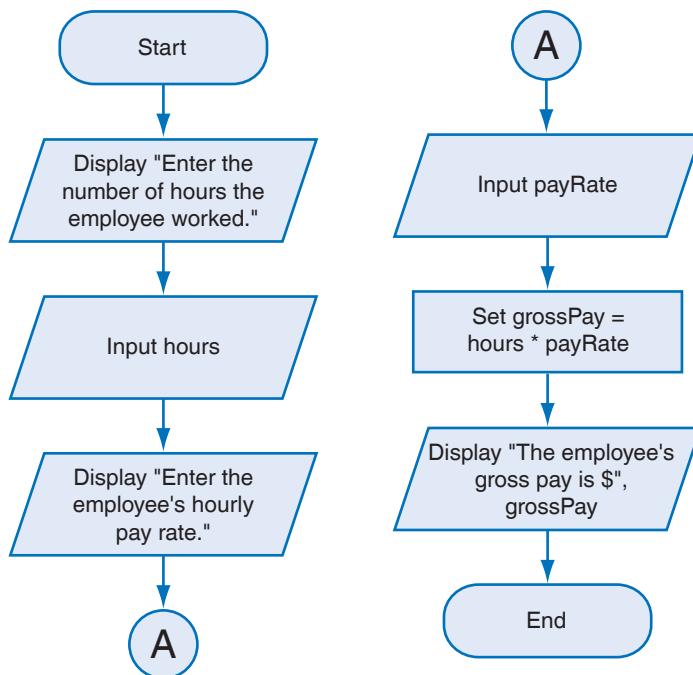
There are a number of different ways that you can draw flowcharts, and your instructor will most likely give you instructions that are specific for your class. Perhaps the simplest and least expensive way is to simply sketch the flowchart by hand with pencil and paper. If you need to make your hand-drawn flowcharts look more professional, you can visit your local office supply store (or possibly your campus bookstore) and purchase a flowchart template, which is a small plastic sheet that has the flowchart symbols cut into it. You can use the template to trace the symbols onto a piece of paper.

The disadvantage of drawing flowcharts by hand is that mistakes have to be manually erased, and in many cases, require that the entire page be redrawn. A more efficient and professional way to create flowcharts is to use software. There are several specialized software packages available that allow you to create flowcharts.

Flowchart Connector Symbols

Often, a flowchart is too long to fit on a page. Sometimes you can remedy this by breaking the flowchart into two or more smaller flowcharts, and placing them side-by-side on the page. When you do this, you use a *connector symbol* to connect the pieces of the flowchart. A connector symbol is a small circle with a letter or number written inside it. Figure 2-3 shows an example of a flowchart with a connector symbol.

Figure 2-3 Flowchart with a connector symbol

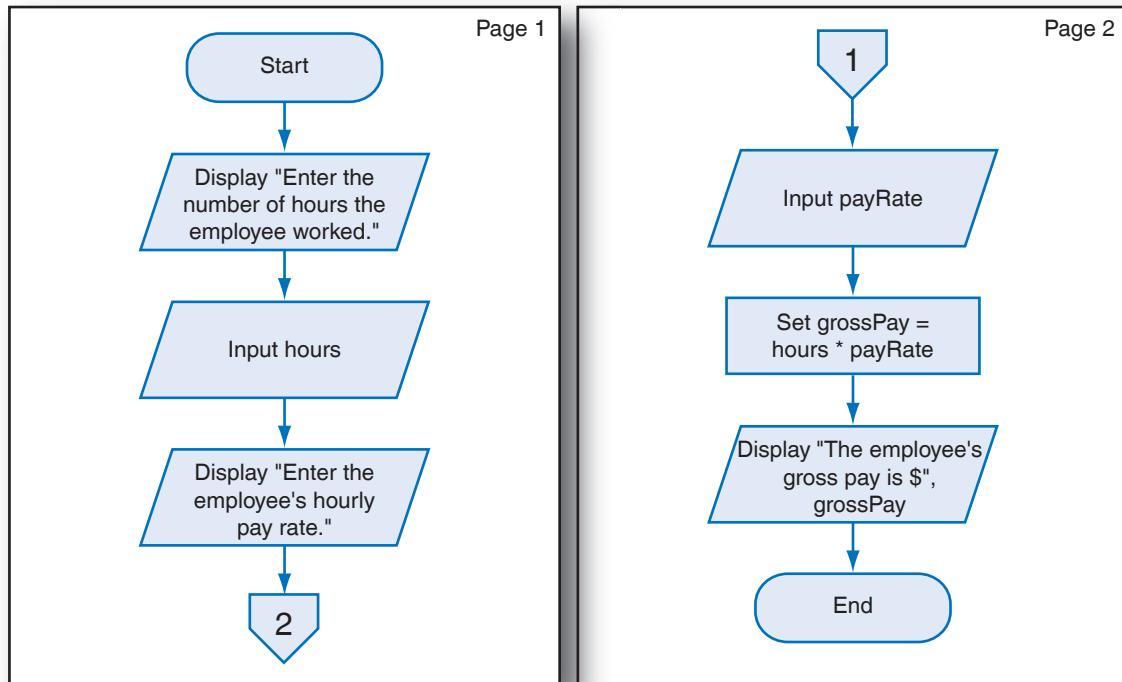


In Figure 2-3, the (A) connector symbol indicates that the second flowchart segment begins where the first flowchart segment ends.

When a flowchart is simply too large to fit on a single page, you can break the flowchart into parts, and place the parts on separate pages. You then use the *off-page connector symbol* to connect the pieces of the flowchart. The off-page connector symbol is the “home plate” shape, with a page number shown inside it. If the connector is at an exit point in the flowchart, the number indicates the page where the next part of the flowchart is located. If the connector is at an entry point in the flowchart, it indicates the page where the previous part of the flowchart is located. Figure 2-4 shows an example. In the figure, the flowchart on the left is on page 1. At the bottom of the flowchart is an off-page connector indicating that the flowchart continues on page 2.

In the flowchart on the right (which is page 2), the off-page connector at the top indicates that the previous part of the flowchart is on page 1.

Figure 2-4 Flowchart with an off-page connector



NOTE: Flowcharting symbols and techniques can vary from one book to another, or from one software package to another. If you are using specialized software to draw flowcharts, you might notice slight differences between some of the symbols that it uses, compared to some of the symbols used in this book.



Checkpoint

- 2.1 Who is a programmer's customer?
- 2.2 What is a software requirement?
- 2.3 What is an algorithm?
- 2.4 What is pseudocode?
- 2.5 What is a flowchart?
- 2.6 What are each of the following symbols in a flowchart?

- Oval
- Parallelogram
- Rectangle

2.2

Output, Input, and Variables

CONCEPT: Output is data that is generated and displayed by the program. Input is data that the program receives. When a program receives data, it stores it in variables, which are named storage locations in memory.

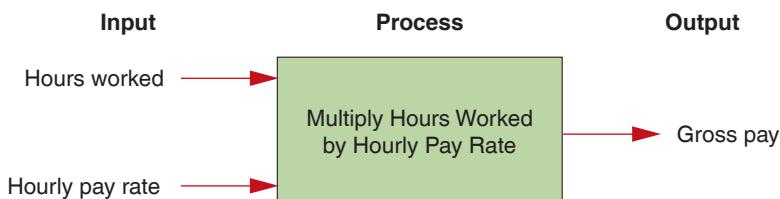
Computer programs typically perform the following three-step process:

1. Input is received.
2. Some process is performed on the input.
3. Output is produced.

Input is any data that the program receives while it is running. One common form of input is data that is typed on the keyboard. Once input is received, some process, such as a mathematical calculation, is usually performed on it. The results of the process are then sent out of the program as output.

Figure 2-5 illustrates these three steps in the pay calculating program that we discussed earlier. The number of hours worked and the hourly pay rate are provided as input.

Figure 2-5 The input, processing, and output of the pay calculating program



The program processes this data by multiplying the hours worked by the hourly pay rate. The results of the calculation are then displayed on the screen as output.

IPO Charts

An IPO chart is a simple but effective tool that programmers commonly use while designing programs. IPO stands for *input*, *processing*, and *output*, and an *IPO chart* describes the input, processing, and output of a program. These items are usually laid out in columns. The input column shows a description of the data that is required as input. The processing column shows a description of the process, or processes, that the program performs. The output column describes the output that is produced by the program. For example, Figure 2-6 shows an IPO chart for the pay calculating program.

In the remainder of this section, you will look at some simple programs that perform output and input. In the next section, we will discuss how to process data.

Displaying Screen Output

Perhaps the most fundamental thing that you can do in a program is to display a message on the computer screen. As previously mentioned, all high-level languages provide

Figure 2-6 IPO chart for the pay calculating program

IPO Chart for the Pay Calculating Program		
Input	Processing	Output
Number of hours worked Hourly pay rate	Multiply the number of hours worked by the hourly pay rate. The result is the gross pay.	Gross pay

a way to display screen output. In this book, we use the word **Display** to write pseudocode statements for displaying output on the screen. Here is an example:

```
Display "Hello world"
```

The purpose of this statement is to display the message *Hello world* on the screen. Notice that after the word **Display**, we have written **Hello world** inside quotation marks. The quotation marks are not to be displayed. They simply mark the beginning and the end of the text that we wish to display.

Suppose your instructor tells you to write a pseudocode program that displays your name and address on the computer screen. The pseudocode shown in Program 2-1 is an example of such a program.

Program 2-1



```
Display "Kate Austen"
Display "1234 Walnut Street"
Display "Asheville, NC 28899"
```

It is important for you to understand that the statements in this program execute in the order that they appear, from the top of the program to the bottom. This is shown in Figure 2-7. If you translated this pseudocode into an actual program and ran it, the first statement would execute, followed by the second statement, and followed by the third statement. If you try to visualize the way this program's output would appear on the screen, you should imagine something like that shown in Figure 2-8. Each **Display** statement produces a line of output.



NOTE: Although this book uses the word **Display** for an instruction that displays screen output, some programmers use other words for this purpose. For example, some programmers use the word **Print**, and others use the word **Write**. Pseudocode has no rules that dictate the words that you may or may not use.

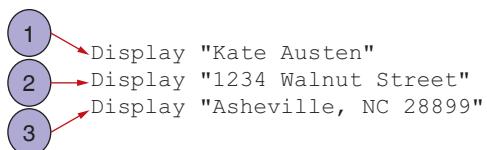
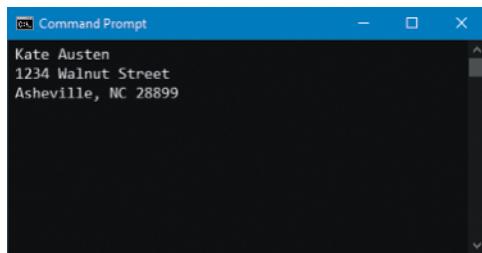
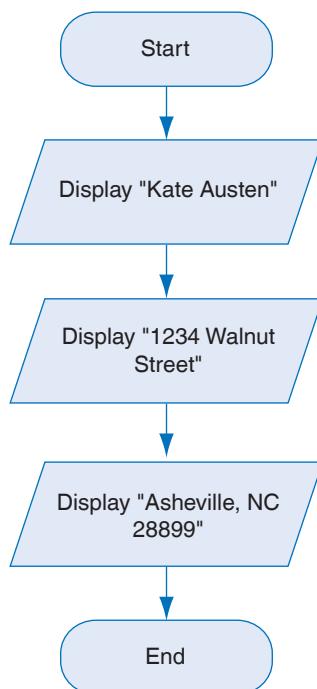
Figure 2-7 The statements execute in order (courtesy of Microsoft Corporation)**Figure 2-8** Output of Program 2-1 (courtesy of Microsoft Corporation)

Figure 2-9 shows the way you would draw a flowchart for this program. Notice that between the *Start* and *End* terminal symbols there are three parallelograms. A parallelogram can be either an output symbol or an input symbol. In this program, all three parallelograms are output symbols. There is one for each of the *Display* statements.

Figure 2-9 Flowchart for Program 2-1

Sequence Structures

It was mentioned earlier that the statements in Program 2-1 execute in the order that they appear, from the top of the program to the bottom. A set of statements that execute in the order that they appear is called a *sequence structure*. In fact, all of the programs that you will see in this chapter are sequence structures.

A *structure*, also called a *control structure*, is a logical design that controls the order in which a set of statements executes. In the 1960s, a group of mathematicians proved that only three program structures are needed to write any type of program. The simplest of these structures is the sequence structure. Later in this book, you will learn about the other two structures—decision structures and repetition structures.

Strings and String Literals

Programs almost always work with data of some type. For example, Program 2-1 uses the following three pieces of data:

```
"Kate Austen"  
"1234 Walnut Street"  
"Asheville, NC 28899"
```

These pieces of data are sequences of characters. In programming terms, a sequence of characters that is used as data is called a *string*. When a string appears in the actual code of a program (or in pseudocode, as it does in Program 2-1) it is called a *string literal*. In program code, or pseudocode, a string literal is usually enclosed in quotation marks. As mentioned earlier, the quotation marks simply mark where the string begins and ends.

In this book, we will always enclose string literals in double quote marks ("). Most programming languages use this same convention, but a few use single quote marks (').

Variables and Input



Quite often a program needs to store data in the computer's memory so it can perform operations on that data. For example, consider the typical online shopping experience: You browse a Web site and add the items that you want to purchase to the shopping cart. As you add items to the shopping cart, data about those items is stored in memory. Then, when you click the checkout button, a program running on the Web site's computer calculates the total of all the items you have in your shopping cart, applicable sales taxes, shipping costs, and the total of all these charges. When the program performs these calculations, it stores the results in the computer's memory.

Programs use variables to store data in memory. A *variable* is a storage location in memory that is represented by a name. For example, a program that calculates the sales tax on a purchase might use a variable named `tax` to hold that value in memory. And a program that calculates the distance from Earth to a distant star might use a variable named `distance` to hold that value in memory.

In this section, we will discuss a basic input operation: reading data that has been typed on the keyboard. When a program reads data from the keyboard, usually it stores that data in a variable so it can be used later by the program. In pseudocode we will read

data from the keyboard with the `Input` statement. As an example, look at the following statement, which appeared earlier in the pay calculating program:

Input hours

The word `Input` is an instruction to read a piece of data from the keyboard. The word `hours` is the name of the variable in which that data will be stored. When this statement executes, two things happen:

- The program pauses and waits for the user to type something on the keyboard, and then press the `Enter ↵` key.
- When the `Enter ↵` key is pressed, the data that was typed is stored in the `hours` variable.

Program 2-2 is a simple pseudocode program that demonstrates the `Input` statement. Before we examine the program, we should mention a couple of things. First, you will notice that each line in the program is numbered. The line numbers are not part of the pseudocode. We will refer to the line numbers later to point out specific parts of the program. Second, the program's output is shown immediately following the pseudocode. From now on, all pseudocode programs will be shown this way.

Program 2-2



```
1 Display "What is your age?"
2 Input age
3 Display "Here is the value that you entered:"
4 Display age
```

Program Output (with Input Shown in Bold)

What is your age?

24 [Enter]

Here is the value that you entered:

24

The statement in line 1 displays the string "What is your age?" Then, the statement in line 2 waits for the user to type a value on the keyboard and press `Enter ↵`. The value that is typed will be stored in the `age` variable. In the example execution of the program, the user has entered 24. The statement in line 3 displays the string "Here is the value that you entered:" and the statement in line 4 displays the value that is stored in the `age` variable.

Notice that in line 4 there are no quotation marks around `age`. If quotation marks were placed around `age`, it would have indicated that we want to display the word `age` instead of the contents of the `age` variable. In other words, the following statement is an instruction to display the contents of the `age` variable:

Display age

This statement, however, is an instruction to display the word `age`:

Display "age"



NOTE: In this section, we have mentioned the user. The *user* is simply any hypothetical person that is using a program and providing input for it. The user is sometimes called the *end user*.

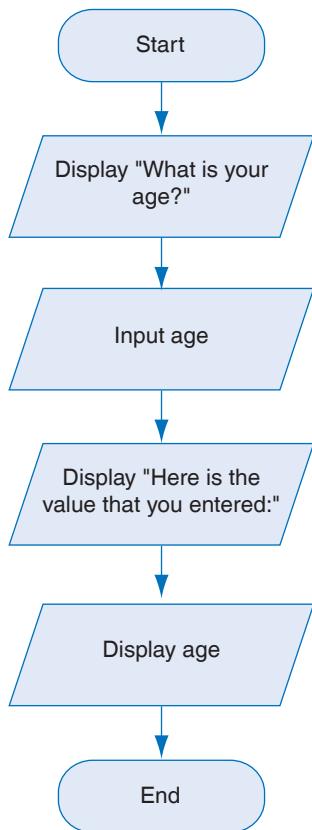
Figure 2-10 Flowchart for Program 2-2

Figure 2-10 shows a flowchart for Program 2-2. Notice that the `Input` operation is also represented by a parallelogram.

Variable Names

All high-level programming languages allow you to make up your own names for the variables that you use in a program. You don't have complete freedom in naming variables, however. Every language has its own set of rules that you must abide by when creating variable names.

Although the rules for naming variables differ slightly from one language to another, there are some common restrictions:

- Variable names must be one word. They cannot contain spaces.
- In most languages, punctuation characters cannot be used in variable names. It is usually a good idea to use only alphabetic letters and numbers in variable names.
- In most languages, the first character of a variable name cannot be a number.

In addition to following the programming language rules, you should always choose names for your variables that give an indication of what they are used for. For example, a variable that holds the temperature might be named `temperature`, and a variable that holds a car's speed might be named `speed`. You may be tempted to give variables names like `x` and `b2`, but names like these give no clue as to what the variable's purpose is.

Because a variable's name should reflect the variable's purpose, programmers often find themselves creating names that are made of multiple words. For example, consider the following variable names:

```
grosspay  
payrate  
hotdogssoldtoday
```

Unfortunately, these names are not easily read by the human eye because the words aren't separated. Because we can't have spaces in variable names, we need to find another way to separate the words in a multiword variable name, and make it more readable to the human eye.

One way to do this is to use the underscore character to represent a space. For example, the following variable names are easier to read than those previously shown:

```
gross_pay  
pay_rate  
hot_dogs_sold_today
```

Another way to address this problem is to use the *camelCase* naming convention. camelCase names are written in the following manner:

- You begin writing the variable name with lowercase letters.
- The first character of the second and subsequent words is written in uppercase.

For example, the following variable names are written in camelCase:

```
grossPay  
payRate  
hotDogsSoldToday
```

Because the camelCase convention is very popular with programmers, we will use it from this point forward. In fact, you have already seen several programs in this chapter that use camelCase variable names. The pay calculating program shown at the beginning of the chapter uses the variable name `payRate`. Later in this chapter, Program 2-9 uses the variable names `originalPrice` and `salePrice`, and Program 2-11 uses the variable names `futureValue` and `presentValue`.



NOTE: This style of naming is called camelCase because the uppercase characters that appear in a name are sometimes reminiscent of a camel's humps.

Displaying Multiple Items with One Display Statement

If you refer to Program 2-2 you will see that we used the following two `Display` statements in lines 3 and 4:

```
Display "Here is the value that you entered:"  
Display age
```

We used two `Display` statements because we needed to display two pieces of data. Line 3 displays the string literal "Here is the value that you entered:" and line 4 displays the contents of the `age` variable.

Most programming languages provide a way to display multiple pieces of data with one statement. Because this is a common feature of programming languages, frequently we will write **Display** statements in our pseudocode that display multiple items. We will simply separate the items with a comma, as shown in line 3 of Program 2-3.

Program 2-3

```
1 Display "What is your age?"
2 Input age
3 Display "Here is the value that you entered: ", age
```

Program Output (with Input Shown in Bold)

What is your age?
24 [Enter]
 Here is the value that you entered: 24

Take a closer look at line 3 of Program 2-3:

Display "Here is the value that you entered: ", age

↑
Notice the space.

Notice that the string literal "Here is the value that you entered: " ends with a space. That is because in the program output, we want a space to appear after the colon, as shown here:

Here is the value that you entered: 24

↑
Notice the space.

In most cases, when you are displaying multiple items on the screen, you want to separate those items with spaces between them. Most programming languages do not automatically print spaces between multiple items that are displayed on the screen. For example, look at the following pseudocode statement:

Display "January", "February", "March"

In most programming languages, such as statement would produce the following output:
 JanuaryFebruaryMarch

To separate the strings with spaces in the output, the **Display** statement should be written as:

Display "January ", "February ", "March"

String Input

Programs 2-2 and 2-3 read numbers from the keyboard, which were stored in variables by **Input** statements. Programs can also read string input. For example, the pseudocode in Program 2-4 uses two **Input** statements: one to read a string and one to read a number.

Program 2-4

```
1 Display "Enter your name."
2 Input name
3 Display "Enter your age."
4 Input age
5 Display "Hello ", name
6 Display "You are ", age, " years old."
```

Program Output (with Input Shown in Bold)

```
Enter your name.
Andrea [Enter]
Enter your age.
24 [Enter]
Hello Andrea
You are 24 years old.
```

The `Input` statement in line 2 reads input from the keyboard and stores it in the `name` variable. In the example execution of the program, the user entered Andrea. The `Input` statement in line 4 reads input from the keyboard and stores it in the `age` variable. In the example execution of the program, the user entered 24.

Prompting the User

Getting keyboard input from the user is normally a two-step process:

1. Display a prompt on the screen.
2. Read a value from the keyboard.

A *prompt* is a message that tells (or asks) the user to enter a specific value. For example, the pseudocode in Program 2-3 gets the user to enter their age with the following statements:

```
Display "What is your age?"
Input age
```

In most programming languages, the statement that reads keyboard input does not display instructions on the screen. It simply causes the program to pause and wait for the user to type something on the keyboard. For this reason, whenever you write a statement that reads keyboard input, you should also write a statement just before it that tells the user what to enter. Otherwise, the user will not know what they are expected to do. For example, suppose we remove line 1 from Program 2-3, as follows:

```
Input age
Display "Here is the value that you entered: ", age
```

If this were an actual program, can you see what would happen when it is executed? The screen would appear blank because the `Input` statement would cause the program to wait for something to be typed on the keyboard. The user would probably think the computer was malfunctioning.

The term *user-friendly* is commonly used in the software business to describe programs that are easy to use. Programs that do not display adequate or correct instructions are frustrating to use, and are not considered user-friendly. One of the simplest things that you can do to increase a program's user-friendliness is to make sure that it displays clear, understandable prompts prior to each statement that reads keyboard input.



TIP: When designing a program, remember that the typical user knows nothing about the program's inner workings. To avoid input mistakes, your programs should provide clear instructions for the user.



Checkpoint

- 2.7 What are the three operations that programs typically perform?
- 2.8 What is an IPO chart?
- 2.9 What is a sequence structure?
- 2.10 What is a string? What is a string literal?
- 2.11 A string literal is usually enclosed inside a set of what characters?
- 2.12 What is a variable?
- 2.13 Summarize three common rules for naming variables.
- 2.14 What variable naming convention do we follow in this book?
- 2.15 Look at the following pseudocode statement:

```
Input temperature
```

What happens when this statement executes?
- 2.16 Who is the user?
- 2.17 What is a prompt?
- 2.18 What two steps usually take place when a program prompts the user for input?
- 2.19 What does the term *user-friendly* mean?

2.3

Variable Assignment and Calculations

CONCEPT: You can store a value in a variable with an assignment statement. The value can be the result of a calculation, which is created with math operators.

Variable Assignment

In the previous section, you saw how the `Input` statement gets a value typed on the keyboard and stores it in a variable. You can also write statements that store specific values in variables. The following is an example, in pseudocode:

```
Set price = 20
```

This is called an assignment statement. An *assignment statement* sets a variable to a specified value. In this case, the variable `price` is set to the value 20. When we write an assignment statement in pseudocode, we will write the word `Set`, followed by the name

of the variable, followed by an equal sign (=), followed by the value we want to store in the variable. The pseudocode in Program 2-5 shows another example.

Program 2-5

```
1 Set dollars = 2.75
2 Display "I have ", dollars, " in my account."
```

Program Output

I have 2.75 in my account.

In line 1, the value 2.75 is stored in the `dollars` variable. Line 2 displays the message “I have 2.75 in my account.” Just to make sure you understand how the `Display` statement in line 2 is working, let’s walk through it. The word `Display` is followed by three pieces of data, so that means it will display three things. The first thing it displays is the string literal “I have ”. Next, it displays the contents of the `dollars` variable, which is 2.75. Last, it displays the string literal “ in my account.”

Variables are called “variable” because they can hold different values while a program is running. Once you set a variable to a value, that value will remain in the variable until you store a different value in the variable. For example, look at the pseudocode in Program 2-6.

Program 2-6

```
1 Set dollars = 2.75
2 Display "I have ", dollars, " in my account."
3 Set dollars = 99.95
4 Display "But now I have ", dollars, " in my account!"
```

Program Output

I have 2.75 in my account.
But now I have 99.95 in my account!

Line 1 sets the `dollars` variable to 2.75, so when the statement in line 2 executes, it displays “I have 2.75 in my account.” Then, the statement in line 3 sets the `dollars` variable to 99.95. As a result, the value 99.95 replaces the value 2.75 that was previously stored in the variable. When line 4 executes, it displays “But now I have 99.95 in my account!” This program illustrates two important characteristics of variables:

- A variable holds only one value at a time.
- When you store a value in a variable, that value replaces the previous value that was in the variable.



NOTE: When writing an assignment statement, all programming languages require that you write the name of the variable that is receiving the value on the left side of the = operator. For example, the following statement is incorrect:

Set 99.95 = dollars ← This is an error!

A statement such as this would be considered a syntax error.



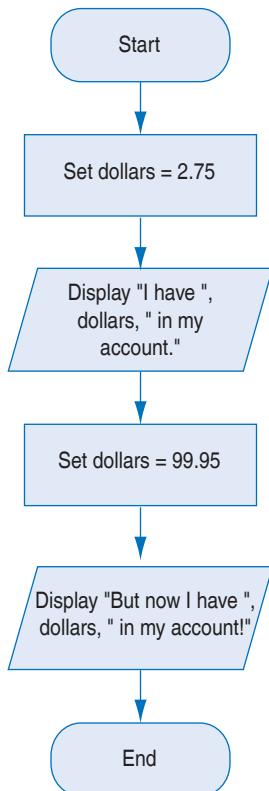
NOTE: In this book, we have chosen to start variable assignment statements with the word `Set` because it makes it clear that we are setting a variable to a value. In most programming languages, however, assignment statements do not start with the word `Set`. In most languages, an assignment statement looks similar to the following:

```
dollars = 99.95
```

If your instructor allows it, it is permissible to write assignment statements without the word `Set` in your pseudocode. Just be sure to write the name of the variable that is receiving the value on the left side of the equal sign.

In flowcharts, an assignment statement appears in a processing symbol, which is a rectangle. Figure 2-11 shows a flowchart for Program 2-6.

Figure 2-11 Flowchart for Program 2-6



Performing Calculations



Most real-world algorithms require calculations to be performed. A programmer's tools for performing calculations are *math operators*. Programming languages commonly provide the operators shown in Table 2-1.

Table 2-1 Common math operators¹

Symbol	Operator	Description
+	Addition	Adds two numbers
-	Subtraction	Subtracts one number from another
*	Multiplication	Multiplies one number by another
/	Division	Divides one number by another and gives the quotient
MOD	Modulus	Divides one number by another and gives the remainder
^	Exponent	Raises a number to a power

Programmers use the operators shown in Table 2-1 to create math expressions. A *math expression* performs a calculation and gives a value. The following is an example of a simple math expression:

12 + 2

The values on the right and left of the + operator are called *operands*. These are values that the + operator adds together. The value that is given by this expression is 14.

Variables may also be used in a math expression. For example, suppose we have two variables named `hours` and `payRate`. The following math expression uses the * operator to multiply the value in the `hours` variable by the value in the `payRate` variable:

`hours * payRate`

When we use a math expression to calculate a value, normally we want to save that value in memory so we can use it again in the program. We do this with an assignment statement. Program 2-7 shows an example.

Program 2-7

```

1 Set price = 100
2 Set discount = 20
3 Set sale = price - discount
4 Display "The total cost is $", sale

```

Program Output

The total cost is \$80

Line 1 sets the `price` variable to 100, and line 2 sets the `discount` variable to 20. Line 3 sets the `sale` variable to the result of the expression `price - discount`. As you can see from the program output, the `sale` variable holds the value 80.

¹ In some programming languages, the % character is used as the modulus operator, and sometimes the ** characters are used as the exponent operator.

In the Spotlight: Calculating Cell Phone Overage Fees



Suppose your cell phone calling plan allows you to use 700 minutes per month. If you use more than this limit in a month, you are charged an overage fee of 35 cents for each excess minute. Your phone shows you the number of excess minutes that you have used in the current month, but it does not show you how much your overage fee currently is. Until now, you've been doing the math the old-fashioned way (with pencil and paper, or with a calculator), but you would like to design a program that will simplify the task. You would like to be able to enter the number of excess minutes, and have the program perform the calculation for you.

First, you want to make sure that you understand the steps that the program must perform. It will be helpful if you closely look at the way you've been solving this problem, using only paper and pencil, or calculator:

Manual Algorithm (Using pencil and paper, or calculator)

1. You get the number of excess minutes that you have used.
2. You multiply the number of excess minutes by 0.35.
3. The result of the calculation is your current overage fee.

Ask yourself the following questions about this algorithm:

Question: What input do I need to perform this algorithm?

Answer: I need the number of excess minutes.

Question: What must I do with the input?

Answer: I must multiply the input (the number of excess minutes) by 0.35. The result of that calculation is the overage fee.

Question: What output must I produce?

Answer: The overage fee.

Now that you have identified the input, the process that must be performed, and the output, you can write the general steps of the program's algorithm:

Computer Algorithm

1. Get the number of excess minutes as input.
2. Calculate the overage fee by multiplying the number of excess minutes by 0.35.
3. Display the overage fee.

In Step 1 of the computer algorithm, the program gets the number of excess minutes from the user. Any time a program needs the user to enter a piece of data, it does two things: (1) it displays a message prompting the user for the piece of data, and (2) it reads the data that the user enters on the keyboard, and stores that data in a variable. In pseudocode, Step 1 of the algorithm will look like this:

Display "Enter the number of excess minutes."

Input excessMinutes

Notice that the Input statement stores the value entered by the user in a variable named excessMinutes.

In Step 2 of the computer algorithm, the program calculates the overage fee by multiplying the number of excess minutes by 0.35. The following pseudocode statement performs this calculation, and stores the result in a variable named `overageFee`:

```
Set overageFee = excessMinutes * 0.35
```

In Step 3 of the computer algorithm, the program displays the overage fee. Because the overage fee is stored in the `overageFee` variable, the program will display a message that shows the value of the `overageFee` variable. In pseudocode we will use the following statement:

```
Display "Your current overage fee is $", overageFee
```

Program 2-8 shows the entire pseudocode program, with example output. Figure 2-12 shows the flowchart for this program.

Program 2-8

- 1 Display "Enter the number of excess minutes."
- 2 Input excessMinutes
- 3 Set overageFee = excessMinutes * 0.35
- 4 Display "Your current overage fee is \$", overageFee

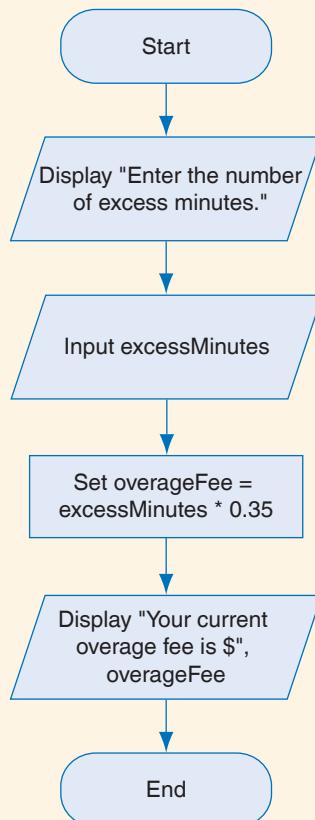
Program Output (with Input Shown in Bold)

Enter the number of excess minutes.

100 [Enter]

Your current overage fee is \$35

Figure 2-12 Flowchart for Program 2-8



In the Spotlight: Calculating a Percentage



Determining percentages is a common calculation in computer programming. In mathematics, the % symbol is used to indicate a percentage, but most programming languages don't use the % symbol for this purpose. In a program, you usually have to convert a percentage to a decimal number. For example, 50 percent would be written as 0.5 and 2 percent would be written as 0.02.

Let's step through the process of writing a program that calculates a percentage. Suppose a retail business is planning to have a storewide sale where the prices of all items will be 20 percent off. We have been asked to write a program to calculate the sale price of an item after the discount is subtracted. Here is the algorithm:

1. Get the original price of the item.
2. Calculate 20 percent of the original price. This is the amount of the discount.
3. Subtract the discount from the original price. This is the sale price.
4. Display the sale price.

In Step 1 we get the original price of the item. We will prompt the user to enter this data on the keyboard. Recall from the previous section that prompting the user is a two-step process: (1) display a message telling the user to enter the desired data, and (2) reading that data from the keyboard. We will use the following pseudocode statements to do this. Notice that the value entered by the user will be stored in a variable named `originalPrice`.

```
Display "Enter the item's original price."  
Input originalPrice
```

In Step 2, we calculate the amount of the discount. To do this we multiply the original price by 20 percent. The following statement performs this calculation and stores the result in the `discount` variable.

```
Set discount = originalPrice * 0.2
```

In Step 3, we subtract the discount from the original price. The following statement does this calculation and stores the result in the `salePrice` variable.

```
Set salePrice = originalPrice - discount
```

Last, in Step 4, we will use the following statement to display the sale price:

```
Display "The sale price is $", salePrice
```

Program 2-9 shows the entire pseudocode program, with example output. Figure 2-13 shows the flowchart for this program.

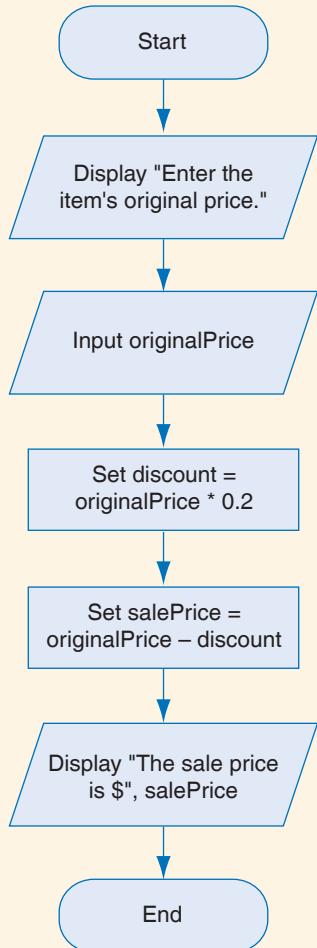
Program 2-9



```
1 Display "Enter the item's original price."  
2 Input originalPrice  
3 Set discount = originalPrice * 0.2  
4 Set salePrice = originalPrice - discount  
5 Display "The sale price is $", salePrice
```

Program Output (with Input Shown in Bold)

Enter the item's original price.
100 [Enter]
The sale price is \$80

Figure 2-13 Flowchart for Program 2-9

The Order of Operations

It is possible to build mathematical expressions with several operators. The following statement assigns the sum of 17, the variable `x`, 21, and the variable `y` to the variable `answer`.

```
Set answer = 17 + x + 21 + y
```

Some expressions are not that straightforward, however. Consider the following statement:

```
Set outcome = 12 + 6 / 3
```

What value will be stored in `outcome`? The number 6 is used as an operand for both the addition and division operators. The `outcome` variable could be assigned either 6 or 14, depending on when the division takes place. The answer is 14 because the *order of operations* dictates that the division operator works before the addition operator does.

In most programming languages, the order of operations can be summarized as follows:

1. Perform any operations that are enclosed in parentheses.
2. Perform any operations that use the exponent operator to raise a number to a power.
3. Perform any multiplications, divisions, or modulus operations as they appear from left to right.
4. Perform any additions or subtractions as they appear from left to right.

Mathematical expressions are evaluated from left to right. When two operators share an operand, the order of operations determines which operator works first. Multiplication and division are always performed before addition and subtraction, so the statement

```
Set outcome = 12 + 6 / 3
```

works like this:

1. 6 is divided by 3, yielding a result of 2
2. 12 is added to 2, yielding a result of 14

It could be diagrammed as shown in Figure 2-14.

Figure 2-14 The order of operations at work

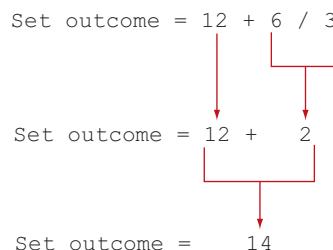


Table 2-2 shows some other sample expressions with their values.

Table 2-2 Some expressions and their values

Expression	Value
$5 + 2 * 4$	13
$10 / 2 - 3$	2
$8 + 12 * 2 - 4$	28
$6 - 3 * 2 + 7 - 1$	6

Grouping with Parentheses

Parts of a mathematical expression may be grouped with parentheses to force some operations to be performed before others. In the following statement, the variables `a` and `b` are added together, and their sum is divided by 4:

```
Set result = (a + b) / 4
```

Without the parentheses, however, *b* would be divided by 4 and the result added to *a*. Table 2-3 shows more expressions and their values.

Table 2-3 More expressions and their values

Expression	Value
$(5 + 2) * 4$	28
$10 / (5 - 3)$	5
$8 + 12 * (6 - 2)$	56
$(6 - 3) * (2 + 7) / 3$	9



NOTE: Parentheses can be used to enhance the clarity of a math expression, even when they are unnecessary to get the correct result. For example, look at the following statement:

```
Set fahrenheit = celsius * 1.8 + 32
```

Even when it is unnecessary to get the correct result, we can insert parentheses to clearly show that *celsius* * 1.8 happens first in the math expression:

```
Set fahrenheit = (celsius * 1.8) + 32
```

In the Spotlight: Calculating an Average



Determining the average of a group of values is a simple calculation: You add all of the values and then divide the sum by the number of values. Although this is a straightforward calculation, it is easy to make a mistake when writing a program that calculates an average. For example, let's assume that the variables *a*, *b*, and *c* each hold a value and we want to calculate the average of those values. If we are careless, we might write a statement such as the following to perform the calculation:

```
Set average = a + b + c / 3
```

Can you see the error in this statement? When it executes, the division will take place first. The value in *c* will be divided by 3, and then the result will be added to *a* + *b*. That is not the correct way to calculate an average. To correct this error we need to put parentheses around *a* + *b* + *c*, as shown here:

```
Set average = (a + b + c) / 3
```

Let's step through the process of writing a program that calculates an average. Suppose you have taken three tests in your computer science class, and you want to write a program that will display the average of the test scores. Here is the algorithm:

1. Get the first test score.
2. Get the second test score.
3. Get the third test score.
4. Calculate the average by adding the three test scores and dividing the sum by 3.
5. Display the average.

In Steps 1, 2, and 3 we will prompt the user to enter the three test scores. We will store those test scores in the variables `test1`, `test2`, and `test3`. In Step 4 we will calculate the average of the three test scores. We will use the following statement to perform the calculation and store the result in the `average` variable:

```
Set average = (test1 + test2 + test3) / 3
```

Last, in Step 5, we display the average. Program 2-10 shows the pseudocode for this program, and Figure 2-15 shows the flowchart.

Program 2-10

```
1 Display "Enter the first test score."
2 Input test1
3 Display "Enter the second test score."
4 Input test2
5 Display "Enter the third test score."
6 Input test3
7 Set average = (test1 + test2 + test3) / 3
8 Display "The average score is ", average
```

Program Output (with Input Shown in Bold)

Enter the first test score.

90 [Enter]

Enter the second test score.

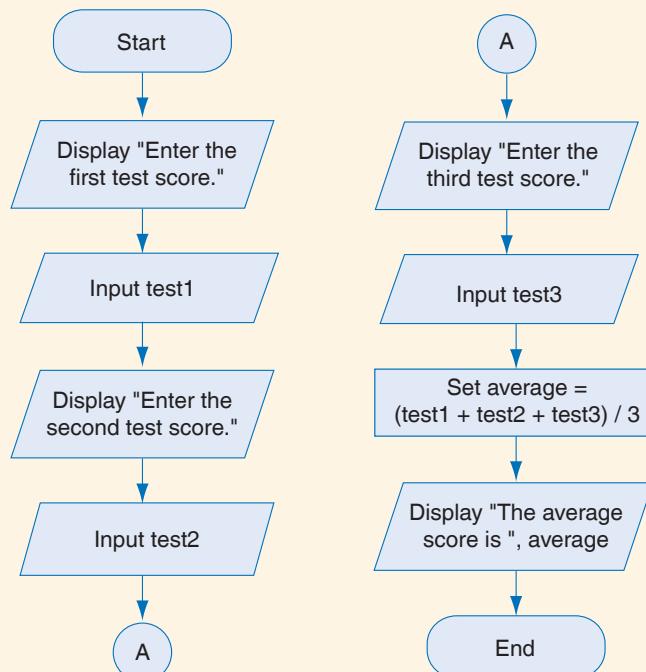
80 [Enter]

Enter the third test score.

100 [Enter]

The average score is 90

Figure 2-15 Flowchart for Program 2-10



Advanced Arithmetic Operators: Exponent and Modulus

In addition to the basic math operators for addition, subtraction, multiplication, and division, many languages provide an exponent operator and a modulus operator. The `^` symbol is commonly used as the exponent operator, and its purpose is to raise a number to a power. For example, the following pseudocode statement raises the `length` variable to the power of 2 and stores the result in the `area` variable:

```
Set area = length^2
```

The word `MOD` is used in many languages as the modulus operator. (Some languages use the `%` symbol for the same purpose.) The modulus operator performs division, but instead of returning the quotient, it returns the remainder. The following statement assigns 2 to `leftover`:

```
Set leftover = 17 MOD 3
```

This statement assigns 2 to `leftover` because 17 divided by 3 is 5 with a remainder of 2. You will not use the modulus operator frequently, but it is useful in some situations. It is commonly used in calculations that detect odd or even numbers, determine the day of the week, measure the passage of time, and other specialized operations.

Converting Math Formulas to Programming Statements

You probably remember from algebra class that the expression $2xy$ is understood to mean 2 times x times y . In math, you do not always use an operator for multiplication. Programming languages, however, require an operator for any mathematical operation. Table 2-4 shows some algebraic expressions that perform multiplication and the equivalent programming expressions.

Table 2-4 Algebraic expressions

Algebraic Expression	Operation Being Performed	Programming Expression
$6B$	6 times B	<code>6 * B</code>
$(3)(12)$	3 times 12	<code>3 * 12</code>
$4xy$	4 times x times y	<code>4 * x * y</code>

When converting some algebraic expressions to programming expressions, you may have to insert parentheses that do not appear in the algebraic expression. For example, look at the following formula:

$$x = \frac{a + b}{c}$$

To convert this to a programming statement, $a + b$ will have to be enclosed in parentheses:

```
Set x = (a + b) / c
```

Table 2-5 shows additional algebraic expressions and their pseudocode equivalents.

Table 2-5 Algebraic expressions and pseudocode statements

Algebraic Expression	Pseudocode Statement
$y = 3\frac{x}{2}$	Set $y = x / 2 * 3$
$z = 3bc + 4$	Set $z = 3 * b * c + 4$
$a = \frac{x + 2}{a - 1}$	Set $a = (x + 2) / (a - 1)$

In the Spotlight: Converting a Math Formula to a Programming Statement



Suppose you want to deposit a certain amount of money into a savings account, and then leave it alone to draw interest for the next 10 years. At the end of 10 years you would like to have \$10,000 in the account. How much do you need to deposit today to make that happen? You can use the following formula to find out:

$$P = \frac{F}{(1 + r)^n}$$

The terms in the formula are as follows:

- P is the present value, or the amount that you need to deposit today.
- F is the future value that you want in the account. (In this case, F is \$10,000.)
- r is the annual interest rate.
- n is the number of years that you plan to let the money sit in the account.

It would be nice to write a computer program to perform the calculation, because then we can experiment with different values for the terms. Here is an algorithm that we can use:

1. Get the desired future value.
2. Get the annual interest rate.
3. Get the number of years that the money will sit in the account.
4. Calculate the amount that will have to be deposited.
5. Display the result of the calculation in Step 4.

In Steps 1 through 3, we will prompt the user to enter the specified values. We will store the desired future value in a variable named `futureValue`, the annual interest rate in a variable named `rate`, and the number of years in a variable named `years`.

In Step 4, we calculate the present value, which is the amount of money that we will have to deposit. We will convert the formula previously shown to the following pseudocode statement. The statement stores the result of the calculation in the `presentValue` variable.

```
Set presentValue = futureValue / (1 + rate)^years
```

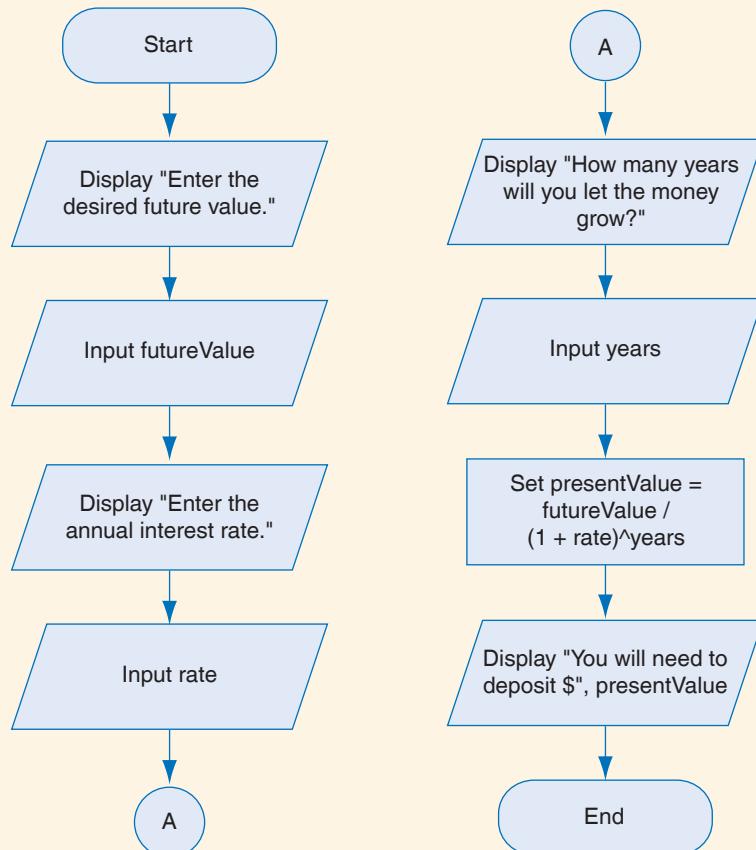
In Step 5, we display the value in the `presentValue` variable. Program 2-11 shows the pseudocode for this program, and Figure 2-16 shows the flowchart.

Program 2-11

```
1 Display "Enter the desired future value."
2 Input futureValue
3 Display "Enter the annual interest rate."
4 Input rate
5 Display "How many years will you let the money grow?"
6 Input years
7 Set presentValue = futureValue / (1 + rate)^years
8 Display "You will need to deposit $", presentValue
```

Program Output (with Input Shown in Bold)

```
Enter the desired future value.
10000 [Enter]
Enter the annual interest rate.
0.05 [Enter]
How many years will you let the money grow?
10 [Enter]
You will need to deposit $6139
```

Figure 2-16 Flowchart for Program 2-11



Checkpoint

- 2.20 What is an assignment statement?
- 2.21 When you assign a value to a variable, what happens to any value that is already stored in the variable?
- 2.22 Summarize the mathematical order of operations, as it works in most programming languages.
- 2.23 What is the purpose of the exponent operator?
- 2.24 What is the purpose of the modulus operator?

2.4

Variable Declarations and Data Types

CONCEPT: Most languages require that variables be declared before they are used in a program. When a variable is declared, it can optionally be initialized with a value. Using an uninitialized variable is the source of many errors in programming.



VideoNote

Variable Declarations

Most programming languages require that you *declare* all of the variables that you intend to use in a program. A *variable declaration* is a statement that typically specifies two things about a variable:

- The variable's name
- The variable's data type

A variable's *data type* is simply the type of data that the variable will hold. Once you declare a variable, it can be used to store values of only the specified data type. In most languages, an error occurs if you try to store values of other types in the variable.

The data types that you are allowed to use depend on the programming language. For example, the Java language provides four data types for integer numbers, two data types for real numbers, one data type for strings, and others.

So far, we haven't declared any of the variables that we have used in our example pseudocode programs. We have simply used the variables without first declaring them. This is permissible with short pseudocode programs, but as programs grow in length and complexity, it makes sense to declare them. When you declare variables in a pseudocode program, it will make the job of translating the pseudocode to actual code easier.

In most of the programs in this book, we will use only three data types when we declare variables: `Integer`, `Real`, and `String`. Here is a summary of each:

- A variable of the `Integer` data type can hold whole numbers. For example, an `Integer` variable can hold values such as 42, 0, and -99. An `Integer` variable cannot hold numbers with a fractional part, such as 22.1 or -4.9.
- A variable of the `Real` data type can hold either whole numbers or numbers with a fractional part. For example, a `Real` variable can hold values such as 3.5, -87.95, and 3.0.
- A variable of the `String` data type can hold any string of characters, such as someone's name, address, password, and so on.

In this book, we will begin variable declarations with the word **Declare**, followed by a data type, followed by the variable's name. Here is an example:

```
Declare Integer length
```

This statement declares a variable named **length**, of the **Integer** data type. Here is another example:

```
Declare Real grossPay
```

This statement declares a variable named **grossPay**, of the **Real** data type. Here is one more example:

```
Declare String name
```

This statement declares a variable named **name**, of the **String** data type.

If we need to declare more than one variable of the same data type, we can use one declaration statement. For example, suppose we want to declare three variables, **length**, **width**, and **height**, all of the **Integer** data type. We can declare all three with one statement, as shown here:

```
Declare Integer length, width, height
```



NOTE: In addition to a **String** data type, many programming languages also provide a **Character** data type. The difference between a **String** variable and a **Character** variable is that a **String** variable can hold a sequence of characters of virtually any length, and a **Character** variable can hold only one character. In this book, we will keep things simple. We will use **String** variables to hold all character data.

Declaring Variables Before Using Them

The purpose of a variable declaration statement is to tell the compiler or interpreter that you plan to use a particular variable in the program. A variable declaration statement typically causes the variable to be created in memory. For this reason, you have to write a variable's declaration statement *before* any other statements in the program that use the variable. This makes perfect sense because you cannot store a value in a variable if the variable has not been created in memory.

For example, look at the following pseudocode. If this code were converted to actual code in a language like Java or C++, it would cause an error because the **Input** statement uses the **age** variable before the variable has been declared.

```
Display "What is your age?"  
Input age  
Declare Integer age
```

} This pseudocode has an error!

Program 2-12 shows the correct way to declare a variable. Notice that the declaration statement for the **age** variable appears before any other statements that use the variable.

Program 2-12

- 1 Declare Integer age
- 2 Display "What is your age?"
- 3 Input age

- ```
4 Display "Here is the value that you entered:"
5 Display age
```

### Program Output (with Input Shown in Bold)

```
What is your age?
24 [Enter]
Here is the value that you entered:
24
```

Program 2-13 shows another example. This program declares a total of four variables: three to hold test scores and another to hold the average of those test scores.

### Program 2-13

```
1 Declare Real test1
2 Declare Real test2
3 Declare Real test3
4 Declare Real average
5
6 Set test1 = 88.0
7 Set test2 = 92.5
8 Set test3 = 97.0
9 Set average = (test1 + test2 + test3) / 3
10 Display "Your average test score is ", average
```

### Program Output

```
Your average test score is 92.5
```

This program shows a common technique for declaring variables: they are all declared at the beginning of the program, before any other statements. This is one way of making sure that all variables are declared before they are used.

Notice that line 5 in this program is blank. This blank line does *not* affect the way the program works because most compilers and interpreters ignore blank lines. For the human reader, however, this blank line visually separates the variable declarations from the other statements. This makes the program appear more organized and easier for people to read.

Programmers commonly use blank lines and indentations in their code to create a sense of organization visually. This is similar to the way that authors visually arrange the text on the pages of a book. Instead of writing each chapter as one long series of sentences, they break it into paragraphs. This does not change the information in the book; it only makes it easier to read.

Although you are generally free to place blank lines and indentations anywhere in your code, you should not do this haphazardly. Programmers follow certain conventions when it comes to this. For example, you have just learned that one convention is to use a blank line to separate a group of variable declaration statements from the rest of the statements in a program. These conventions are known as *programming style*. As you progress through this book you will see many other programming style conventions.

## Variable Initialization

When you declare a variable, you can optionally assign a value to it in the declaration statement. This is known as *initialization*. For example, the following statement declares a variable named `price` and assigns the value 49.95 to it:

```
Declare Real price = 49.95
```

We would say that this statement *initializes* the `price` variable with the value 49.95. The following statement shows another example:

```
Declare Integer length = 2, width = 4, height = 8
```

This statement declares and initializes three variables. The `length` variable is initialized with the value 2, `width` is initialized with the value 4, and `height` is initialized with the value 8.

## Uninitialized Variables

An *uninitialized variable* is a variable that has been declared, but has not been initialized or assigned a value. Uninitialized variables are a common cause of logic errors in programs. For example, look at the following pseudocode:

```
Declare Real dollars
Display "I have ", dollars, " in my account."
```

In this pseudocode, we have declared the `dollars` variable, but we have not initialized it or assigned a value to it. Therefore, we do not know what value the variable holds. Nevertheless, we have used the variable in a `Display` statement.

You're probably wondering what a program like this would display. An honest answer would be "I don't know." This is because each language has its own way of handling uninitialized variables. Some languages assign a default value such as 0 to uninitialized variables. In many languages, however, uninitialized variables hold unpredictable values. This is because those languages set aside a place in memory for the variable, but do not alter the contents of that place in memory. As a result, an uninitialized variable holds the value that happens to be stored in its memory location. Programmers typically refer to unpredictable values such as this as "garbage."

Uninitialized variables can cause logic errors that are hard to find in a program. This is especially true when an uninitialized variable is used in a calculation. For example, look at the following pseudocode, which is a modified version of Program 2-13. Can you spot the error?

```
1 Declare Real test1
2 Declare Real test2
3 Declare Real test3
4 Declare Real average
5
6 Set test1 = 88.0
7 Set test2 = 92.5
8 Set average = (test1 + test2 + test3) / 3
9 Display "Your average test score is ", average
```

This pseudocode contains an error!

This program will not work properly because the `test3` variable is never assigned a value. The `test3` variable will contain garbage when it is used in the calculation in line 8. This means that the calculation will result in an unpredictable value, which will be assigned to the `average` variable. A beginning programmer might have trouble finding this error because it would initially be assumed that something is wrong with the math in line 8.

In the next section, we will discuss a debugging technique that will help uncover errors such as the one in the modified version of Program 2-13. However, as a rule you should always make sure that your variables either (1) are initialized with the correct value when you declare them, or (2) receive the correct value from an assignment statement or an `Input` statement before they are used for any other purpose.

## Numeric Literals and Data Type Compatibility

Many of the programs that you have seen so far have numbers written into their pseudocode. For example, the following statement, which appears in Program 2-6, has the number 2.75 written into it.

```
Set dollars = 2.75
```

And, the following statement, which appears in Program 2-7, has the number 100 written into it.

```
Set price = 100
```

A number that is written into a program's code is called a *numeric literal*. In most programming languages, if a numeric literal is written with a decimal point, such as 2.75, that numeric literal will be stored in the computer's memory as a `Real` and it will be treated as a `Real` when the program runs. If a numeric literal does not have a decimal point, such as 100, that numeric literal will be stored in the computer's memory as an `Integer` and it will be treated as an `Integer` when the program runs.

This is important to know when you are writing assignment statements or initializing variables. In many languages, an error will occur if you try to store a value of one data type in a variable of another data type. For example, look at the following pseudocode:

```
Declare Integer i
Set i = 3.7 ← This is an error!
```

The assignment statement will cause an error because it attempts to assign a real number, 3.7, in an `Integer` variable. The following pseudocode will also cause an error.

```
Declare Integer i
Set i = 3.0 ← This is an error!
```



**NOTE:** Most languages do not allow you to assign real numbers to `Integer` variables because `Integer` variables cannot hold fractional amounts. In many languages, however, you are allowed to assign an integer value to a `Real` variable without causing an error. Here is an example:

```
Declare Real r
Set r = 77
```

Even though the numeric literal 77 is treated as an `Integer`, it can be assigned to a `Real` variable without the loss of data.

Even though the numeric literal 3.0 does not have a fractional value (it is mathematically the same as the integer 3), it is still treated as a real number by the computer because it is written with a decimal point.

## Integer Division

Be careful when dividing an integer by another integer. In many programming languages, when an integer is divided by an integer the result will also be an integer. This behavior is known as *integer division*. For example, look at the following pseudocode:

```
Set number = 3 / 2
```

This statement divides 3 by 2 and stores the result in the `number` variable. What will be stored in `number`? You would probably assume that 1.5 would be stored in `number` because that's the result your calculator shows when you divide 3 by 2. However, that's not what will happen in many programming languages. Because the numbers 3 and 2 are both treated as integers, the programming language that you are using might throw away the fractional part of the answer. (Throwing away the fractional part of a number is called *truncation*.) As a result, the statement will store 1 in the `number` variable, not 1.5.

If you are using a language that behaves this way and you want to make sure that a division operation yields a real number, at least one of the operands must be a real number or a `Real` variable.



**NOTE:** In Java, C++, and C, the `/` operator throws away the fractional part of the result when both operands are integers. In these languages the result of the expression `3/2` would be 1. In Visual Basic, the `/` operator does not throw away the fractional part of the answer. In Visual Basic, the result of the expression `3/2` would be 1.5.



## Checkpoint

- 2.25 What two items do you usually specify with a variable declaration?
- 2.26 Does it matter where you write the variable declarations in a program?
- 2.27 What is variable initialization?
- 2.28 Do uninitialized variables pose any danger in a program?
- 2.29 What is an uninitialized variable?

2.5

## Named Constants

**CONCEPT:** A **named constant** is a name that represents a value that cannot be changed during the program's execution.

Assume that the following statement appears in a banking program that calculates data pertaining to loans:

```
Set amount = balance * 0.069
```

In such a program, two potential problems arise. First, it is not clear to anyone other than the original programmer what 0.069 is. It appears to be an interest rate, but in some situations there are fees associated with loan payments. How can the purpose of this statement be determined without painstakingly checking the rest of the program?

The second problem occurs if this number is used in other calculations throughout the program and must be changed periodically. Assuming the number is an interest rate, what if the rate changes from 6.9 percent to 7.2 percent? The programmer would have to search through the source code for every occurrence of the number. (It is not advisable to use an editor's global search and replace feature to change values in a program. You might change an unintended value in the program, and inadvertently cause a logic error.)

Both of these problems can be addressed by using named constants. A *named constant* is a name that represents a value that cannot be changed during the program's execution. The following is an example of how we will declare named constants in our pseudocode:

```
Constant Real INTEREST_RATE = 0.069
```

This creates a constant named `INTEREST_RATE`. The constant's value is the `Real` number 0.069. Notice that the declaration looks a lot like a variable declaration, except that we use the word `Constant` instead of `Declare`. Also, notice that the name of the constant is written in all uppercase letters. This is a standard practice in most programming languages because it makes named constants easily distinguishable from regular variable names. An initialization value must be given when declaring a named constant.

An advantage of using named constants is that they make programs more self-explanatory. The following statement:

```
Set amount = balance * 0.069
```

can be changed to read

```
Set amount = balance * INTEREST_RATE
```

A new programmer can read the second statement and know what is happening. It is evident that `balance` is being multiplied by the interest rate. Another advantage to this approach is that widespread changes can easily be made to the program. Let's say the interest rate appears in a dozen different statements throughout the program. When the rate changes, the initialization value in the declaration of the named constant is the only value that needs to be modified. If the rate increases to 7.2 percent, the declaration can be changed to the following:

```
Constant Real INTEREST_RATE = 0.072
```

The new value of 0.072 will then be used in each statement that uses the `INTEREST_RATE` constant.



**NOTE:** A named constant cannot be assigned a value with a `Set` statement. If a statement in a program attempts to change the value of a named constant, an error will occur.

## 2.6

## Hand Tracing a Program

**CONCEPT:** Hand tracing is a simple debugging process for locating hard-to-find errors in a program.

*Hand tracing* is a debugging process where you imagine that you are the computer executing a program. (This process is also known as *desk checking*.) You step through each of the program's statements one by one. As you carefully look at a statement, you record the contents that each variable will have after the statement executes. This process is often helpful in finding mathematical mistakes and other logic errors.

To hand trace a program, you construct a chart that has a column for each variable, and a row for each line in the program. For example, Figure 2-17 shows how we would construct a hand trace chart for the program that you saw in the previous section. The chart has a column for each of the four variables: `test1`, `test2`, `test3`, and `average`. The chart also has nine rows, one for each line in the program.

**Figure 2-17** A program with a hand trace chart

```

1 Declare Real test1
2 Declare Real test2
3 Declare Real test3
4 Declare Real average
5
6 Set test1 = 88.0
7 Set test2 = 92.5
8 Set average = (test1 + test2 + test3) / 3
9 Display "Your average test score is ", average

```

|   | test1 | test2 | test3 | average |
|---|-------|-------|-------|---------|
| 1 |       |       |       |         |
| 2 |       |       |       |         |
| 3 |       |       |       |         |
| 4 |       |       |       |         |
| 5 |       |       |       |         |
| 6 |       |       |       |         |
| 7 |       |       |       |         |
| 8 |       |       |       |         |
| 9 |       |       |       |         |

To hand trace this program, you step through each statement, observing the operation that is taking place, and then record the value that each variable will hold *after* the statement executes. When the process is complete, the chart will appear as shown in Figure 2-18. We have written question marks in the chart to indicate that a variable is uninitialized.

**Figure 2-18** Program with the hand trace chart completed

```

1 Declare Real test1
2 Declare Real test2
3 Declare Real test3
4 Declare Real average
5
6 Set test1 = 88.0
7 Set test2 = 92.5
8 Set average = (test1 + test2 + test3) / 3
9 Display "Your average test score is ", average

```

|   | test1 | test2 | test3 | average   |
|---|-------|-------|-------|-----------|
| 1 | ?     | ?     | ?     | ?         |
| 2 | ?     | ?     | ?     | ?         |
| 3 | ?     | ?     | ?     | ?         |
| 4 | ?     | ?     | ?     | ?         |
| 5 | ?     | ?     | ?     | ?         |
| 6 | 88    | ?     | ?     | ?         |
| 7 | 88    | 92.5  | ?     | ?         |
| 8 | 88    | 92.5  | ?     | undefined |
| 9 | 88    | 92.5  | ?     | undefined |

When we get to line 8 we will carefully do the math. This means we look at the values of each variable in the expression. At that point we discover that one of the variables, `test3`,

is uninitialized. Because it is uninitialized, we have no way of knowing the value that it contains. Consequently, the result of the calculation will be undefined. After making this discovery, we can correct the problem by adding a line that assigns a value to `test3`.

Hand tracing is a simple process that focuses your attention on each statement in a program. Often this helps you locate errors that are not obvious.

## 2.7

# Documenting a Program

**CONCEPT:** A program's external documentation describes aspects of the program for the user. The internal documentation is for the programmer, and explains how parts of the program work.

A program's documentation explains various things about the program. There are usually two types of program documentation: external and internal. *External documentation* is typically designed for the user. It consists of documents such as a reference guide that describes the program's features, and tutorials that teach the user how to operate the program.

Sometimes the programmer is responsible for writing all or part of a program's external documentation. This might be the case in a small organization, or in a company that has a relatively small programming staff. Some organizations, particularly large companies, will employ a staff of technical writers whose job is to produce external documentation. These documents might be in printed manuals, or in files that can be viewed on the computer. In recent years it has become common for software companies to provide all of a program's external documentation in PDF (Portable Document Format) files.

*Internal documentation* appears as *comments* in a program's code. Comments are short notes placed in different parts of a program, explaining how those parts of the program work. Although comments are a critical part of a program, they are ignored by the compiler or interpreter. Comments are intended for human readers of a program's code, not the computer.

Programming languages provide special symbols or words for writing comments. In several languages, including Java, C, and C++, you begin a comment with two forward slashes (`//`). Everything that you write on the same line, after the slashes, is ignored by the compiler. Here is an example of a comment in any of those languages:

```
// Get the number of hours worked.
```

Some languages use symbols other than the two forward slashes to indicate the beginning of a comment. For example, Visual Basic uses an apostrophe ('), and Python uses the # symbol. In this book, we will use two forward slashes (`//`) in pseudocode.

## Block Comments and Line Comments

Programmers generally write two types of comments in a program: block comments and line comments. *Block comments* take up several lines and are used when lengthy explanations are required. For example, a block comment often appears at the beginning of a program, explaining what the program does, listing the name of the author, giving

the date that the program was last modified, and any other necessary information. The following is an example of a block comment:

```
// This program calculates an employee's gross pay.
// Written by Kiran Sharma.
// Last modified on 12/14/2021
```



**NOTE:** Some programming languages provide special symbols to mark the beginning and ending of a block comment.

*Line comments* are comments that occupy a single line, and explain a short section of the program. The following statements show an example:

```
// Calculate the interest.
Set interest = balance * interest_Rate
// Add the interest to the balance.
Set balance = balance + interest
```

A line comment does not have to occupy an entire line. Anything appearing after the // symbol, to the end of the line, is ignored, so a comment can appear after an executable statement. Here is an example:

```
Input age // Get the user's age.
```

As a beginning programmer, you might be resistant to the idea of liberally writing comments in your programs. After all, it's a lot more fun to write code that actually does something! It is crucial that you take the extra time to write comments, however. They will almost certainly save you time in the future when you have to modify or debug the program. Even large and complex programs can be made easy to read and understand if they are properly commented.

## In the Spotlight: Using Named Constants, Style Conventions, and Comments



Suppose we have been given the following programming problem: Scientists have determined that the world's ocean levels are currently rising at about 1.5 millimeters per year. Write a program to display the following:

- The number of millimeters that the oceans will rise in five years
- The number of millimeters that the oceans will rise in seven years
- The number of millimeters that the oceans will rise in ten years

Here is the algorithm:

1. Calculate the amount that the oceans will rise in five years.
2. Display the result of the calculation in Step 1.
3. Calculate the amount that the oceans will rise in seven years.
4. Display the result of the calculation in Step 3.
5. Calculate the amount that the oceans will rise in ten years.
6. Display the result of the calculation in Step 5.

This program is straightforward. It performs three calculations and displays the results of each. The calculations should give the amount the oceans will rise in five, seven, and ten years. Each of these values can be calculated with the following formula:

$$\text{Amount of yearly rise} \times \text{Number of years}$$

The amount of yearly rise is the same for each calculation, so we will create a constant to represent that value. Program 2-14 shows the pseudocode for the program.

### Program 2-14

```
1 // Declare the variables
2 Declare Real fiveYears
3 Declare Real sevenYears
4 Declare Real tenYears
5
6 // Create a constant for the yearly rise
7 Constant Real YEARLY_RISE = 1.5
8
9 // Display the amount of rise in five years
10 Set fiveYears = YEARLY_RISE * 5
11 Display "The ocean levels will rise ", fiveYears,
12 " millimeters in five years."
13
14 // Display the amount of rise in seven years
15 Set sevenYears = YEARLY_RISE * 7
16 Display "The ocean levels will rise ", sevenYears,
17 " millimeters in seven years."
18
19 // Display the amount of rise in ten years
20 Set tenYears = YEARLY_RISE * 10
21 Display "The ocean levels will rise ", tenYears,
22 " millimeters in ten years."
```

### Program Output

```
The ocean levels will rise 7.5 millimeters in five years.
The ocean levels will rise 10.5 millimeters in seven years.
The ocean levels will rise 15 millimeters in ten years.
```

Three variables, `fiveYears`, `sevenYears`, and `tenYears`, are declared in lines 2 through 4. These variables will hold the amount that the ocean levels will rise in five, seven, and ten years.

Line 7 creates a constant, `YEARLY_RISE`, which is set to the value 1.5. This is the amount that the oceans rise per year. This constant will be used in each of the program's calculations.

Lines 10 through 12 calculate and display the amount that the oceans will rise in five years. The same values for seven years and ten years are calculated and displayed in lines 15 through 17 and 20 through 22.

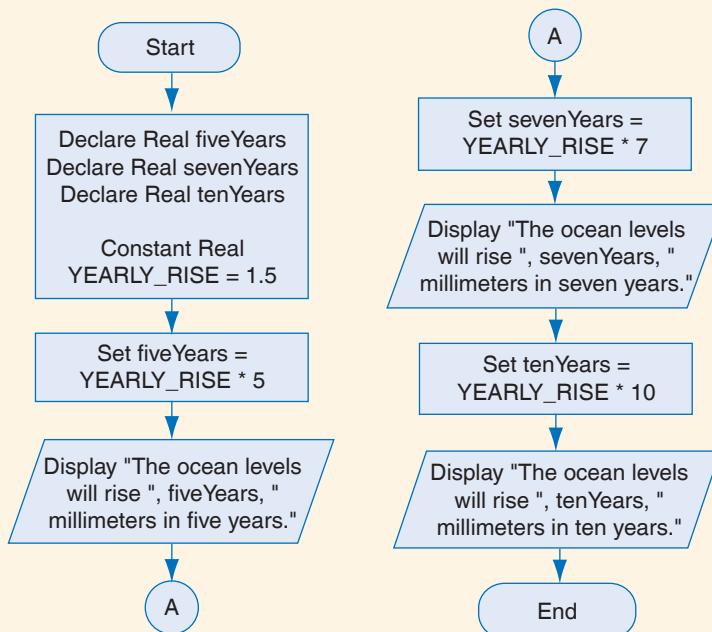
This program illustrates the following programming style conventions:

- Several blank lines appear throughout the program (see lines 5, 8, 13, and 18). These blank lines do not affect the way the program works, but make the pseudocode easier to read.

- Line comments are used in various places to explain what the program is doing.
- Notice that each of the Display statements is too long to fit on one line. (See lines 11 and 12, 16 and 17, 21 and 22.) Most programming languages allow you to write long statements across several lines. When we do this in pseudocode, we will indent the second and subsequent lines. This will give a visual indication that the statement spans more than one line.

Figure 2-19 shows a flowchart for the program.

**Figure 2-19** Flowchart for Program 2-14



### Checkpoint

- 2.30 What is external documentation?
- 2.31 What is internal documentation?
- 2.32 What are the two general types of comments that programmers write in a program's code? Describe each.

## 2.8

### Designing Your First Program

Sometimes, as a beginning student, you might have trouble getting started with a programming problem. In this section we will present a simple problem, go through the process of analyzing the program's requirements, and design the algorithm in pseudocode and a flowchart. Here is the programming problem:

## Batting Average

In baseball, batting average is commonly used to measure a player's batting ability. You use the following formula to calculate a player's batting average:

$$\text{Batting Average} = \text{Hits} \div \text{Times at Bat}$$

In the formula, *Hits* is the number of successful hits made by the player, and *Times at Bat* is the number of times the player was at bat. For example, if a player is at bat 500 times during a season, and gets 150 hits, that player's batting average is .300. Design a program to calculate any player's batting average.

Recall from Section 2.2 that a program's actions can typically be divided into the following three phases:

1. Input is received.
2. Some process (such as a calculation) is performed on the input.
3. Output is produced.

Your first step is to determine what is required in each phase. Usually these requirements are not stated directly in the problem description. For example, the previously shown batting average problem explains what a batting average is, and merely instructs you to design a program to calculate any player's batting average. It is up to you to brainstorm the problem and determine the requirements of each phase. Let's take a closer look at each phase of the batting average problem.

### 1. Input is received.

To determine a program's input requirements, you must determine the pieces of data that are required for the program to complete its task. If we look at the batting average formula, we see that two values are needed to perform the calculation:

- The number of hits
- The number of times at bat

Because these values are unknown, the program will have to prompt the user to enter them.

Each piece of input will be stored in a variable. You will have to declare those variables when you design the program, so it is helpful in this phase to think about each variable's name and data type. In the batting average program we will use the name `hits` for the variable that stores the number of hits, and the name `atBat` for the variable that holds the number of times at bat. Both of these values will be whole numbers, so these variables will be declared as `Integers`.

### 2. Some process (such as a calculation) is performed on the input.

Once the program has gathered the required input, it can proceed to use that input in any necessary calculations, or other operations. The batting average program will divide the number of hits by the number of times at bat. The result of the calculation is the player's batting average.

Keep in mind that when a mathematical calculation is performed, you typically want to store the result of that calculation in a variable. So, you should think about the names and data types of any variables that are needed in this phase. In this example, we will use the name `battingAverage` for the variable that stores the player's batting average. Because this variable will store the result of a division, we will declare it as a `Real`.

### 3. Output is produced.

A program's output will typically be the result of the process or processes that it has performed. The output of the batting average program will be the result of the calculation, which is stored in a variable named `battingAverage`. The program will display this number in a message that explains what it is.

Now that we have identified the input, processing, and output requirements, we can create the pseudocode and/or flowcharts. First, we will write the pseudocode variable declarations:

```
Declare Integer hits
Declare Integer atBat
Declare Real battingAverage
```

Next we will write the pseudocode for gathering input. Recall that a program typically does two things when it needs the user to enter a piece of input on the keyboard: (1) it displays a message prompting the user for the piece of data, and (2) it reads the user's input and stores that data in a variable. Here is the pseudocode for reading the two pieces of input required by the batting average program:

```
Display "Enter the player's number of hits."
Input hits

Display "Enter the player's number of times at bat."
Input atBat
```

Next we will write the pseudocode for calculating the batting average:

```
Set battingAverage = hits / atBat
```

And finally, we write the pseudocode for displaying the output:

```
Display "The player's batting average is ", battingAverage
```

Now we can put all of these pieces together to form a complete program. Program 2-15 shows the pseudocode program with comments, and Figure 2-20 shows the flowchart.

#### Program 2-15

```
1 // Declare the necessary variables.
2 Declare Integer hits
3 Declare Integer atBat
4 Declare Real battingAverage
5
6 // Get the number of hits.
7 Display "Enter the player's number of hits."
8 Input hits
9
10 // Get the number of times at bat.
11 Display "Enter the player's number of times at bat."
12 Input atBat
13
14 // Calculate the batting average.
15 Set battingAverage = hits / atBat
16
17 // Display the batting average.
18 Display "The player's batting average is ", battingAverage
```

### Program Output (with Input Shown in Bold)

```
Enter the player's number of hits.

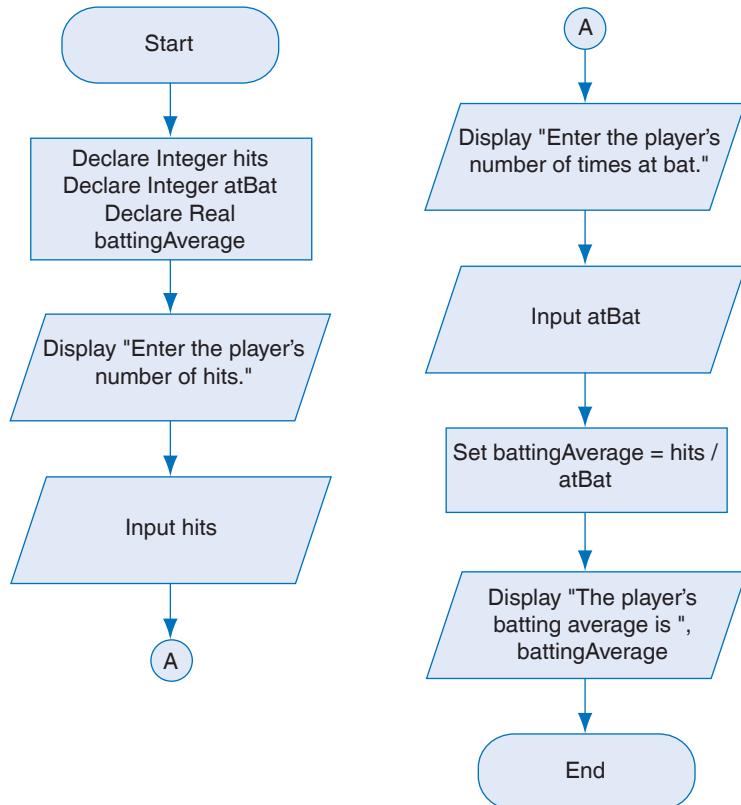
150 [Enter]

Enter the player's number of times at bat.

500 [Enter]

The player's batting average is 0.3
```

**Figure 2-20** Flowchart for Program 2-15



## Summary

As a beginning student, whenever you have trouble getting started with a program design, determine the program's requirements as follows:

1. **Input:** Carefully study the problem and identify the pieces of data that the program needs to read as input. Once you know what data is needed as input, decide the names of the variables for those pieces of data, and their data types.
2. **Process:** What must the program do with the input that it will read? Determine the calculations and/or other processes that must be performed. At this time, decide the names and data types of any variables needed to hold the results of calculations.
3. **Output:** What output must the program produce? In most cases, it will be the results of the program's calculations and/or other processes.

Once you have determined these requirements, you will have an understanding of what the program must do. You will also have a list of variables and their data types. The next step is writing the algorithm in pseudocode, or drawing it as a flowchart.

**2.9**

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

#### Input, Processing, and Output in Java

##### Setting Up a Java Program

When you start a new Java program, you must first write a *class declaration* to contain your Java code. For now, simply think of a class declaration as a container for Java code. Here is an example

```
public class Simple
{
}
```

The first line of the class declaration is called the *class header*. In this example, the class header reads:

```
public class Simple
```

The words `public` and `class` are key words in the Java language, and the word `Simple` is the name of the class. Notice that the words `public` and `class` are written in all lowercase letters. In Java, all key words are written in lowercase letters. If you mistakenly write an uppercase letter in a key word, an error will occur when you compile the program.

The class name, which in this case is `Simple`, does not have to be written in all lowercase letters because it is not a key word in the Java language. This is just a word that the programmer uses as the name of the class. Notice that the first character of the class name is written in uppercase. It is not required, but it is a standard practice in Java to write the first character of a class name in uppercase. Java programmers do this so class names are more easily distinguishable from the names of other items in a program.

Another important thing to remember about the class name is that it must be the same as the name of the file that the class is stored in. For example, if you create a class named `Simple` (as shown previously), that class declaration will be stored in a file named `Simple.java`. (All Java source code files must be named with the `.java` extension.)

Notice that a set of curly braces follows the class header. Curly braces are meant to enclose things, and these curly braces will enclose all the code that will be written inside the class. So, the next step is to write some code inside the curly braces.

Inside the class's curly braces you must write the definition of a method named `main`. A *method* is another type of container that holds code. When a Java program executes, it

automatically begins running the code that is inside the `main` method. Here is how our `Simple` class will appear after we have added the `main` method declaration:

```
public class Simple
{
 public static void main(String[] args)
 {

 }
}
```

The first line of the method definition, which is called the *method header*, begins with the words `public static void main` and so forth. At this point, don't be concerned about the meaning of any of these words. Just remember that you have to write the method header *exactly* as it is shown. Notice that a set of curly braces follow the method header. All of the code that you will write inside the method must be written inside these curly braces.

### Displaying Screen Output in Java

To display text on the screen in Java, you use the following statements:

- `System.out.println()`
- `System.out.print()`

First, let's look at the `System.out.println()` statement. The purpose of this statement is to display a line of output. Notice that the statement ends with a set of parentheses. The text that you want to display is written as a string inside the parentheses. Program 2-16 shows an example. (Remember, the line numbers are NOT part of the program! Don't type the line numbers when you are entering program code. The line numbers are shown for reference purposes only.)

#### Program 2-16 (Output.java)

```
1 public class Output
2 {
3 public static void main(String[] args)
4 {
5 System.out.println("My major is Computer Science.");
6 System.out.println("I plan to be a software developer.");
7 System.out.println("Programming is fun!");
8 }
9 }
```

#### Program Output

```
My major is Computer Science.
I plan to be a software developer.
Programming is fun!
```

The statements that appear in lines 5 through 7 end with a semicolon. Just as a period marks the end of a sentence in English, a semicolon marks the end of a statement in Java. You'll notice that some lines of code in the program do not end with a semicolon, however.

For example, class headers and method headers do not end with a semicolon because they are not considered statements. Also, the curly braces are not followed by a semicolon because they are not considered statements. (If this is confusing, don't despair! As you practice writing Java programs more and more, you will develop an intuitive understanding of the difference between statements and lines of code that are not considered statements.)

Notice that the output of the `System.out.println()` statements appears on separate lines. When the `System.out.println()` statement displays output, it advances the output cursor (the location where the next item of output will appear) to the next line. That means the `System.out.println()` statement displays its output, and then the next thing that is displayed will appear on the following line.

The `System.out.print()` statement displays output, but it does not advance the output cursor to the next line. Program 2-17 shows an example.

### Program 2-17 (Output2.java)

```
1 public class Output2
2 {
3 public static void main(String[] args)
4 {
5 System.out.print("Programming");
6 System.out.print("is");
7 System.out.print("fun.");
8 }
9 }
```

### Program Output

Programmingisfun.

Notice in the program output that all the words are jammed together into one long series of characters. If you want spaces to appear between the words, you have to explicitly display them. Program 2-18 shows how we have to insert spaces into the strings that we are displaying, if we want the words to be separated on the screen. Notice that in line 5, we have inserted a space in the string, after the letter `g`, and in line 6, we have inserted a space in the string after the letter `s`.

### Program 2-18 (Output3.java)

```
1 public class Output3
2 {
3 public static void main(String[] args)
4 {
5 System.out.print("Programming ");
6 System.out.print("is ");
7 System.out.print("fun.");
8 }
9 }
```

### Program Output

Programming is fun.

### Variables in Java

In Java, variables must be declared before they can be used in a program. A variable declaration statement is written in the following general format:

```
DataType VariableName;
```

In the general format, *DataType* is the name of a Java data type, and *VariableName* is the name of the variable that you are declaring. The declaration statement ends with a semicolon. For example, the key word `int` is the name of the integer data type in Java, so the following statement declares a variable named `number`.

```
int number;
```

Table 2-6 lists the Java data types, gives their memory size in bytes, and describes the type of data that each can hold. Note that in this book, we will primarily use the `int`, `double`, and `String` data types.<sup>2</sup>

**Table 2-6** Java Data Types

| Data Type           | What It Can Hold                                                                                                            |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------|
| <code>byte</code>   | Integers in the range of $-128$ to $+127$                                                                                   |
| <code>short</code>  | Integers in the range of $-32,768$ to $+32,767$                                                                             |
| <code>int</code>    | Integers in the range of $-2,147,483,648$ to $+2,147,483,647$                                                               |
| <code>long</code>   | Integers in the range of $-9,223,372,036,854,775,808$ to $+9,223,372,036,854,775,807$                                       |
| <code>float</code>  | Floating-point numbers in the range of $\pm 3.4 \times 10^{-38}$ to $\pm 3.4 \times 10^{38}$ , with 7 digits of accuracy    |
| <code>double</code> | Floating-point numbers in the range of $\pm 1.7 \times 10^{-308}$ to $\pm 1.7 \times 10^{308}$ , with 15 digits of accuracy |
| <code>String</code> | Strings of text                                                                                                             |

Here are some other examples of Java variable declarations:

```
int speed;
double distance;
String name;
```

Several variables of the same data type can be declared with the same declaration statement. For example, the following statement declares three `int` variables named `width`, `height`, and `length`.

```
int width, height, length;
```

You can also initialize variables with starting values when you declare them. The following statement declares an `int` variable named `hours`, initialized with the starting value 40:

```
int hours = 40;
```

---

<sup>2</sup> Notice that `String` is written with an initial uppercase letter. To be correct, `String` is not a data type in Java, it is a class. We use it as a data type, though.

### Variable Names in Java

You may choose your own variable names (and class names) in Java, as long as you do not use any of the Java key words. The key words make up the core of the language and each has a specific purpose. See Table 2-2 in the *Java Language Companion* for a complete list of Java key words.

The following are some specific rules that must be followed when naming variables in Java:

- The first character must be one of the letters a–z, A–Z, an underscore (\_), or a dollar sign (\$).
- After the first character, you may use the letters a–z or A–Z, the digits 0–9, underscores (\_), or dollar signs (\$).
- Uppercase and lowercase characters are distinct. This means `itemsOrdered` is not the same as `itemsordered`.
- Variable names cannot include spaces.

Program 2-19 shows an example with three variable declarations. Line 5 declares a `String` variable named `name`, initialized with the string “Alex Prieto.” Line 6 declares an `int` variable named `hours` initialized with the value 40. Line 7 declares a `double` variable named `pay`, initialized with the value 852.99. Notice that in lines 9 through 11, we use `System.out.println` to display the contents of each variable.

### Program 2-19 (VariableDemo.java)

```
1 public class VariableDemo
2 {
3 public static void main(String[] args)
4 {
5 String name = "Alex Prieto";
6 int hours = 40;
7 double pay = 852.99;
8
9 System.out.println(name);
10 System.out.println(hours);
11 System.out.println(pay);
12 }
13 }
```

### Program Output

```
Alex Prieto
40
852.99
```

### Reading Keyboard Input in Java

To read keyboard input in Java, you have to create a type of object in memory known as a `Scanner` object. You can then use the `Scanner` object to read values from the keyboard, and assign those values to variables. Program 2-20 shows an example of how

this is done. (This is the Java version of pseudocode Program 2-2 shown earlier in this chapter.) Let's take a closer look at the code:

- Line 1 has the following statement: `import java.util.Scanner;` This statement is necessary to tell the Java compiler that we are going to create a `Scanner` object in the program.
- Line 7 creates a `Scanner` object and gives it the name `keyboard`.
- Line 8 declares an `int` variable named `age`.
- Line 10 displays the string "What is your age?"
- Line 11 reads an integer value from the keyboard and assigns that value to the `age` variable.
- Line 12 displays the string "Here is the value that you entered:"
- Line 13 displays the value of the `age` variable.

### Program 2-20 (GetAge.java)

```
1 import java.util.Scanner;
2
3 public class GetAge
4 {
5 public static void main(String[] args)
6 {
7 Scanner keyboard = new Scanner(System.in);
8 int age;
9
10 System.out.println("What is your age?");
11 age = keyboard.nextInt();
12 System.out.println("Here is the value that you entered:");
13 System.out.println(age);
14 }
15 }
```

### Program Output (with Input Shown in Bold)

```
What is your age?
24 [Enter]
Here is the value that you entered:
24
```

Notice that in line 11, we used the expression `keyboard.nextInt()` to read an integer from the keyboard. If we wanted to read a `double` from the keyboard, we would use the expression `keyboard.nextDouble()`. Moreover, if we want to read a string from the keyboard, we would use the expression `keyboard.nextLine()`.

Program 2-21 shows how a `Scanner` object can be used to read not only integers, but also `doubles` and strings:

- Line 7 creates a `Scanner` object and gives it the name `keyboard`.
- Line 8 declares a `String` variable named `name`, line 9 declares a `double` variable named `payRate`, and line 10 declares an `int` variable named `hours`.
- Line 13 uses the expression `keyboard.nextLine()` to read a string from the keyboard, and assigns the string to the `name` variable.

- Line 16 uses the expression `keyboard.nextDouble()` to read a double from the keyboard, and assigns it to the `payRate` variable.
- Line 19 uses the expression `keyboard.nextInt()` to read an integer from the keyboard, and assigns it to the `hours` variable.

### Program 2-21 (GetInput.java)

```

1 import java.util.Scanner;
2
3 public class GetInput
4 {
5 public static void main(String[] args)
6 {
7 Scanner keyboard = new Scanner(System.in);
8 String name;
9 double payRate;
10 int hours;
11
12 System.out.print("Enter your name: ");
13 name = keyboard.nextLine();
14
15 System.out.print("Enter your hourly pay rate: ");
16 payRate = keyboard.nextDouble();
17
18 System.out.print("Enter the number of hours worked: ");
19 hours = keyboard.nextInt();
20
21 System.out.println("Here are the values that you entered:");
22 System.out.println(name);
23 System.out.println(payRate);
24 System.out.println(hours);
25 }
26 }
```

### Program Output (with Input Shown in Bold)

```

Enter your name: Rosa Lopez [Enter]
Enter your hourly pay rate: 55.25 [Enter]
Enter the number of hours worked: 40 [Enter]
Here are the values that you entered:
Rosa Lopez
55.25
40
```

### Displaying Multiple Items with the + Operator in Java

When the `+` operator is used with strings, it is known as the *string concatenation operator*. To concatenate means to append, so the string concatenation operator appends one string to another. For example, look at the following statement:

```
System.out.println("This is " + "one string.");
```

This statement will display:

This is one string.

The + operator produces a string that is the combination of the two strings used as its operands. You can also use the + operator to concatenate the contents of a variable to a string. The following code shows an example:

```
number = 5;
System.out.println("The value is " + number);
```

The second line uses the + operator to concatenate the contents of the number variable with the string "The value is ". Although number is not a string, the + operator converts its value to a string and then concatenates that value with the first string. The output that will be displayed is:

```
The value is 5
```

### Performing Calculations in Java

The Java arithmetic operators are nearly the same as those presented in Table 2-1 earlier in this chapter:

---

|   |                |
|---|----------------|
| + | Addition       |
| - | Subtraction    |
| * | Multiplication |
| / | Division       |
| % | Modulus        |

---

Here are some examples of Java statements that use an arithmetic operator to calculate a value, and assign that value to a variable:

```
total = price + tax;
sale = price - discount;
population = population * 2;
half = number / 2;
leftOver = 17 % 3;
```

Java does not have an exponent operator, but it does provide a method named `Math.pow` for this purpose. Here is an example of how the `Math.pow` method is used:

```
result = Math.pow(4.0, 2.0);
```

The method takes two `double` arguments (the numbers shown inside the parentheses). It raises the first argument to the power of the second argument, and returns the result as a `double`. In this example, 4.0 is raised to the power of 2.0. This statement is equivalent to the following algebraic statement:

```
result = 42
```

### Named Constants in Java

You create named constants in Java using the `final` key word in a variable declaration. The word `final` is written just before the data type. Here is an example:

```
final double INTEREST_RATE = 0.069;
```

This statement looks just like a regular variable declaration except that the word `final` appears before the data type, and the variable name is written in all uppercase letters.

It is not required that the variable name appear in all uppercase letters, but many programmers prefer to write them this way so they are easily distinguishable from regular variable names.

### Documenting a Java Program with Comments

To write a line comment in Java, you simply place two forward slashes (//) where you want the comment to begin. The compiler ignores everything from that point to the end of the line. Here is an example:

```
// This program calculates an employee's gross pay.
```

Multiline comments, or block comments, start with /\* (a forward slash followed by an asterisk) and end with \*/ (an asterisk followed by a forward slash). Everything between these markers is ignored. Here is an example:

```
/*
 This program calculates an employee's gross pay
 including any overtime wages the employee has worked.
*/
```

## Python

### Input, Processing, and Output in Python

#### Displaying Screen Output in Python

To display output on the computer's screen in Python, you use the `print` function. Here is an example of a statement that uses the `print` function to display the message *Hello world*.

```
print('Hello world')
```

To use the `print` function, you type the word `print`, followed by a set of parentheses. Inside the parentheses, you type an *argument*, which is the data that you want displayed on the screen. In this example, the argument is '*Hello world*'. The quote marks will not be displayed when the statement executes, however. The quote marks simply specify the beginning and the end of the text that we wish to display. Program 2-22 shows an example of a complete program that displays output on the screen. (Remember, the line numbers are NOT part of the program! Don't type the line numbers when you are entering program code. The line numbers are shown for reference purposes only.)

#### Program 2-22 (output.py)

```
1 print('My major is Computer Science.')
2 print('I plan to be a software developer.')
3 print('Programming is fun!')
```

#### Program Output

```
My major is Computer Science.
I plan to be a software developer.
Programming is fun!
```

In Python, you can enclose string literals in a set of single-quote marks (' ) or a set of double-quote marks (" ). The string literals in Program 2-22 are enclosed in single-quote marks, but the program could also be written as shown here:

```
print("My major is Computer Science.")
print("I plan to be a software developer.")
print("Programming is fun!")
```

### Python Variables

You do not declare variables in Python. Instead, you use an *assignment statement* to create a variable. Here is an example of an assignment statement:

```
age = 25
```

After this statement executes, a variable named `age` will be created and it will be assigned the integer value 25. Here is another example:

```
title = 'Vice President'
```

After this statement executes, a variable named `title` will be created and it will be assigned the string 'Vice President'.

### Variable Names in Python

You may choose your own variable names in Python, as long as you do not use any of the Python key words. (See Table 2-1 in the *Python Language Companion* for a complete list of Python key words.) Additionally, you must follow these rules when naming variables in Python:

- A variable name cannot contain spaces.
- The first character must be one of the letters a through z, A through Z, or an underscore character (\_).
- After the first character you may use the letters a through z or A through Z, the digits 0 through 9, or underscores.
- Uppercase and lowercase characters are distinct. This means the variable name `ItemsOrdered` is not the same as `itemsordered`.

### Displaying Multiple Items with the print Function in Python

You can pass multiple arguments to the `print` function, and Python will print each argument's value on the screen, separated by a space. Program 2-23 shows an example.

#### Program 2-23 (print\_multiple.py)

```
1 room = 503
2 print('I am staying in room number', room)
```

#### Program Output

```
I am staying in room number 503
```

The statement in line 1 creates a variable named `room`, and assigns it the integer value 503. The statement in line 2 displays two items: a string literal followed by the value of the `room` variable. Notice that Python automatically displayed a space between these two items.

### Reading Input from the Keyboard in Python

You can use Python's built-in `input` function to read input from the keyboard. The `input` function reads a piece of data that has been entered at the keyboard and returns that piece of data, as a string, back to the program. You normally use the `input` function in an assignment statement that follows this general format:

```
variable = input(prompt)
```

In the general format, `prompt` is a string that is displayed on the screen. The string's purpose is to instruct the user to enter a value. `variable` is the name of a variable that will reference the data that was entered on the keyboard. Here is an example of a statement that uses the `input` function to read data from the keyboard:

```
name = input('What is your name? ')
```

When this statement executes, the following things happen:

- The string 'What is your name? ' is displayed on the screen.
- The program pauses and waits for the user to type something on the keyboard, and then press the Enter key.
- When the Enter key is pressed, the data that was typed is returned as a string, and assigned to the `name` variable.

Program 2-24 shows a complete program that uses the `input` function to read two strings as input from the keyboard.

#### Program 2-24 (string\_input.py)

```
1 first_name = input('Enter your first name: ')
2 last_name = input('Enter your last name: ')
3 print('Hello', first_name, last_name)
```

#### Program Output (with Input Shown in Bold)

```
Enter your first name: Vinny [Enter]
Enter your last name: Brown [Enter]
Hello Vinny Brown
```

### Reading Numbers with the `input` Function in Python

The `input` function always returns the user's input as a string, even if the user enters numeric data. For example, suppose you call the `input` function and the user types the number 72 and pressed the Enter key. The value that is returned from the `input` function is the string '72'. This can be a problem if you want to use the value in a math operation. Math operations can be performed only on numeric values, not strings.

Fortunately, Python has built-in functions that you can use to convert a string to a numeric type. Table 2-7 summarizes two of these functions.

**Table 2-7** Python Data Conversion Functions

| Function                 | Description                                                                                                                         |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <code>int(item)</code>   | You pass an argument to the <code>int()</code> function and it returns the argument's value converted to an integer.                |
| <code>float(item)</code> | You pass an argument to the <code>float()</code> function and it returns the argument's value converted to a floating-point number. |

For example, the following code gets an integer and a floating-point number from the user:

```
hours = int(input('How many hours did you work? '))
pay_rate = float(input('What is your hourly pay rate? '))
```

### Performing Calculations in Python

The Python arithmetic operators are nearly the same as those presented in Table 2-1 earlier in this chapter:

|    |                |
|----|----------------|
| +  | Addition       |
| -  | Subtraction    |
| *  | Multiplication |
| /  | Division       |
| %  | Modulus        |
| ** | Exponent       |

Here are some examples of Python statements that use an arithmetic operator to calculate a value, and assign that value to a variable:

```
total = price + tax
sale = price - discount
population = population * 2
half = number / 2
leftOver = 17 % 3
result = 4**2
```

Program 2-25 shows an example program that performs mathematical calculations (This program is the Python version of pseudocode Program 2-8 in your textbook.)

### Program 2-25 (sale\_price.py)

```
1 original_price = float(input("Enter the item's original price: "))
2 discount = original_price * 0.2
3 sale_price = original_price - discount
4 print('The sale price is', sale_price)
```

### Program Output (With Input Shown in Bold)

```
Enter the item's original price: 100.00 [Enter]
The sale price is 80.0
```

In Python, the order of operations and the use of parentheses as grouping symbols work just as described earlier in this chapter.

### Comments in Python

To write a line comment in Python, you simply place the # symbol where you want the comment to begin. The Python interpreter ignores everything from that point to the end of the line. Here is an example:

```
This program calculates an employee's gross pay.
```

## C++

### Input, Processing, and Output in C++

#### The Parts of a C++ Program

The typical C++ program contains the following code:

```
#include <iostream>
using namespace std;

int main()
{
 return 0;
}
```

You can think of this as a skeleton program. As it is, it does absolutely nothing. However, you can add additional code to this program to make it perform an operation. When you write your first C++ programs, you will write other statements inside the curly braces, as indicated in Figure 2-21.

**Figure 2-21** The Skeleton C++ Program

```
#include <iostream>
using namespace std;

int main()
{
 return 0;
}
```

A diagram showing the structure of a C++ program. It consists of three lines of code: an include directive, a using directive, and the definition of the main function. The main function is enclosed in curly braces {}, with a red arrow pointing to the opening brace. To the right of the arrow, the text "You will write other C++ statements in this area." is displayed.

### Semicolons in C++

In C++, a complete programming statement ends with a semicolon. Just as a period marks the end of a sentence in English, a semicolon marks the end of a statement in C++. You'll notice that some lines of code in our example programs do not end with a semicolon, however. That's because not every line of code is a statement. If this is confusing, don't despair! As you practice writing C++ programs, you will develop an

intuitive understanding of the difference between statements and lines of code that are not considered statements.

### Displaying Screen Output in C++

To display output on the screen in C++, you write a cout statement (pronounced *see out*). A cout statement begins with the word cout, followed by the << operator, followed by an item of data that is to be displayed. The statement ends with a semicolon. Program 2-26 demonstrates. (Remember, the line numbers are NOT part of the program! They are shown for reference purposes only. Don't type the line numbers when you are entering program code.)

#### Program 2-26 (DisplayOutput.cpp)

```
1 #include <iostream>
2 using namespace std;
3
4 int main()
5 {
6 cout << "Hello world";
7 return 0;
8 }
```

#### Program Output

```
Hello world
```

The << operator is known as the *stream insertion operator*. It always appears on the left side of the item of data that you want to display. Notice that in line 6, the << operator appears to the left of the string "Hello world". When the program runs, *Hello world* is displayed.

You can display multiple items with a single cout statement, as long as a << operator appears to the left of each item. Program 2-27 shows an example. In line 6, three items of data are being displayed: the string "Programming ", the string "is ", and the string "fun.". Notice that the << operator appears to the left of each item.

#### Program 2-27 (DisplayMultipleItems.cpp)

```
1 #include <iostream>
2 using namespace std;
3
4 int main()
5 {
6 cout << "Programming " << "is " << "fun.";
7 return 0;
8 }
```

#### Program Output

```
Programming is fun.
```

When you display output with cout, the output is displayed as one continuous line on the screen, for example, look at Program 2-28. Even though the program has three cout statements, its output appears on one line.

**Program 2-28****(DisplayOneLine.cpp)**

```
1 #include <iostream>
2 using namespace std;
3
4 int main()
5 {
6 cout << "Programming ";
7 cout << "is ";
8 cout << "fun.";
9 return 0;
10 }
```

**Program Output**

Programming is fun.

The output comes out as one long line because the cout statement does not start a new line unless told to do so. You can use the endl manipulator to instruct cout to start a new line. Program 2-29 shows an example.

**Program 2-29****(EndlManipulator.cpp)**

```
1 #include <iostream>
2 using namespace std;
3
4 int main()
5 {
6 cout << "Programming" << endl;
7 cout << "is" << endl;
8 cout << "fun." << endl;
9 return 0;
10 }
```

**Program Output**

Programming  
is  
fun.

**Variables in C++**

In C++, variables must be declared before they can be used in a program. A variable declaration statement is written in the following general format:

*DataType VariableName;*

In the general format, *DataType* is the name of a C++ data type, and *VariableName* is the name of the variable that you are declaring. The declaration statement ends with a

semicolon. For example, the key word `int` is the name of the integer data type in C++, so the following statement declares a variable named `number`.

```
int number;
```

Table 2-8 lists some of the C++ data types, gives their memory size in bytes, and describes the type of data that each can hold. Note that in this book, we will primarily use the `int`, `double`, and `string` data types.<sup>3</sup>

**Table 2-8** C++ Data Types

| Data Type           | What It Can Hold                                                                                                            |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------|
| <code>short</code>  | Integers in the range of $-32,768$ to $+32,767$                                                                             |
| <code>int</code>    | Integers in the range of $-2,147,483,648$ to $+2,147,483,647$                                                               |
| <code>long</code>   | Integers in the range of $-2,147,483,648$ to $+2,147,483,647$                                                               |
| <code>float</code>  | Floating-point numbers in the range of $\pm 3.4 \times 10^{-38}$ to $\pm 3.4 \times 10^{38}$ , with 7 digits of accuracy    |
| <code>double</code> | Floating-point numbers in the range of $\pm 1.7 \times 10^{-308}$ to $\pm 1.7 \times 10^{308}$ , with 15 digits of accuracy |
| <code>char</code>   | Can store integers in the range of $-128$ to $+127$ . Typically used to store characters.                                   |
| <code>string</code> | Strings of text                                                                                                             |
| <code>bool</code>   | Stores the values <code>true</code> or <code>false</code>                                                                   |

Here are some other examples of variable declarations:

```
int speed;
double distance;
String name;
```

Several variables of the same data type can be declared with the same declaration statement. For example, the following statement declares three `int` variables named `width`, `height`, and `length`.

```
int width, height, length;
```

You can also initialize variables with starting values when you declare them. The following statement declares an `int` variable named `hours`, initialized with the starting value 40:

```
int hours = 40;
```

---

<sup>3</sup> To use the `string` data type, you must write the directive `#include <string>` at the top of your program. To be correct, `string` is not a data type in C++, it is a class. We use it as a data type, though.

### Variable Names in C++

You may choose your own variable names in C++, as long as you do not use any of the C++ key words. (See Table 1-1 in the *C++ Language Companion* for a complete list of C++ key words.) The key words make up the core of the language and each has a specific purpose. The following are some additional rules that must be followed when naming variables:

- The first character must be one of the letters a–z, A–Z, or an underscore (\_).
- After the first character, you may use the letters a–z or A–Z, the digits 0–9, underscores (\_).
- Uppercase and lowercase characters are distinct. This means `itemsOrdered` is not the same as `itemsordered`.
- Variable names cannot include spaces.

Program 2-30 shows an example with three variable declarations. Notice that, because we are using a `string` variable, we have the `#include <string>` directive in line 2. Line 7 declares a `string` variable named `name`, initialized with the string “Alex Prieto.” Line 8 declares an `int` variable named `hours` initialized with the value 40. Line 9 declares a `double` variable named `pay`, initialized with the value 852.99. Notice that in lines 11 through 13, we use `cout` to display the contents of each variable.

#### Program 2-30 (Variables.cpp)

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 int main()
6 {
7 string name = "Alex Prieto";
8 int hours = 40;
9 double pay = 852.99;
10
11 cout << name << endl;
12 cout << hours << endl;
13 cout << pay << endl;
14
15 }
```

#### Program Output

```
Alex Prieto
40
852.99
```

### Reading Keyboard Input in C++

To read keyboard input in C++, you write a `cin` statement (pronounced *see in*). A `cin` statement begins with the word `cin`, followed by the `>>` operator, followed by the name of a variable. The statement ends with a semicolon. When the statement executes, the program will wait for the user to enter input at the keyboard, and press the Enter key. When the user presses Enter, the input will be assigned to the variable that is listed after

the `>>` operator. (The `>>` operator is known as the *stream extraction operator*.) Program 2-31 demonstrates.

**Program 2-31 (KeyboardInput1.cpp)**

```
1 #include <iostream>
2 using namespace std;
3
4 int main()
5 {
6 int age;
7
8 cout << "What is your age?" << endl;
9 cin >> age;
10 cout << "Here is the value that you entered:" << endl;
11 cout << age;
12 return 0;
13 }
```

**Program Output (with Input Shown in Bold)**

```
What is your age?
24 [Enter]
Here is the value that you entered:
24
```

The program shown in Program 2-32 uses `cin` statements to read a string, an integer, and a double.

**Program 2-32 (KeyboardInput2.cpp)**

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 int main()
6 {
7 string name;
8 double payRate;
9 int hours;
10
11
12 cout << "Enter your first name." << endl;
13 cin >> name;
14 cout << "Enter your hourly pay rate." << endl;
15 cin >> payRate;
16 cout << "Enter the number of hours worked." << endl;
17 cin >> hours;
18
19 cout << "Here are the values that you entered:" << endl;
20 cout << name << endl;
21 cout << payRate << endl;
22 cout << hours << endl;
23
24 }
```

**Program Output (with Input Shown in Bold)**

```

Enter your first name.
Connie [Enter]
Enter your hourly pay rate.
55.25 [Enter]
Enter the number of hours worked.
40 [Enter]
Here are the values that you entered:
Connie
55.25
40

```

**Special Case: Reading String Input Containing Spaces**

A `cin` statement can read one-word string input, as previously shown in Program 2-32, but it does not behave as you would expect when the user's input is a string containing multiple words, separated by spaces. If you want to read a string that contains multiple words, you must use the `getline` function. The `getline` function reads an entire line of input, including embedded spaces, and stores it in a `string` variable. The `getline` function looks like the following, where `inputLine` is the name of the `string` variable receiving the input.

```
getline(cin, inputLine);
```

Program 2-33 shows an example of how the `getline` function is used.

**Program 2-33 (KeyboardInput3.cpp)**

```

1 // This program demonstrates using the getline function
2 // to read input into a string variable.
3 #include <iostream>
4 #include <string>
5 using namespace std;
6
7 int main()
8 {
9 string name;
10 string city;
11
12 cout << "Please enter your name." << endl;
13 getline(cin, name);
14
15 cout << "Enter the city you live in." << endl;
16 getline(cin, city);
17
18 cout << "Hello, " << name << endl;
19 cout << "You live in " << city << endl;
20
21 }
```

### Program Output (with Input Shown in Bold)

```
Please enter your name.
Kiran Sharma [Enter]
Enter the city you live in.
New York City [Enter]
Hello, Kiran Sharma
You live in New York City
```

### Performing Calculations in C++

The C++ arithmetic operators are nearly the same as those presented in Table 2-1 in your textbook:

|   |                |
|---|----------------|
| + | Addition       |
| - | Subtraction    |
| * | Multiplication |
| / | Division       |
| % | Modulus        |

Here are some examples of C++ statements that use an arithmetic operator to calculate a value, and assign that value to a variable:

```
total = price + tax;
sale = price - discount;
population = population * 2;
half = number / 2;
leftOver = 17 % 3;
```

C++ does not have an exponent operator, but it does provide a function named `pow` for this purpose. Here is an example of how the `pow` function is used:

```
result = pow(4.0, 2.0);
```

The function takes two `double` arguments (the numbers shown inside the parentheses). It raises the first argument to the power of the second argument, and returns the result as a `double`. In this example, 4.0 is raised to the power of 2.0. This statement is equivalent to the following algebraic statement:

```
result = 42
```

### Named Constants in C++

You create named constants in C++ using the `const` key word in a variable declaration. The word `const` is written just before the data type. Here is an example:

```
const double INTEREST_RATE = 0.069;
```

It is not required that the variable name appear in all uppercase letters, but many programmers prefer to write them this way so they are easily distinguishable from regular variable names.

An initialization value must be given when declaring a variable with the `const` modifier, or an error will result when the program is compiled. A compiler error will also result if there are any statements in the program that attempt to change the value of a `const` variable.

### Documenting a Program with Comments in C++

To write a line comment in C++, you simply place two forward slashes (`//`) where you want the comment to begin. The compiler ignores everything from that point to the end of the line. Here is an example:

```
// This program calculates an employee's gross pay.
```

Multiline comments, or block comments, start with `/*` (a forward slash followed by an asterisk) and end with `*/` (an asterisk followed by a forward slash). Everything between these markers is ignored. Here is an example:

```
/*
 This program calculates an employee's gross pay
 including any overtime wages the employee has worked.
*/
```

## Review Questions

### Multiple Choice

1. A \_\_\_\_\_ error does not prevent the program from running, but causes it to produce incorrect results.
  - a. syntax
  - b. hardware
  - c. logic
  - d. fatal
2. A \_\_\_\_\_ is a single function that the program must perform in order to satisfy the customer.
  - a. task
  - b. software requirement
  - c. prerequisite
  - d. predicate
3. A(n) \_\_\_\_\_ is a set of well-defined logical steps that must be taken to perform a task.
  - a. logarithm
  - b. plan of action
  - c. logic schedule
  - d. algorithm

4. An informal language that has no syntax rules, and is not meant to be compiled or executed is called \_\_\_\_\_.
  - a. faux code
  - b. pseudocode
  - c. Java
  - d. a flowchart
5. A \_\_\_\_\_ is a diagram that graphically depicts the steps that take place in a program.
  - a. flowchart
  - b. step chart
  - c. code graph
  - d. program graph
6. A(n) \_\_\_\_\_ is a set of statements that execute in the order that they appear.
  - a. serial program
  - b. sorted code
  - c. sequence structure
  - d. ordered structure
7. A \_\_\_\_\_ is a sequence of characters that is used as data.
  - a. sequence structure
  - b. character collection
  - c. string
  - d. text block
8. A \_\_\_\_\_ is a storage location in memory that is represented by a name.
  - a. variable
  - b. register
  - c. RAM slot
  - d. byte
9. A \_\_\_\_\_ is any hypothetical person that is using a program and providing input for it.
  - a. designer
  - b. user
  - c. guinea pig
  - d. test subject
10. A(n) \_\_\_\_\_ is a message that tells (or asks) the user to enter a specific value.
  - a. inquiry
  - b. input statement
  - c. directive
  - d. prompt
11. A(n) \_\_\_\_\_ sets a variable to a specified value.
  - a. variable declaration
  - b. assignment statement
  - c. math expression
  - d. string literal

12. In the expression  $12 + 7$ , the values on the right and left of the  $+$  symbol are called \_\_\_\_\_.
- operands
  - operators
  - arguments
  - math expressions
13. A(n) \_\_\_\_\_ operator raises a number to a power.
- modulus
  - multiplication
  - exponent
  - operand
14. A(n) \_\_\_\_\_ operator performs division, but instead of returning the quotient it returns the remainder.
- modulus
  - multiplication
  - exponent
  - operand
15. A(n) \_\_\_\_\_ specifies a variable's name and data type.
- assignment
  - variable specification
  - variable certification
  - variable declaration
16. Assigning a value to a variable in a declaration statement is called \_\_\_\_\_.
- allocation
  - initialization
  - certification
  - programming style
17. A(n) \_\_\_\_\_ variable is one that has been declared, but has not been initialized or assigned a value.
- undefined
  - uninitialized
  - empty
  - default
18. A(n) \_\_\_\_\_ is a variable whose content has a value that is read only and cannot be changed during the program's execution.
- static variable
  - uninitialized variable
  - named constant
  - locked variable

19. A debugging process in which you imagine that you are the computer executing a program is called \_\_\_\_\_.
  - a. imaginative computing
  - b. role playing
  - c. mental simulation
  - d. hand tracing
20. Short notes placed in different parts of a program, explaining how those parts of the program work, are called \_\_\_\_\_.
  - a. comments
  - b. reference manuals
  - c. tutorials
  - d. external documentation

### True or False

1. Programmers must be careful not to make syntax errors when writing pseudocode programs.
2. In a math expression, multiplication and division take place before addition and subtraction.
3. Variable names can have spaces in them.
4. In most languages, the first character of a variable name cannot be a number.
5. The name `gross_pay` is written in the camelCase convention.
6. In languages that require variable declarations, a variable's declaration must appear before any other statements that use the variable.
7. Uninitialized variables are a common cause of errors.
8. The value of a named constant cannot be changed during the program's execution.
9. Hand tracing is the process of translating a pseudocode program into machine language by hand.
10. Internal documentation refers to books and manuals that document a program, and are intended for use within a company's programming department.

### Short Answer

1. What does a professional programmer usually do first to gain an understanding of a problem?
2. What is pseudocode?
3. Computer programs typically perform what three steps?
4. What does the term *user-friendly* mean?
5. What two things must you normally specify in a variable declaration?
6. What value is stored in uninitialized variables?

### Algorithm Workbench

1. Design an algorithm that prompts the user to enter the temperature and stores the user's input in a variable named `temperature`.
2. Design an algorithm that prompts the user to enter their favorite color and stores the user's input in a variable named `color`.
3. Write assignment statements that perform the following operations with the variables `a` and `b`.
  - a. Adds 2 to `a` and stores the result in `b`
  - b. Multiplies `b` times 4 and stores the result in `a`
  - c. Divides `a` by 3.14 and stores the result in `b`
  - d. Subtracts 8 from `b` and stores the result in `a`
4. Assume the variables `result`, `x`, `y`, and `z` are all integers, and that `x = 4`, `y = 8`, and `z = 2`. What value will be stored in `result` in each of the following statements?
  - a. Set `result = x + y`
  - b. Set `result = z * 2`
  - c. Set `result = y / x`
  - d. Set `result = y - z`
5. Write a pseudocode statement that declares the variable `cost` so it can hold real numbers.
6. Write a pseudocode statement that declares the variable `total` so it can hold integers. Initialize the variable with the value 0.
7. Write a pseudocode statement that assigns the value 27 to the variable `count`.
8. Write a pseudocode statement that assigns the sum of 10 and 14 to the variable `total`.
9. Write a pseudocode statement that subtracts the variable `downPayment` from the variable `total` and assigns the result to the variable `due`.
10. Write a pseudocode statement that multiplies the variable `subtotal` by 0.15 and assigns the result to the variable `totalFee`.
11. If the following pseudocode were an actual program, what would it display?

```
Declare Integer a = 5
Declare Integer b = 2
Declare Integer c = 3
Declare Integer result

Set result = a + b * c
Display result
```

12. If the following pseudocode were an actual program, what would it display?

```
Declare Integer num = 99
Set num = 5
Display num
```

## Debugging Exercises

1. If the following pseudocode were an actual program, why would it not display the output that the programmer expects?

```
Declare String favoriteFood
```

```
Display "What is the name of your favorite food?"
Input favoriteFood
```

```
Display "Your favorite food is "
Display "favoriteFood"
```

2. If the programmer translates the following pseudocode to an actual programming language, a syntax error is likely to occur. Can you find the error?

```
Declare String 1stPrize
```

```
Display "Enter the award for first prize."
Input 1stPrize
```

```
Display "The first prize winner will receive ", 1stPrize
```

3. The following code will not display the results expected by the programmer. Can you find the error?

```
Declare Real lowest, highest, average
```

```
Display "Enter the lowest score."
Input lowest
```

```
Display "Enter the highest score."
Input highest
```

```
Set average = low + high / 2
Display "The average is ", average, ". "
```

4. Find the error in the following pseudocode.

```
Display "Enter the length of the room."
Input length
Declare Integer length
```

5. Find the error in the following pseudocode.

```
Declare Integer value1, value2, value3, sum
Set sum = value1 + value2 + value3
```

```
Display "Enter the first value."
Input value1
```

```
Display "Enter the second value."
Input value2
```

```
Display "Enter the third value."
Input value3
```

```
Display "The sum of numbers is ", sum
```

6. Find the error in the following pseudocode.

```
Declare Real pi
Set 3.14159265 = pi
Display "The value of pi is ", pi
```

7. Find the error in the following pseudocode.

```
Constant Real GRAVITY = 9.81
Display "Rates of acceleration of an object in free fall:"
Display "Earth: ", GRAVITY, " meters per second every second."
Set GRAVITY = 1.63
Display "Moon: ", GRAVITY, " meters per second every second."
```

## Programming Exercises

### 1. Personal Information

Design a program that displays the following information:

- Your name
- Your address, with city, state, and ZIP
- Your telephone number
- Your college major

### 2. Sales Prediction

A company has determined that its annual profit is typically 23 percent of total sales. Design a program that asks the user to enter the projected amount of total sales, and then displays the profit that will be made from that amount.

*Hint:* Use the value 0.23 to represent 23 percent.

### 3. Land Calculation

One acre of land is equivalent to 43,560 square feet. Design a program that asks the user to enter the total square feet in a tract of land and calculates the number of acres in the tract.

*Hint:* Divide the amount entered by 43,560 to get the number of acres.

### 4. Total Purchase

A customer in a store is purchasing five items. Design a program that asks for the price of each item, and then displays the subtotal of the sale, the amount of sales tax, and the total. Assume the sales tax is 6 percent.

### 5. Distance Traveled

Assuming there are no accidents or delays, the distance that a car travels down the interstate can be calculated with the following formula:

$$\text{Distance} = \text{Speed} \times \text{Time}$$

A car is traveling at a constant 60 miles per hour. Design a program that displays the following:

- The distance the car will travel in 5 hours
- The distance the car will travel in 8 hours
- The distance the car will travel in 12 hours

## 6. Sales Tax

Design a program that will ask the user to enter the amount of a purchase. The program should then compute the state and county sales tax. Assume the state sales tax is 4 percent and the county sales tax is 2 percent. The program should display the amount of the purchase, the state sales tax, the county sales tax, the total sales tax, and the total of the sale (which is the sum of the amount of purchase plus the total sales tax).

*Hint:* Use the value 0.02 to represent 2 percent, and 0.04 to represent 4 percent.

## 7. Miles-per-Gallon

A car's miles-per-gallon (MPG) can be calculated with the following formula:

$$\text{MPG} = \text{Miles driven}/\text{Gallons of gas used}$$

Design a program that asks the user for the number of miles driven and the gallons of gas used. It should calculate the car's miles-per-gallon and display the result on the screen.



VideoNote

The Tip, Tax, and Total Problem

## 8. Tip, Tax, and Total

Design a program that calculates the total amount of a meal purchased at a restaurant. The program should ask the user to enter the charge for the food, and then calculate the amount of a 15 percent tip and 7 percent sales tax. Display each of these amounts and the total.

## 9. Customer Acquisition Cost

Suppose a business launches a new marketing campaign and spends money on the following items:

- Advertising
- Marketing personnel salaries
- Sales staff commissions

The marketing campaign results in the business acquiring new customers. The business owner is curious to know how much money was spent per new customer. This amount, which is known as the customer acquisition cost, can be calculated as follows:

$$\text{CAC} = (A + M + S) \div NC$$

where

- CAC is customer acquisition cost
- A is the advertising cost
- M is the cost of marketing personnel salaries
- S is the cost of sales staff commissions
- NC is the number of new customers acquired

Design a program that asks the user to enter each of the costs of the marketing campaign (advertising, marketing personnel salaries, and sales staff commissions). The program should also ask the user to enter the number of new customers that were acquired. Then, the program should calculate and display the customer acquisition cost.

**10. Amount Paid Over Time**

A person pays a fixed amount each month as a car payment. Design a program that asks the user to enter the amount paid each month, and the number of months the user has been making payments. The program should then display the total amount that the user has paid.

**11. Leftover Pizza**

You're planning a pizza party and you plan to give each person three slices of pizza. Design a program that displays the number of slices that will be leftover. The program should ask for the following input:

- The number of pizzas you will have
- The number of slices that each pizza is cut into
- The number of people that will be attending

The program should display the number of slices that will be left over.

**12. Celsius to Fahrenheit Temperature Converter**

Design a program that converts Celsius temperatures to Fahrenheit temperatures. The formula is as follows:

$$F = \frac{9}{5}C + 32$$

The program should ask the user to enter a temperature in Celsius, and then display the temperature converted to Fahrenheit.

**13. Stock Transaction Program**

Last month Jaden purchased some stock in Acme Software, Inc. Here are the details of the purchase:

- The number of shares that Jaden purchased was 1,000.
- When Jaden purchased the stock, he paid \$32.87 per share.
- Jaden paid his stockbroker a commission that amounted to 2 percent of the amount he paid for the stock.

Two weeks later Jaden sold the stock. Here are the details of the sale:

- The number of shares that Jaden sold was 1,000.
- He sold the stock for \$33.92 per share.
- He paid his stockbroker another commission that amounted to 2 percent of the amount he received for the stock.

Design a program that displays the following information:

- The amount of money Jaden paid for the stock.
- The amount of commission Jaden paid his broker when he bought the stock.
- The amount that Jaden sold the stock for.
- The amount of commission Jaden paid his broker when he sold the stock.
- Display the amount of profit or loss after Jaden sold the stock and paid his broker (both times).

**14. Major and Nonmajor Percentages**

The computer science department at a college offers a programming course that is required for all computer science majors. The course is also popular with students who are not computer science majors. Design a program that asks the user to enter the number of computer science majors that are registered in the class, and the number of nonmajor students that are registered in the class. The program should display the percentages of computer science majors and nonmajor students that are registered in the class.

*Hint:* Suppose there are 12 computer science majors and 8 nonmajor students in the class. There are 20 students in the class. The percentage of computer science majors can be calculated as  $12 \div 20 = 0.6$ , or 60%. The percentage of nonmajors can be calculated as  $8 \div 20 = 0.4$ , or 40%.

**15. Ingredient Adjuster**

A cookie recipe calls for the following ingredients:

- 1.5 cups of sugar
- 1 cup of butter
- 2.75 cups of flour

The recipe produces 48 cookies with these amounts of the ingredients. Design a program that asks the user how many cookies they want to make, and then displays the number of cups of each ingredient needed for the specified number of cookies.

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# Decision Structures and Boolean Logic

## TOPICS

- |                                          |                                               |
|------------------------------------------|-----------------------------------------------|
| 3.1 Introduction to Decision Structures  | 3.6 Logical Operators                         |
| 3.2 Dual Alternative Decision Structures | 3.7 Boolean Variables                         |
| 3.3 Comparing Strings                    | 3.8 Focus on Languages: Java, Python, and C++ |
| 3.4 Nested Decision Structures           |                                               |
| 3.5 The Case Structure                   |                                               |

### 3.1

## Introduction to Decision Structures

**CONCEPT:** A decision structure (which is also known as a selection structure) allows a program to perform actions only under certain conditions.



VideoNote  
The Single  
Alternative  
Decision  
Structure

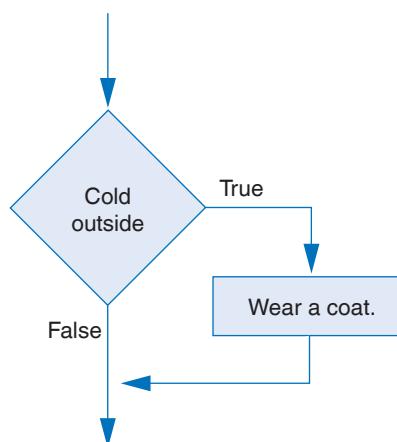
A control structure is a logical design that controls the order in which a set of statements executes. So far in this book we have used only the simplest type of control structure: the sequence structure. Recall from Chapter 2 that a sequence structure is a set of statements that execute in the order that they appear. For example, the following pseudocode is a sequence structure because the statements execute from top to bottom.

```
Declare Integer age
Display "What is your age?"
Input age
Display "Here is the value that you entered:"
Display age
```

Although the sequence structure is heavily used in programming, it cannot handle every type of task. Some problems simply cannot be solved by performing a set of ordered steps, one after the other. For example, consider a pay calculating program that determines whether an employee has worked overtime. If the employee has worked more than 40 hours, they are paid extra for all the hours over 40. Otherwise, the overtime calculation should be skipped. Programs like this require a different type of control structure: one that can execute a set of statements only under certain circumstances. This can be accomplished with a *decision structure*. (Decision structures are also known as *selection structures*.)

In a decision structure's simplest form, a specific action is performed only if a certain condition exists. If the condition does not exist, the action is not performed. The flowchart shown in Figure 3-1 shows how the logic of an everyday decision can be diagrammed as a decision structure. The diamond symbol represents a true/false condition. If the condition is true, we follow one path, which leads to an action being performed. If the condition is false, we follow another path, which skips the action.

**Figure 3-1** A simple decision structure for an everyday task



In the flowchart, the diamond symbol indicates some condition that must be tested. In this case, we are determining whether the condition *Cold outside* is true or false. If this condition is true, the action *Wear a coat* is performed. If the condition is false, the action is skipped. The action is *conditionally executed* because it is performed only when a certain condition is true.

Programmers call the type of decision structure shown in Figure 3-1 a *single alternative decision structure*. This is because it provides only one alternative path of execution. If the condition in the diamond symbol is true, we take the alternative path. Otherwise, we exit the structure.

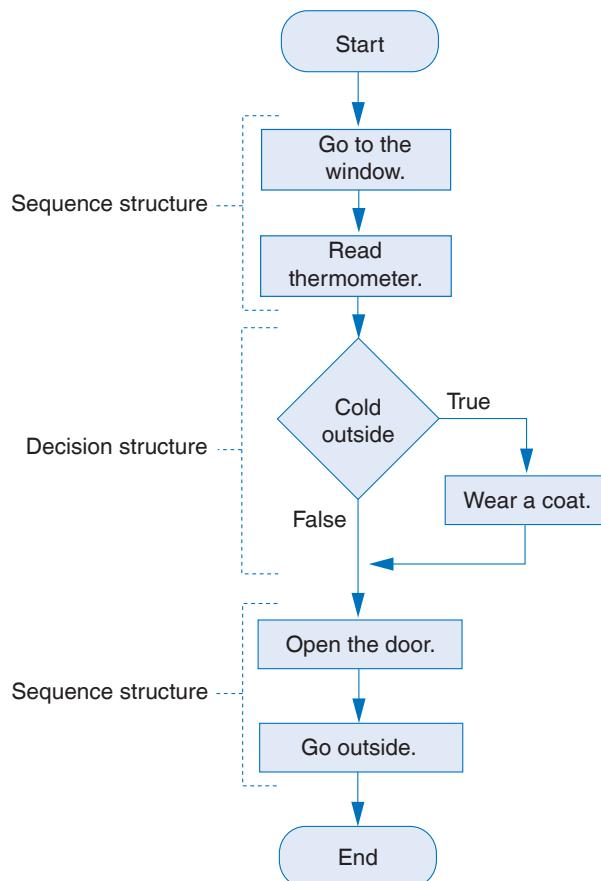
## Combining Structures

You cannot use decision structures alone to create a complete program. You use a decision structure to handle any part of a program that needs to test a condition and conditionally execute an action depending on the outcome of the condition. For other parts of a program you need to use other structures. For example, Figure 3-2 shows a complete flowchart that combines a decision structure with two sequence structures. (Figure 3-2 is not a flowchart of a computer algorithm, but of a human action.)

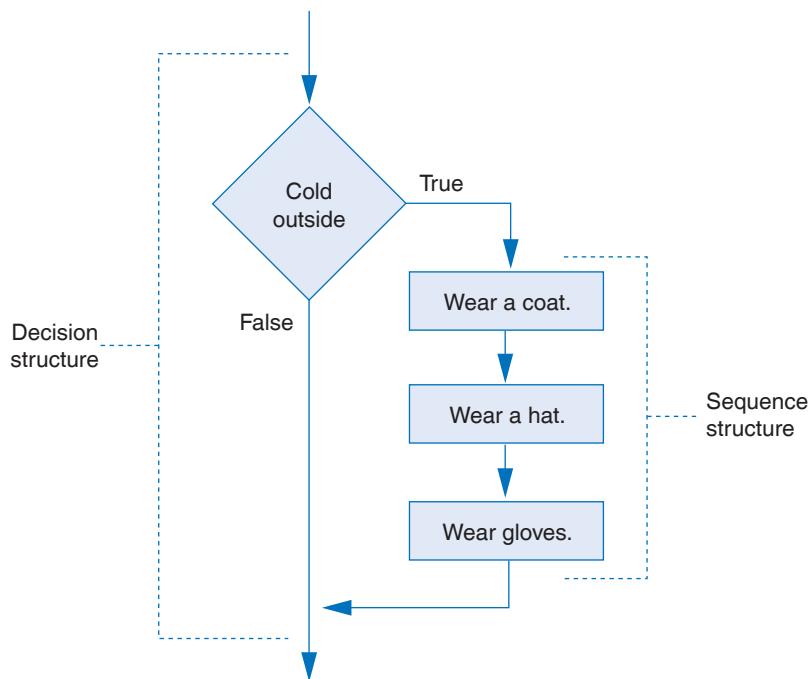
The flowchart in the figure starts with a sequence structure. Assuming you have an outdoor thermometer in your window, the first step is *Go to the window*, and the next step is *Read thermometer*. A decision structure appears next, testing the condition *Cold outside*. If this is true, the action *Wear a coat* is performed. Another sequence structure appears next. The step *Open the door* is performed, followed by *Go outside*.

Quite often, structures must be nested inside of other structures. For example, look at the partial flowchart in Figure 3-3. It shows a decision structure with a sequence structure nested inside it. (Once again, this is a flowchart showing human actions, not program statements.) The decision structure tests the condition *Cold outside*. If that condition is true, the steps in the sequence structure are executed.

**Figure 3-2** Combining sequence structures with a decision structure



**Figure 3-3** A sequence structure nested inside a decision structure



## Writing a Decision Structure in Pseudocode

In pseudocode we use the **If - Then** statement to write a single alternative decision structure. Here is the general format of the **If - Then** statement:

```

If condition Then
 statement
 statement
 etc.
}
 } These statements are conditionally executed.
End If

```

For simplicity, we will refer to the line that begins with the word **If** as the *If clause*, and we will refer to the line that reads **End If** as the *End If clause*. In the general format, the *condition* is any expression that can be evaluated as either true or false. When the **If - Then** statement executes, the *condition* is tested. If it is true, the statements that appear between the **If clause** and the **End If clause** are executed. The **End If** clause marks the end of the **If - Then** statement.

### Boolean Expressions and Relational Operators

All programming languages allow you to create expressions that can be evaluated as either true or false. These are called *Boolean expressions*, named in honor of the English mathematician George Boole. In the 1800s Boole invented a system of mathematics in which the abstract concepts of true and false can be used in computations. The condition that is tested by an **If - Then** statement must be a Boolean expression.

Typically, the Boolean expression that is tested by an **If - Then** statement is formed with a relational operator. A *relational operator* determines whether a specific relationship

exists between two values. For example, the greater than operator ( $>$ ) determines whether one value is greater than another. The equal to operator ( $==$ ) determines whether two values are equal. Table 3-1 lists the relational operators that are commonly available in most programming languages.

**Table 3-1** Relational operators

| Operator | Meaning                  |
|----------|--------------------------|
| $>$      | Greater than             |
| $<$      | Less than                |
| $\geq$   | Greater than or equal to |
| $\leq$   | Less than or equal to    |
| $==$     | Equal to                 |
| $\neq$   | Not equal to             |

The following is an example of an expression that uses the greater than ( $>$ ) operator to compare two variables, `length` and `width`:

```
length > width
```

This expression determines whether the value of `length` is greater than the value of `width`. If `length` is greater than `width`, the value of the expression is true. Otherwise, the value of the expression is false. Because the expression can be only true or false, it is a Boolean expression. The following expression uses the less than operator to determine whether `length` is less than `width`:

```
length < width
```

Table 3-2 shows examples of several Boolean expressions that compare the variables `x` and `y`.

**Table 3-2** Boolean expressions using relational operators

| Expression            | Meaning                                                     |
|-----------------------|-------------------------------------------------------------|
| <code>x &gt; y</code> | Is <code>x</code> greater than <code>y</code> ?             |
| <code>x &lt; y</code> | Is <code>x</code> less than <code>y</code> ?                |
| <code>x \geq y</code> | Is <code>x</code> greater than or equal to <code>y</code> ? |
| <code>x \leq y</code> | Is <code>x</code> less than or equal to <code>y</code> ?    |
| <code>x == y</code>   | Is <code>x</code> equal to <code>y</code> ?                 |
| <code>x \neq y</code> | Is <code>x</code> not equal to <code>y</code> ?             |

### The `\geq` and `\leq` Operators

Two of the operators, `\geq` and `\leq`, test for more than one relationship. The `\geq` operator determines whether the operand on its left is greater than *or* equal to the operand on its right. For example, assuming that `a` is 4, `b` is 6, and `c` is 4, both of the expressions `b \geq a` and `a \geq c` are true, and the expression `a \geq 5` is false.

The `<=` operator determines whether the operand on its left is less than *or* equal to the operand on its right. Once again, assuming that `a` is 4, `b` is 6, and `c` is 4, both `a <= c` and `b <= 10` are true, but `b <= a` is false.

### The `==` Operator

The `==` operator determines whether the operand on its left is equal to the operand on its right. If both operands have the same value, the expression is true. Assuming that `a` is 4, the expression `a == 4` is true and the expression `a == 2` is false.

In this book, we use two `=` characters as the equal to operator to avoid confusion with the assignment operator, which is one `=` character. Several programming languages, most notably Java, Python, C, and C++, also follow this practice.



**WARNING!** When programming in a language that uses `==` as the equal to operator, take care not to confuse this operator with the assignment operator, which is one `=` sign. In languages such as Java, Python, C, and C++ the `==` operator determines whether a variable is equal to another value, but the `=` operator assigns the value to a variable.

### The `!=` Operator

The `!=` operator is the not equal to operator. It determines whether the operand on its left is not equal to the operand on its right, which is the opposite of the `==` operator. As before, assuming `a` is 4, `b` is 6, and `c` is 4, both `a != b` and `b != c` are true because `a` is not equal to `b` and `b` is not equal to `c`. However, `a != c` is false because `a` is equal to `c`.

Note that `!=` is the same character sequence used by several languages for the not equal to operator, including Java, C, and C++. Some languages, such as Visual Basic, use `<>` as the not equal to operator.

## Putting It All Together

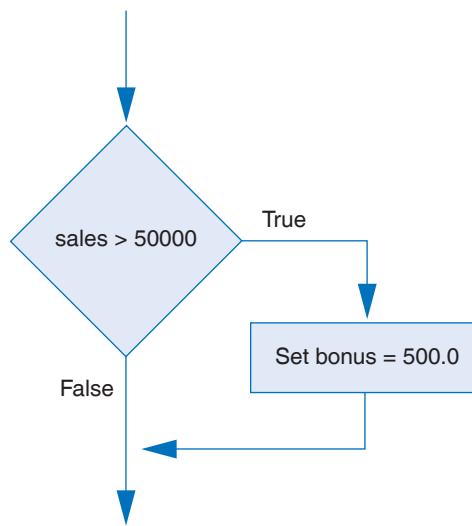
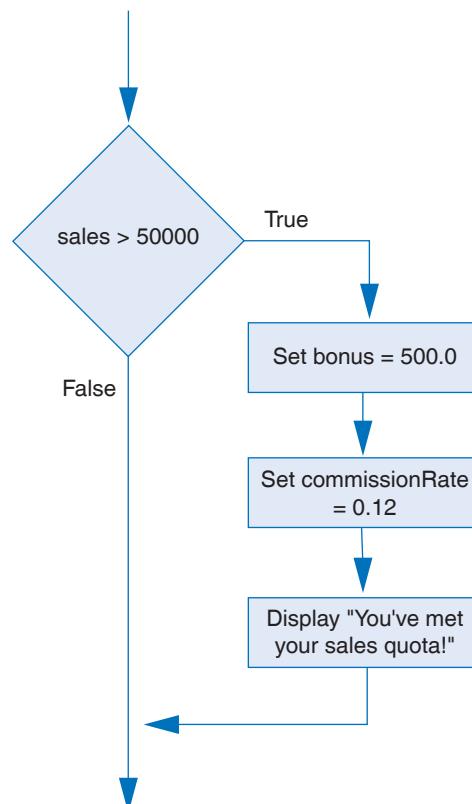
Let's look at the following example of the If-Then statement in pseudocode:

```
If sales > 50000 Then
 Set bonus = 500.0
End If
```

This statement uses the `>` operator to determine whether `sales` is greater than 50,000. If the expression `sales > 50000` is true, the variable `bonus` is assigned 500.0. If the expression is false, however, the assignment statement is skipped. Figure 3-4 shows a flowchart for this section of code.

The following example conditionally executes a set of statements. Figure 3-5 shows a flowchart for this section of code.

```
If sales > 50000 Then
 Set bonus = 500.0
 Set commissionRate = 0.12
 Display "You've met your sales quota!"
End If
```

**Figure 3-4** Example decision structure**Figure 3-5** Example decision structure

The following pseudocode uses the `==` operator to determine whether two values are equal. The expression `balance == 0` will be true if the `balance` variable is set to 0. Otherwise the expression will be false.

```

If balance == 0 Then
 // Statements appearing here will
 // be executed only if balance is
 // equal to 0.
End If

```

The following pseudocode uses the `!=` operator to determine whether two values are *not* equal. The expression `choice != 5` will be true if the `choice` variable is not set to 5. Otherwise the expression will be false.

```

If choice != 5 Then
 // Statements appearing here will
 // be executed only if choice is
 // not equal to 5.
End If

```

## Programming Style and the If-Then Statement

As shown in Figure 3-6, you should use the following conventions when you write an If-Then statement:

- Make sure the `If` clause and the `End If` clause are aligned.
- Indent the conditionally executed statements that appear between the `If` clause and the `End If` clause.

By indenting the conditionally executed statements you visually set them apart from the surrounding code. This makes your program easier to read and debug. Most programmers use this style of writing If-Then statements in both pseudocode and actual code.

**Figure 3-6** Programming style with an If-Then statement

```

If sales > 50000 Then
 |Set bonus = 500.0
 |Set commissionRate = 0.12
 |Display "You've met your sales quota!"
End If

```

Align the If and End If clauses.

Indent the conditionally executed statements.

### In the Spotlight: Using the If-Then Statement

Martina teaches a science class and her students are required to take three tests. She wants to write a program that her students can use to calculate their average test score. She also wants the program to congratulate the student enthusiastically if the average is greater than 95. Here is the algorithm:

1. Get the first test score.
2. Get the second test score.
3. Get the third test score.
4. Calculate the average.
5. Display the average.
6. If the average is greater than 95, congratulate the user.



Program 3-1 shows the pseudocode, and Figure 3-7 shows a flowchart for the program.

**Program 3-1**

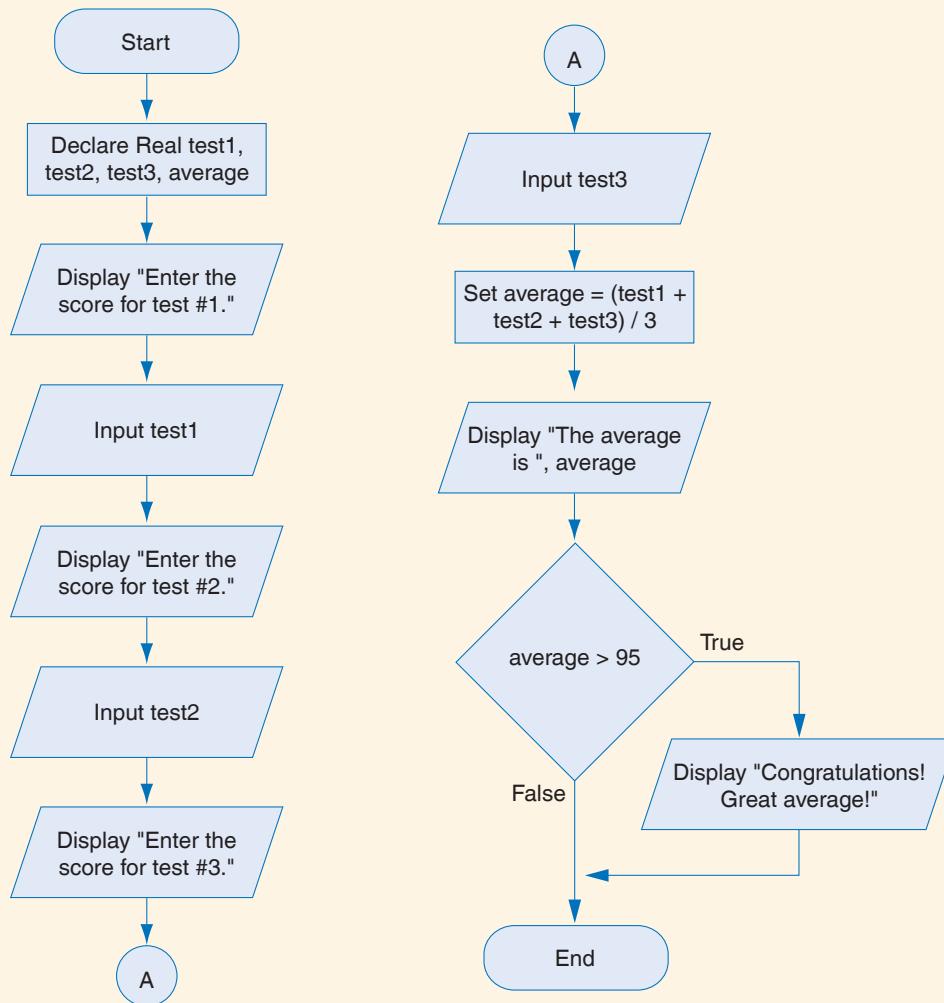
```
1 // Declare variables
2 Declare Real test1, test2, test3, average
3
4 // Get test 1
5 Display "Enter the score for test #1."
6 Input test1
7
8 // Get test 2
9 Display "Enter the score for test #2."
10 Input test2
11
12 // Get test 3
13 Display "Enter the score for test #3."
14 Input test3
15
16 // Calculate the average score.
17 Set average = (test1 + test2 + test3) / 3
18
19 // Display the average.
20 Display "The average is ", average
21
22 // If the average is greater than 95
23 // congratulate the user.
24 If average > 95 Then
25 Display "Congratulations! Great average!"
26 End If
```

**Program Output (with Input Shown in Bold)**

```
Enter the score for test #1.
82 [Enter]
Enter the score for test #2.
76 [Enter]
Enter the score for test #3.
91 [Enter]
The average is 83
```

**Program Output (with Input Shown in Bold)**

```
Enter the score for test #1.
93 [Enter]
Enter the score for test #2.
99 [Enter]
Enter the score for test #3.
96 [Enter]
The average is 96
Congratulations! Great average!
```

**Figure 3-7** Flowchart for Program 3-1

### Checkpoint

- 3.1 What is a control structure?
- 3.2 What is a decision structure?
- 3.3 What is a single alternative decision structure?
- 3.4 What is a Boolean expression?
- 3.5 What types of relationships between values can you test with relational operators?
- 3.6 Write a pseudocode If-Then statement that assigns 0 to x if y is equal to 20.
- 3.7 Write a pseudocode If-Then statement that assigns 0.2 to commission if sales is greater than or equal to 10,000.

## 3.2

## Dual Alternative Decision Structures

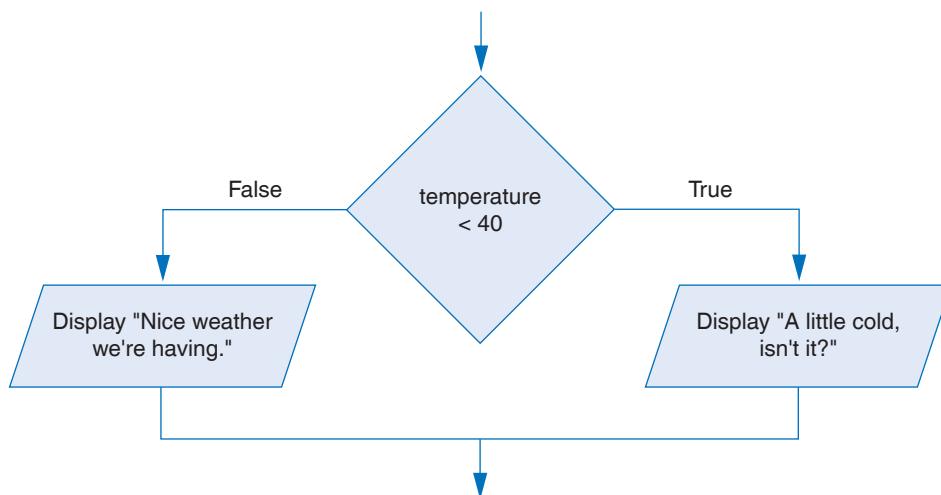


VideoNote  
The Dual Alternative Decision Structure

**CONCEPT:** A dual alternative decision structure will execute one group of statements if its Boolean expression is true, or another group if its Boolean expression is false.

A *dual alternative decision structure* has two possible paths of execution—one path is taken if a condition is true, and the other path is taken if the condition is false. Figure 3-8 shows a flowchart for a dual alternative decision structure.

**Figure 3-8** A dual alternative decision structure



The decision structure in the flowchart tests the condition  $\text{temperature} < 40$ . If this condition is true, the statement `Display "A little cold, isn't it?"` is performed. If the condition is false, the statement `Display "Nice weather we're having."` is performed.

In pseudocode we write a dual alternative decision structure as an `If-Then-Else` statement. Here is the general format of the `If-Then-Else` statement:

```

If condition Then
 statement
 statement
 etc. } These statements are executed if the condition is true.

Else
 statement
 statement
 etc. } These statements are executed if the condition is false.

End If

```

In the general format, the *condition* is any Boolean expression. If the expression is true, the statements that appear next are executed, up to the line that reads `Else`. If the expression is false, the statements that appear between `Else` and `End If` are executed. The line that reads `End If` marks the end of the `If-Then-Else` statement.

The following pseudocode shows an example of an **If-Then-Else** statement. This pseudocode matches the flowchart that was shown in Figure 3-8.

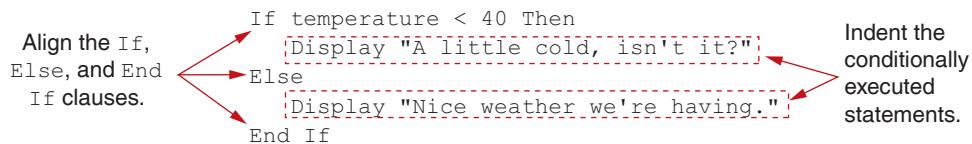
```
If temperature < 40 Then
 Display "A little cold, isn't it?"
Else
 Display "Nice weather we're having."
End If
```

We will refer to the line that reads **Else** as the *Else clause*. When you write an **If-Then-Else** statement, use the following style conventions:

- Make sure the **If** clause, the **Else** clause, and the **End If** clause are aligned.
- Indent the conditionally executed statements that appear between the **If** clause and the **Else** clause, and between the **Else** clause and the **End If** clause.

This is shown in Figure 3-9.

**Figure 3-9** Programming style with an **If-Then-Else** statement



## In the Spotlight: Using the **If-Then-Else** Statement



Kris owns an auto repair business and has several employees. If an employee works more than 40 hours in a week, Kris pays that employee 1.5 times their regular hourly pay rate for all hours over 40. For example, suppose an employee's regular hourly pay rate is \$20, and that employee works 45 hours in a week. Kris will pay the employee \$20 per hour for the first 40 hours, plus \$30 per hour for the 5 hours of overtime work. Here is a summary of the calculation:

Regular pay for the first 40 hours:  $40 \times \$20 = \$800$

Overtime pay for 5 hours:  $5 \times \$30 = \$150$

Total Pay:  $\$800 + \$150 = \$950$

Kris has asked you to design a simple payroll program that calculates an employee's gross pay, including any overtime wages. You design the following algorithm:

1. Get the number of hours worked.
2. Get the hourly pay rate.
3. If the employee worked more than 40 hours, calculate the gross pay with overtime. Otherwise, calculate the gross pay as usual.
4. Display the gross pay.

The pseudocode for the program is shown in Program 3-2, and Figure 3-10 shows a flowchart for the program.

**Program 3-2**

```
1 // Constants
2 Constant Integer BASE_HOURS = 40
3 Constant Real OT_MULTIPLIER = 1.5
4
5 // Variables
6 Declare Real hoursWorked, payRate, grossPay,
7 overtimeHours, overtimePay
8
9 // Get the number of hours worked.
10 Display "Enter the number of hours worked."
11 Input hoursWorked
12
13 // Get the hourly pay rate.
14 Display "Enter the hourly pay rate."
15 Input payRate
16
17 // Calculate the gross pay.
18 If hoursWorked > BASE_HOURS Then
19 // Calculate the number of overtime hours.
20 Set overtimeHours = hoursWorked - BASE_HOURS
21
22 // Calculate the overtime pay.
23 Set overtimePay = overtimeHours * payRate * OT_MULTIPLIER
24
25 // Calculate the gross pay.
26 Set grossPay = BASE_HOURS * payRate + overtimePay
27 Else
28 Set grossPay = hoursWorked * payRate
29 End If
30
31 // Display the gross pay.
32 Display "The gross pay is $", grossPay
```

**Program Output (with Input Shown in Bold)**

Enter the number of hours worked.

40 [Enter]

Enter the hourly pay rate.

20 [Enter]

The gross pay is \$800

**Program Output (with Input Shown in Bold)**

Enter the number of hours worked.

50 [Enter]

Enter the hourly pay rate.

20 [Enter]

The gross pay is \$1100

Let's take a closer look at the pseudocode. Two named constants are declared in lines 2 and 3. The `BASE_HOURS` constant is set to 40, which is the number of hours an employee can work in a week without getting paid overtime. The `OT_MULTIPLIER` constant is set to 1.5, which is the pay rate multiplier for overtime hours. This means that the employee's hourly pay rate is multiplied by 1.5 for all overtime hours.

The variables that are declared in lines 6 and 7 are used for the following purposes:

- The `hoursWorked` variable will hold the number of hours worked by the employee. This value will be entered as input.
- The `payRate` variable will hold the employee's hourly payrate. This value will also be entered as input.
- The `grossPay` variable will hold the employee's gross pay. This value will be calculated.
- The `overtimeHours` variable will hold the number of hours over 40 worked by the employee. This value will be calculated.
- The `overtimePay` variable will hold the amount of pay the employee earned for overtime hours. This value will be calculated.

Line 10 prompts the user to enter the number of hours the employee worked, and line 11 reads that value, assigning it to the `hoursWorked` variable.

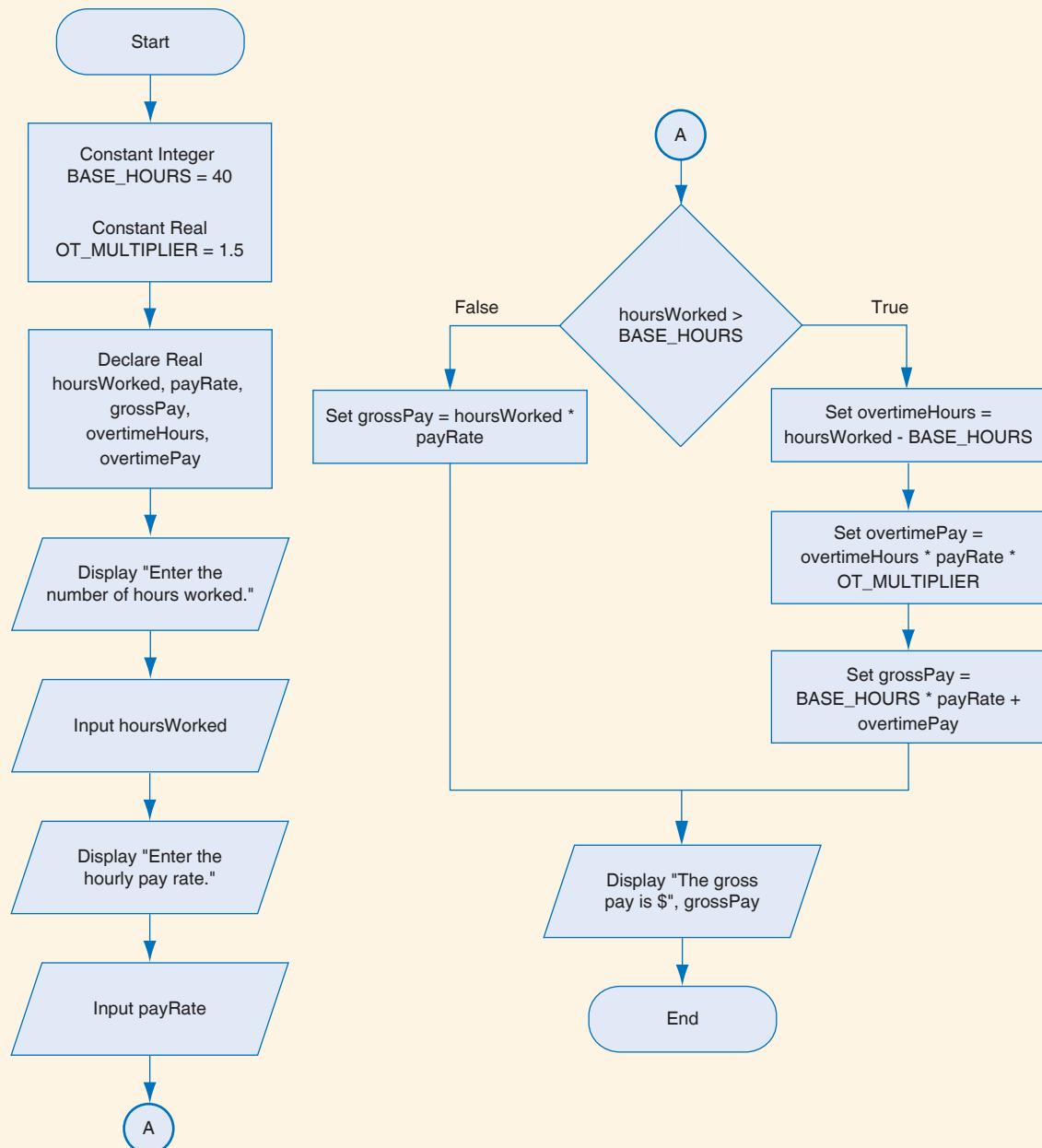
Line 14 prompts the user to enter the employee's hourly payrate, and line 15 reads that value, assigning it to the `payRate` variable.

The `If` statement in line 18 determines whether `hoursWorked` is greater than 40. If this is true, it means the employee has worked overtime hours and the program executes the statements in lines 19–26. Those statements perform the following actions:

- Line 20 calculates the number of overtime hours worked, which is the number of hours over 40. The result is assigned to the `overtimeHours` variable.
- Line 23 calculates the amount of pay for the overtime hours. The result is assigned to the `overtimePay` variable.
- Line 26 calculates the employee's gross pay. This is the amount of pay for 40 hours worked at the regular payrate, plus the overtime pay. The result is assigned to the `grossPay` variable.

When the `If` statement in line 18 executes, if `hoursWorked` is not greater than 40, it means the employee has not worked more than 40 hours. In this case, the program will branch to the `Else` clause in line 27. This causes the statement line 28 to execute. This statement calculates the gross pay by multiplying the number of hours worked by the hourly payrate. The result is assigned to the `grossPay` variable.

Last, the statement in line 32 displays the employee's gross pay.

**Figure 3-10** Flowchart for Program 3-2

## Checkpoint

- 3.8 How does a dual alternative decision structure work?
- 3.9 What statement do you use in pseudocode to write a dual alternative decision structure?
- 3.10 When you write an **If-Then-Else** statement, under what circumstances do the statements that appear between **Else** and **End If** execute?

**3.3**

## Comparing Strings

**CONCEPT:** Most programming languages allow you to compare strings. This allows you to create decision structures that test the value of a string.

You saw in the preceding examples how numbers can be compared. Most programming languages also allow you to compare strings. For example, look at the following pseudocode:

```
Declare String name1 = "Mary"
Declare String name2 = "Mark"
If name1 == name2 Then
 Display "The names are the same."
Else
 Display "The names are NOT the same."
End If
```

The `==` operator tests `name1` and `name2` to determine whether they are equal. Because the strings "Mary" and "Mark" are not equal, the `Else` clause will display the message "The names are NOT the same."

You can compare `String` variables with string literals as well. Assume `month` is a `String` variable. The following pseudocode sample uses the `!=` operator to determine whether `month` is not equal to "October".

```
If month != "October" Then
 statement
End If
```

The pseudocode in Program 3-3 demonstrates how two strings can be compared. The program prompts the user to enter a password and then determines whether the string entered is equal to "prospero."

**Program 3-3**

```
1 // A variable to hold a password.
2 Declare String password
3
4 // Prompt the user to enter the password.
5 Display "Enter the password."
6 Input password
7
8 // Determine whether the correct password
9 // was entered.
10 If password == "prospero" Then
11 Display "Password accepted."
12 Else
13 Display "Sorry, that is not the correct password."
14 End If
```

**Program Output (with Input Shown in Bold)**

```
Enter the password.
ferdinand [Enter]
Sorry, that is not the correct password.
```

**Program Output (with Input Shown in Bold)**

```
Enter the password.
prospero [Enter]
Password accepted.
```



**NOTE:** In most languages, string comparisons are case sensitive. For example, the strings "saturday" and "Saturday" are not equal because the "s" is lowercase in the first string, but uppercase in the second string.

## Other String Comparisons

In addition to determining whether strings are equal or not equal, many languages allow you to determine whether one string is greater than or less than another string. This is a useful capability because programmers commonly need to design programs that sort strings in some order.

Recall from Chapter 1 that computers do not actually store characters, such as A, B, C, and so on, in memory. Instead, they store numeric codes that represent the characters. We mentioned in Chapter 1 that ASCII (the American Standard Code for Information Interchange) is the most commonly used character coding system. You can see the set of ASCII codes in Appendix A, but here are some facts about it:

- The uppercase characters “A” through “Z” are represented by the numbers 65 through 90.
- The lowercase characters “a” through “z” are represented by the numbers 97 through 122.
- When the digits “0” through “9” are stored in memory as characters, they are represented by the numbers 48 through 57. (For example, the string “abc123” would be stored in memory as the codes 97, 98, 99, 49, 50, and 51.)
- A blank space is represented by the number 32.

In addition to establishing a set of numeric codes to represent characters in memory, ASCII also establishes an order for characters. The character “A” comes before the character “B,” which comes before the character “C,” and so on.

When a program compares characters, it actually compares the codes for the characters. For example, look at the following pseudocode:

```
If "a" < "b" Then
 Display "The letter a is less than the letter b."
End If
```

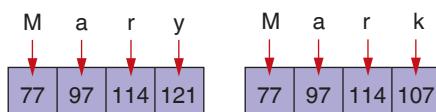
This If statement determines whether the ASCII code for the character “a” is less than the ASCII code for the character “b.” The expression “a” < “b” is true because the code for “a” is less than the code for “b.” So, if this were part of an actual program it would display the message “The letter a is less than the letter b.”

Let’s look at how strings containing more than one character are typically compared. Suppose we have the strings “Mary” and “Mark” stored in memory, as follows:

```
Declare String name1 = "Mary"
Declare String name2 = "Mark"
```

Figure 3-11 shows how the strings “Mary” and “Mark” would actually be stored in memory, using ASCII codes.

**Figure 3-11** Character codes for the strings “Mary” and “Mark”

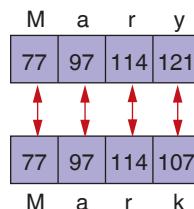


When you use relational operators to compare these strings, they are compared character-by-character. For example, look at the following pseudocode:

```
Declare String name1 = "Mary"
Declare String name2 = "Mark"
If name1 > name2 Then
 Display "Mary is greater than Mark."
Else
 Display "Mary is not greater than Mark."
End If
```

The > operator compares each character in the strings “Mary” and “Mark,” beginning with the first, or leftmost, characters. This is shown in Figure 3-12.

**Figure 3-12** Comparing each character in a string



Here is how the comparison typically takes place:

1. The “M” in “Mary” is compared with the “M” in “Mark.” Because these are the same, the next characters are compared.
2. The “a” in “Mary” is compared with the “a” in “Mark.” Because these are the same, the next characters are compared.

3. The "r" in "Mary" is compared with the "r" in "Mark." Because these are the same, the next characters are compared.
4. The "y" in "Mary" is compared with the "k" in "Mark." Because these are not the same, the two strings are not equal. The character "y" has a higher ASCII code (121) than "k" (107), so it is determined that the string "Mary" is greater than the string "Mark."

If one of the strings in a comparison is shorter than the other, many languages compare only the corresponding characters. If the corresponding characters are identical, then the shorter string is considered less than the longer string. For example, suppose the strings "High" and "Hi" were being compared. The string "Hi" would be considered less than "High" because it is shorter.

The pseudocode in Program 3-4 shows a simple demonstration of how two strings can be compared with the < operator. The user is prompted to enter two names and the program displays those two names in alphabetical order.

#### Program 3-4

```
1 // Declare variables to hold two names.
2 Declare String name1
3 Declare String name2
4
5 // Prompt the user for two names.
6 Display "Enter a name (last name first)."
7 Input name1
8 Display "Enter another name (last name first)."
9 Input name2
10
11 // Display the names in alphabetical order.
12 Display "Here are the names, listed alphabetically."
13 If name1 < name2 Then
14 Display name1
15 Display name2
16 Else
17 Display name2
18 Display name1
19 End If
```

#### Program Output (with Input Shown in Bold)

```
Enter a name (last name first).
Sharma, Kiran [Enter]
Enter another name (last name first).
Costa, Joan [Enter]
Here are the names, listed alphabetically:
Costa, Joan
Sharma, Kiran
```


**Checkpoint**

3.11 If the following pseudocode were an actual program, what would it display?

```
If "z" < "a" Then
 Display "z is less than a."
Else
 Display "z is not less than a."
End If
```

3.12 If the following pseudocode were an actual program, what would it display?

```
Declare String s1 = "New York"
Declare String s2 = "Boston"
If s1 > s2 Then
 Display s2
 Display s1
Else
 Display s1
 Display s2
End If
```

**3.4**

## Nested Decision Structures

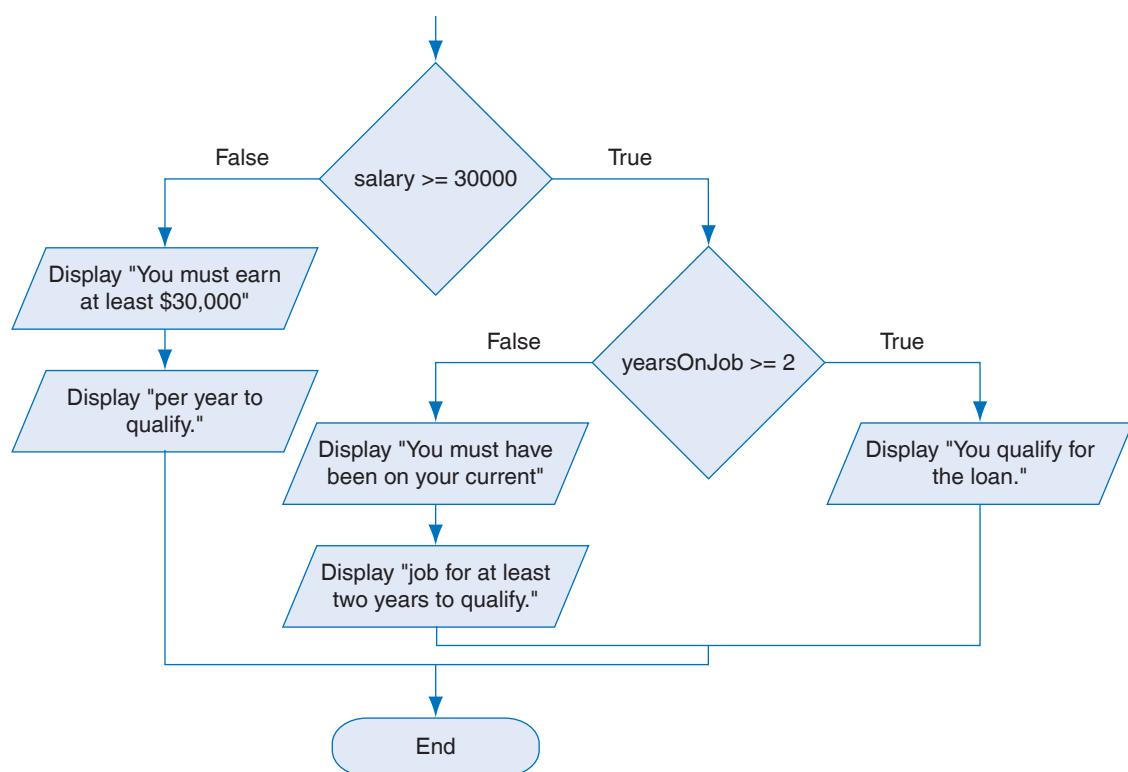
**CONCEPT:** To test more than one condition, a decision structure can be nested inside another decision structure.

In Section 3.1, we mentioned that programs are usually designed as combinations of different control structures. In that section you saw an example of a sequence structure nested inside a decision structure (see Figure 3-3). You can also nest decision structures inside of other decision structures. In fact, this is a common requirement in programs that need to test more than one condition.

For example, consider a program that determines whether a bank customer qualifies for a loan. To qualify, two conditions must exist: (1) the customer must earn at least \$30,000 per year, and (2) the customer must have been employed at their current job for at least two years. Figure 3-13 shows a flowchart for an algorithm that could be used in such a program. Assume that the `salary` variable contains the customer's annual salary, and the `yearsOnJob` variable contains the number of years that the customer has worked at their current job.

If we follow the flow of execution, we see that the condition `salary >= 30000` is tested. If this condition is false, there is no need to perform further tests; we know that the customer does not qualify for the loan. If the condition is true, however, we need to test the second condition. This is done with a nested decision structure that tests the condition `yearsOnJob >= 2`. If this condition is true, then the customer qualifies for the loan. If this condition is false, then the customer does not qualify. Program 3-5 shows the pseudocode for the complete program.

### **Figure 3-13** A nested decision structure



## **Program 3-5**

```
1 // Declare variables
2 Declare Real salary, yearsOnJob
3
4 // Get the annual salary.
5 Display "Enter your annual salary."
6 Input salary
7
8 // Get the number of years on the current job.
9 Display "Enter the number of years on your"
10 Display "current job."
11 Input yearsOnJob
12
13 // Determine whether the user qualifies.
14 If salary >= 30000 Then
15 If yearsOnJob >= 2 Then
16 Display "You qualify for the loan."
17 Else
18 Display "You must have been on your current"
19 Display "job for at least two years to qualify."
20 End If
21 Else
22 Display "You must earn at least $30,000"
23 Display "per year to qualify."
24 End If
```

**Program Output (with Input Shown in Bold)**

```
Enter your annual salary.

35000 [Enter]

Enter the number of years on your

current job.

1 [Enter]

You must have been on your current

job for at least two years to qualify.
```

**Program Output (with Input Shown in Bold)**

```
Enter your annual salary.

25000 [Enter]

Enter the number of years on your

current job.

5 [Enter]

You must earn at least $30,000

per year to qualify.
```

**Program Output (with Input Shown in Bold)**

```
Enter your annual salary.

35000 [Enter]

Enter the number of years on your

current job.

5 [Enter]

You qualify for the loan.
```

Look at the If-Then-Else statement that begins in line 14. It tests the condition `salary >= 30000`. If this condition is true, the If-Then-Else statement that begins in line 15 is executed. Otherwise the program jumps to the Else clause in line 21 and executes the two Display statements in lines 22 and 23. The program then leaves the decision structure and the program ends.

## Programming Style and Nested Decision Structures

For debugging purposes, it's important to use proper alignment and indentation in a nested decision structure. This makes it easier to see which actions are performed by each part of the structure. For example, in most languages the following pseudocode is functionally equivalent to lines 14 through 24 in Program 3-5. Although this pseudocode is logically correct, it would be very difficult to debug because it is not properly indented.

```
If salary >= 30000 Then
 If yearsOnJob >= 2 Then
 Display "You qualify for the loan."
 Else
 Display "You must have been on your current"
 Display "job for at least two years to qualify."
 End If
```

Don't write  
pseudocode  
like this!

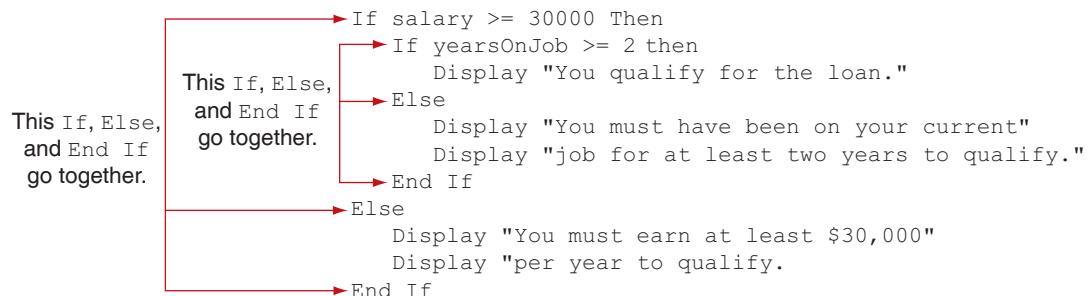
```

Else
Display "You must earn at least $30,000"
Display "per year to qualify."
End If

```

Proper indentation and alignment also makes it easier to see which **If**, **Else**, and **End If** clauses belong together, as shown in Figure 3-14.

**Figure 3-14** Alignment of **If**, **Else**, and **End If** clauses



## Testing a Series of Conditions

In the previous example you saw how a program can use nested decision structures to test more than one condition. It is not uncommon for a program to have a series of conditions to test, and then perform an action depending on which condition is true. One way to accomplish this is to have a decision structure with numerous other decision structures nested inside it. For example, consider the program presented in the following *In the Spotlight* section.

### In the Spotlight: Multiple Nested Decision Structures



Dr. Suarez teaches a literature class and uses the following 10 point grading scale for all of his exams:

| Test Score   | Grade |
|--------------|-------|
| 90 and above | A     |
| 80–89        | B     |
| 70–79        | C     |
| 60–69        | D     |
| Below 60     | F     |

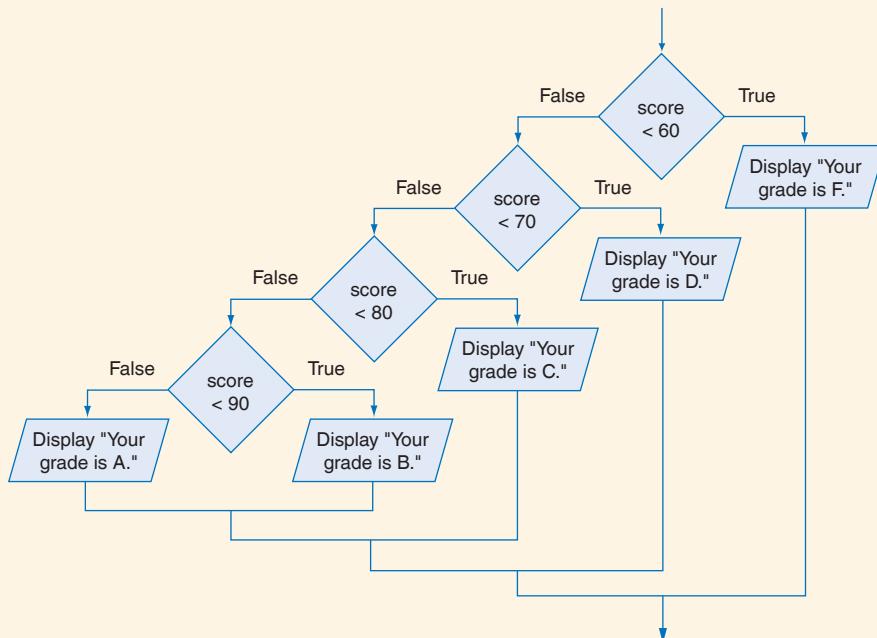
He has asked you to write a program that will allow a student to enter a test score and then display the grade for that score. Here is the algorithm that you will use:

1. Ask the user to enter a test score.
2. Determine the grade in the following manner:

If the score is less than 60, then the grade is “F.”  
 Otherwise, if the score is less than 70, then the grade is “D.”  
 Otherwise, if the score is less than 80, then the grade is “C.”  
 Otherwise, if the score is less than 90, then the grade is “B.”  
 Otherwise, the grade is “A.”

You decide that the process of determining the grade will require several nested decision structures, as shown in Figure 3-15. Program 3-6 shows the pseudocode for the complete program. The code for the nested decision structures is in lines 9 through 25.

**Figure 3-15** Nested decision structure to determine a grade



### Program 3-6

```

1 // Variable to hold the test score
2 Declare Real score
3
4 // Get the test score.
5 Display "Enter your test score."
6 Input score
7
8 // Determine the grade.
9 If score < 60 Then
10 Display "Your grade is F."
11 Else
12 If score < 70 Then
13 Display "Your grade is D."
14 Else
15 If score < 80 Then

```

```

16 Display "Your grade is C."
17 Else
18 If score < 90 Then
19 Display "Your grade is B."
20 Else
21 Display "Your grade is A."
22 End If
23 End If
24 End If
25 End If

```

### Program Output (with Input Shown in Bold)

Enter your test score.  
**78 [Enter]**  
 Your grade is C.

### Program Output (with Input Shown in Bold)

Enter your test score.  
**84 [Enter]**  
 Your grade is B.

## The If-Then-Else If Statement

Even though Program 3-6 is a simple example, the logic of the nested decision structure is fairly complex. Most languages provide a special version of the decision structure known as the If-Then-Else If statement, which makes this type of logic simpler to write. In pseudocode we will write the If-Then-Else If statement using the following general format:

```

If condition_1 Then
 statement
 statement
 etc. } If condition_1 is true these statements are executed,
 and the rest of the structure is ignored.

Else If condition_2 Then
 statement
 statement
 etc. } If condition_2 is true these statements are executed,
 and the rest of the structure is ignored.

Insert as many Else If clauses as necessary

Else
 statement
 statement
 etc. } These statements are executed if none of the conditions
 above are true.

End If

```

When the statement executes, *condition\_1* is tested. If *condition\_1* is true, the statements that immediately follow are executed, up to the *Else If* clause. The rest of the structure is ignored. If *condition\_1* is false, however, the program jumps to the very next *Else If* clause and tests *condition\_2*. If it is true, the statements that immediately follow are executed, up to the next *Else If* clause. The rest of the structure is then ignored. This process continues until a condition is found to be true, or no more *Else*

If clauses are left. If none of the conditions are true, the statements following the Else clause are executed.

The pseudocode in Program 3-7 shows an example of the If-Then-Else If statement. This program works the same as Program 3-6. Instead of using a nested decision structure, this program uses the If-Then-Else If statement in lines 9 through 19.

### Program 3-7

```

1 // Variable to hold the test score
2 Declare Real score
3
4 // Get the test score.
5 Display "Enter your test score."
6 Input score
7
8 // Determine the grade.
9 If score < 60 Then
10 Display "Your grade is F."
11 Else If score < 70 Then
12 Display "Your grade is D."
13 Else If score < 80 Then
14 Display "Your grade is C."
15 Else If score < 90 Then
16 Display "Your grade is B."
17 Else
18 Display "Your grade is A."
19 End If

```

### Program Output (with Input Shown in Bold)

```

Enter your test score.
78 [Enter]
Your grade is C.

```

### Program Output (with Input Shown in Bold)

```

Enter your test score.
84 [Enter]
Your grade is B.

```

Notice the alignment and indentation that are used with the If-Then-Else If statement: The If, Else If, Else, and End If clauses are all aligned, and the conditionally executed statements are indented.

You never have to use the If-Then-Else If statement because its logic can be coded with nested If-Then-Else statements. However, a long series of nested If-Then-Else statements has two particular disadvantages when you are debugging code:

- The code can grow complex and become difficult to understand.
- Because indenting is important in nested statements, a long series of nested If-Then-Else statements can become too long to be displayed on the computer screen without horizontal scrolling. Also, long statements tend to “wrap around” when printed on paper, making the code even more difficult to read.

The logic of an **If-Then-Else If** statement is usually easier to follow than a long series of nested **If-Then-Else** statements. And, because all of the clauses are aligned in an **If-Then-Else If** statement, the lengths of the lines in the statement tend to be shorter.



## Checkpoint

- 3.13 How does a dual alternative decision structure work?
- 3.14 What statement do you use in pseudocode to write a dual alternative decision structure?
- 3.15 When you write an **If-Then-Else** statement, under what circumstances do the statements that appear between the **Else** clause and the **End If** clause execute?
- 3.16 Convert the following pseudocode to an **If-Then-Else If** statement:

```
If number == 1 Then
 Display "One"
Else
 If number == 2 Then
 Display "Two"
 Else
 If number == 3 Then
 Display "Three"
 Else
 Display "Unknown"
 End If
 End If
End If
```

**3.5**

## The Case Structure

**CONCEPT:** The case structure lets the value of a variable or an expression determine which path of execution the program will take.

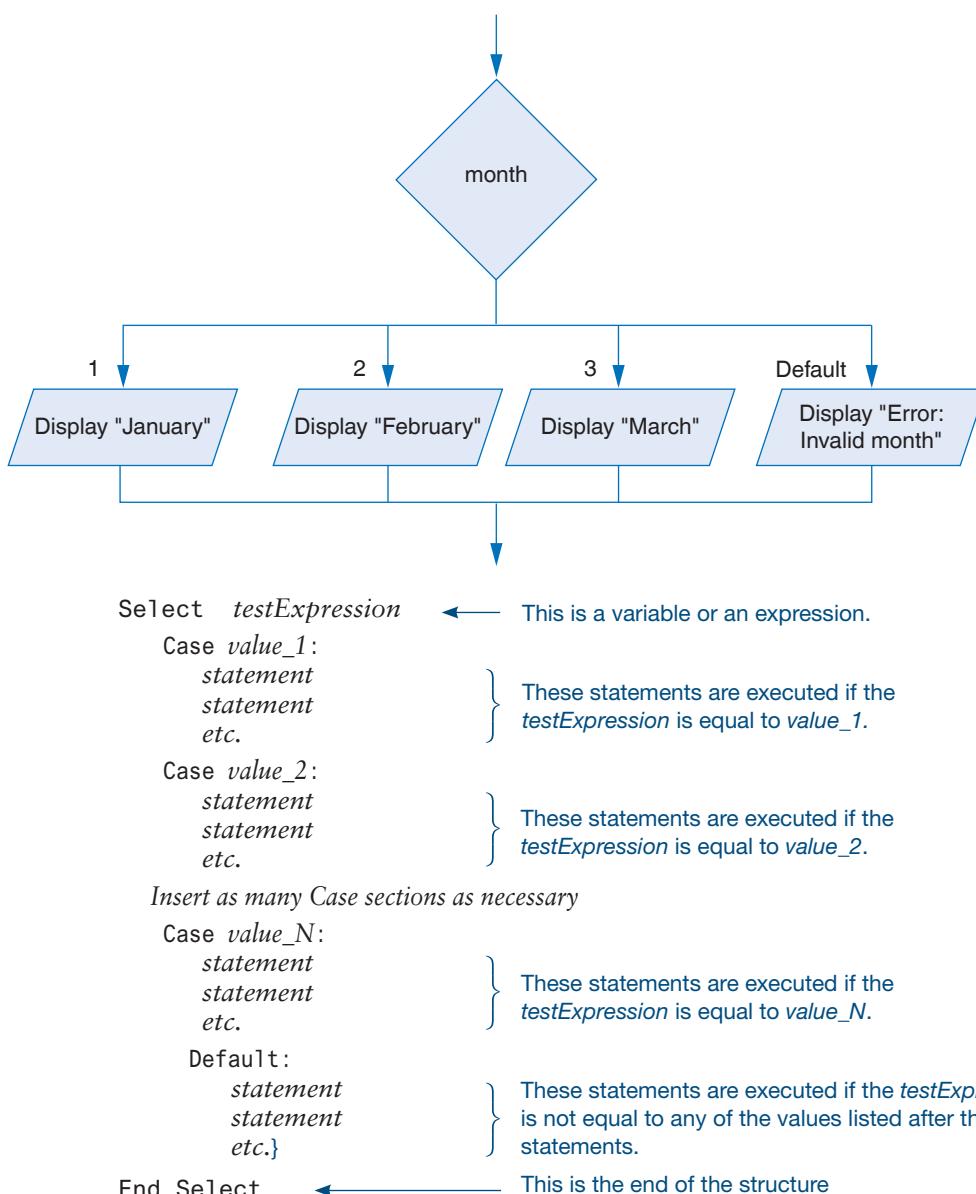


VideoNote  
The Case Structure

The *case structure* is a *multiple alternative decision structure*. It allows you to test the value of a variable or an expression and then use that value to determine which statement or set of statements to execute. In many situations, case structures accomplish the same thing as nested **If-Then** statements, but with simpler and more straightforward code. Figure 3-16 shows an example of how a case structure looks in a flowchart.

In the flowchart, the diamond symbol contains the name of a variable. If the variable contains the value 1 the statement **Display "January"** is executed. If the variable contains the value 2 the statement **Display "February"** is executed. If the variable contains the value 3 the statement **Display "March"** is executed. If the variable contains none of these values, the statement labeled **Default** is executed. In this case, the statement **Display "Error: Invalid month"** is executed.

To write a case structure in pseudocode we will use a **Select Case** statement. The general format follows Figure 3-16.

**Figure 3-16** A case structure

The first line of the structure starts with the word `Select`, followed by a `testExpression`. The `testExpression` is usually a variable, but in many languages it can also be anything that gives a value (such as a math expression). Inside the structure there is one or more blocks of statements that begin with a `Case` statement. Notice that the word `Case` is followed by a value.

When the `Select Case` statement executes, it compares the value of the `testExpression` with the values that follow each of the `Case` statements (from top to bottom). When it finds a `Case` value that matches the `testExpression`'s value, the program branches to the `Case` statement. The statements that immediately follow the `Case` statement are executed, and then the program jumps out of the structure. If the `testExpression` does not match any of the `Case` values, the program branches to the `Default` statement and executes the statements that immediately follow it.

For example, the following pseudocode performs the same operation as the flowchart shown in Figure 3-16:

```
Select month
Case 1:
 Display "January"
Case 2:
 Display "February"
Case 3:
 Display "March"
Default:
 Display "Error: Invalid month"
End Select
```

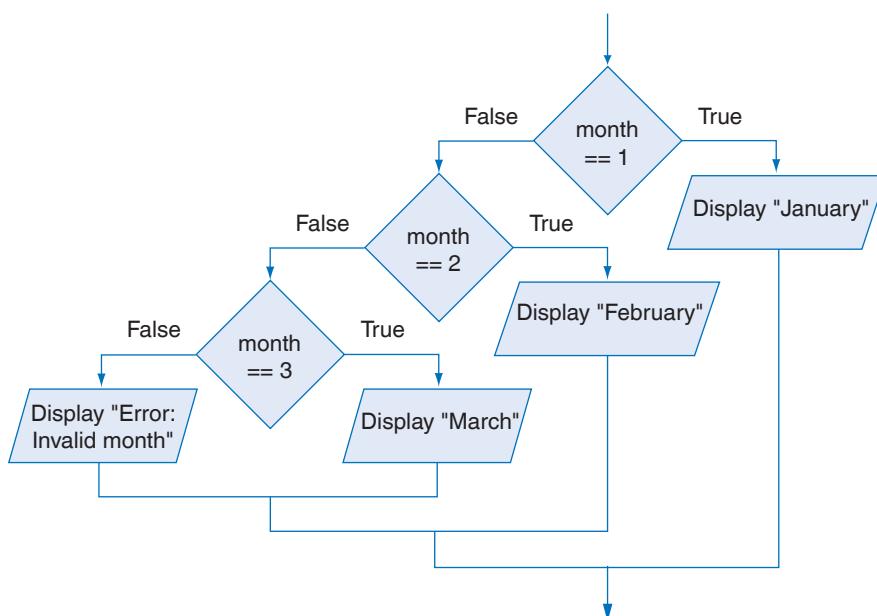
In this example, the *testExpression* is the *month* variable. If the value in the *month* variable is 1, the program will branch to the *Case 1:* section and execute the *Display "January"* statement that immediately follows it. If the value in the *month* variable is 2, the program will branch to the *Case 2:* section and execute the *Display "February"* statement that immediately follows it. If the value in the *month* variable is 3, the program will branch to the *Case 3:* section and execute the *Display "March"* statement that immediately follows it. If the value in the *month* variable is not 1, 2, or 3, the program will branch to the *Default:* section; and if the value in the *month* variable is 1, the program will branch to the *Case 1:* section and execute the *Display "Error: Invalid month"* statement that immediately follows it.



**NOTE:** In many languages the case structure is called a **switch** statement.

Case structures are never required because the same logic can be achieved with nested decision structures. For example, Figure 3-17 shows nested decision structures that are equivalent to the case structure in Figure 3-16. In situations where they can be used, however, case structures are more straightforward.

**Figure 3-17** Nested decision structures



## In the Spotlight: Using a Case Structure

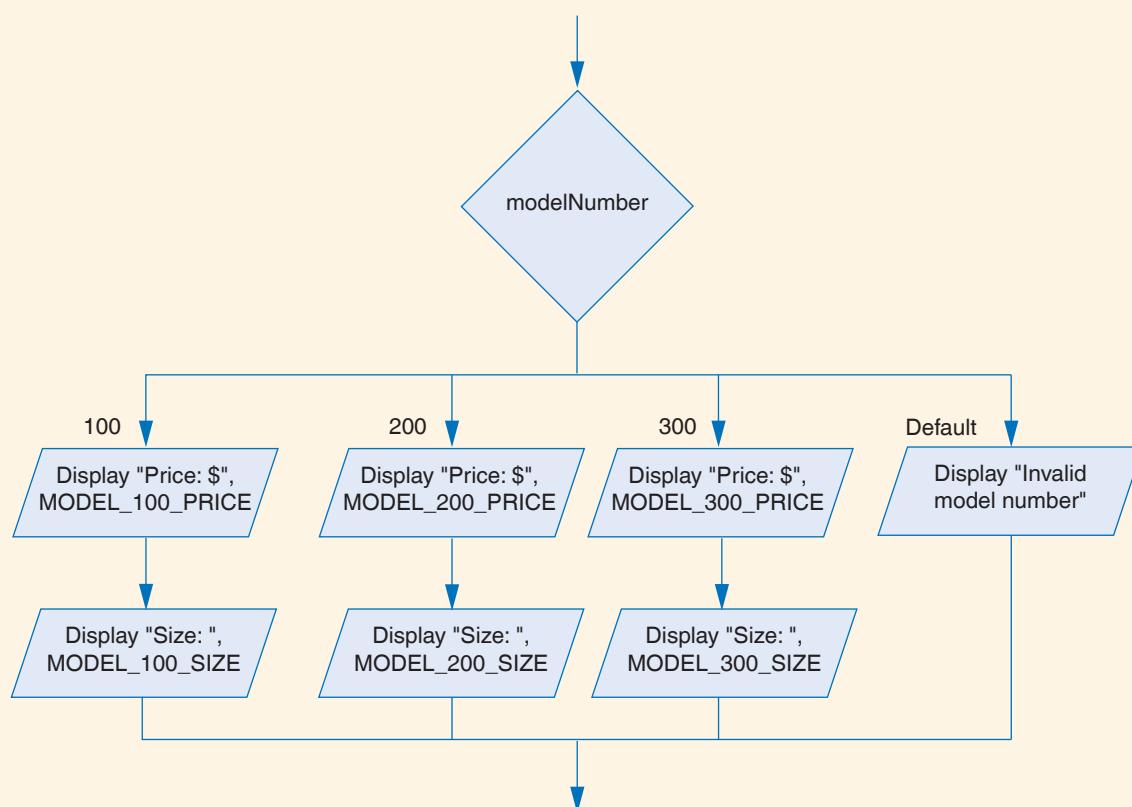


Leila, who owns Leila's Electronics Shop, has asked you to write a program that will let a customer pick one of three TV models and then displays the price and size of the selected model. Here is the algorithm:

1. Get the TV model number.
2. If the model is 100, then display the information for that model.  
Otherwise, if the model is 200, then display the information for that model.  
Otherwise, if the model is 300, then display the information for that model.

At first, you consider designing a nested decision structure to determine the model number and display the correct information. But you realize that a case structure will work just as well because a single value, the model number, will be used to determine the action that the program will perform. The model number can be stored in a variable, and that variable can be tested by the case structure. Assuming that the model number is stored in a variable named `modelNumber`, Figure 3-18 shows a flowchart for the case structure. Program 3-8 shows the pseudocode for the program.

**Figure 3-18** Flowchart for the case structure



**Program 3-8**

```
1 // Constants for the TV prices
2 Constant Real MODEL_100_PRICE = 199.99
3 Constant Real MODEL_200_PRICE = 269.99
4 Constant Real MODEL_300_PRICE = 349.99
5
6 // Constants for the TV sizes
7 Constant Integer MODEL_100_SIZE = 24
8 Constant Integer MODEL_200_SIZE = 27
9 Constant Integer MODEL_300_SIZE = 32
10
11 // Variable for the model number
12 Declare Integer modelNumber
13
14 // Get the model number.
15 Display "Which TV are you interested in?"
16 Display "The 100, 200, or 300?"
17 Input modelNumber
18
19 // Display the price and size.
20 Select modelNumber
21 Case 100:
22 Display "Price: $", MODEL_100_PRICE
23 Display "Size: ", MODEL_100_SIZE
24 Case 200:
25 Display "Price: $", MODEL_200_PRICE
26 Display "Size: ", MODEL_200_SIZE
27 Case 300:
28 Display "Price $", MODEL_300_PRICE
29 Display "Size: ", MODEL_300_SIZE
30 Default:
31 Display "Invalid model number"
32 End Select
```

**Program Output (with Input Shown in Bold)**

Which TV are you interested in?

The 100, 200, or 300?

**100 [Enter]**

Price: \$199.99

Size: 24

**Program Output (with Input Shown in Bold)**

Which TV are you interested in?

The 100, 200, or 300?

**200 [Enter]**

Price: \$269.99

Size: 27

**Program Output (with Input Shown in Bold)**

Which TV are you interested in?

The 100, 200, or 300?

**300 [Enter]**

Price: \$349.99

Size: 32

**Program Output (with Input Shown in Bold)**

Which TV are you interested in?

The 100, 200, or 300?

**500 [Enter]**

Invalid model number



**NOTE:** The details of writing a case structure differ from one language to another. Because of the specific rules that each language uses for writing case structures, you might not be able to use the case structure for every multiple alternative decision. In such an event, you can use the If-Then-Else If statement or a nested decision structure.

**Checkpoint**

- 3.17 What is a multiple alternative decision structure?
- 3.18 How do you write a multiple alternative decision structure in pseudocode?
- 3.19 What does the case structure test, in order to determine which set of statements to execute?
- 3.20 You need to write a multiple alternative decision structure, but the language you are using will not allow you to perform the test you need in a Select Case statement. What can you do to achieve the same results?

**3.6****Logical Operators**

**CONCEPT:** The logical AND operator and the logical OR operator allow you to connect multiple Boolean expressions to create a compound expression. The logical NOT operator reverses the truth of a Boolean expression.

Programming languages provide a set of operators known as *logical operators*, which you can use to create complex Boolean expressions. Table 3-3 describes these operators.

Table 3-4 shows examples of several compound Boolean expressions that use logical operators.

**Table 3-3** Logical operators

| Operator | Meaning                                                                                                                                                                                                                                                                                                                             |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AND      | The AND operator connects two Boolean expressions into one compound expression. Both subexpressions must be true for the compound expression to be true.                                                                                                                                                                            |
| OR       | The OR operator connects two Boolean expressions into one compound expression. One or both subexpressions must be true for the compound expression to be true. It is only necessary for one of the subexpressions to be true, and it does not matter which.                                                                         |
| NOT      | The NOT operator is a unary operator, meaning it works with only one operand. The operand must be a Boolean expression. The NOT operator reverses the truth of its operand. If it is applied to an expression that is true, the operator returns false. If it is applied to an expression that is false, the operator returns true. |

**Table 3-4** Compound Boolean expressions using logical operators

| Expression                         | Meaning                                   |
|------------------------------------|-------------------------------------------|
| <code>x &gt; y AND a &lt; b</code> | Is x greater than y AND is a less than b? |
| <code>x == y OR x == z</code>      | Is x equal to y OR is x equal to z?       |
| <code>NOT (x &gt; y)</code>        | Is the expression x > y NOT true?         |



**NOTE:** In many languages, most notably C, C++, and Java, the AND operator is written as `&&`, the OR operator is written as `||`, and the NOT operator is written as `!`.

## The AND Operator

The AND operator takes two Boolean expressions as operands and creates a compound Boolean expression that is true only when both subexpressions are true. The following is an example of an If-Then statement that uses the AND operator:

```
If temperature < 20 AND minutes > 12 Then
 Display "The temperature is in the danger zone."
End If
```

In this statement, the two Boolean expressions `temperature < 20` and `minutes > 12` are combined into a compound expression. The `Display` statement will be executed only if `temperature` is less than 20 AND `minutes` is greater than 12. If either of the Boolean subexpressions is false, the compound expression is false and the message is not displayed.

Table 3-5 shows a truth table for the AND operator. The truth table lists expressions showing all the possible combinations of true and false connected with the AND operator. The resulting values of the expressions are also shown.

**Table 3-5** Truth table for the AND operator

| Expression      | Value of the Expression |
|-----------------|-------------------------|
| true AND false  | false                   |
| false AND true  | false                   |
| false AND false | false                   |
| true AND true   | true                    |

As Table 3-5 shows, both sides of the AND operator must be true for the operator to return a true value.

## The OR Operator

The OR operator takes two Boolean expressions as operands and creates a compound Boolean expression that is true when either of the subexpressions is true. The following is an example of an If-Then statement that uses the OR operator:

```
If temperature < 20 OR temperature > 100 Then
 Display "The temperature is in the danger zone."
End If
```

The Display statement will execute only if temperature is less than 20 OR temperature is greater than 100. If either subexpression is true, the compound expression is true. Table 3-6 shows a truth table for the OR operator.

**Table 3-6** Truth table for the OR operator

| Expression     | Value of the Expression |
|----------------|-------------------------|
| true OR false  | true                    |
| false OR true  | true                    |
| false OR false | false                   |
| true OR true   | true                    |

All it takes for an OR expression to be true is for one side of the OR operator to be true. It doesn't matter if the other side is false or true.

## Short-Circuit Evaluation

In many languages both the AND and OR operators perform *short-circuit evaluation*. Here's how it works with the AND operator: If the expression on the left side of the AND operator is false, the expression on the right side will not be checked. Because the compound expression will be false if only one of the subexpressions is false, it would waste CPU time to check the remaining expression. So, when the AND operator finds that the expression on its left is false, it short-circuits and does not evaluate the expression on its right.

Here's how short-circuit evaluation works with the OR operator: If the expression on the left side of the OR operator is true, the expression on the right side will not be checked. Because it is only necessary for one of the expressions to be true, it would waste CPU time to check the remaining expression.



**TIP:** If you are using a programming language that performs short-circuit evaluation, you should put some thought into the order in which you write the subexpressions in a compound Boolean expression. If you know which of the subexpressions is most likely to be true, you can improve the efficiency of the code.

For example, when writing an expression that uses the OR operator, you can improve the code's efficiency by writing the subexpression that is most likely to be true on the left side of the OR operator. If the left subexpression is true most of the time, that means the right subexpression will not be tested as many times, and the code will execute faster.

When writing an expression that uses the AND operator, you can improve the code's efficiency by writing the subexpression that is least likely to be true on the left side of the AND operator. If the left subexpression is false most of the time, that means the right subexpression will not be tested as many times, and the code will execute faster.

## The NOT Operator

The NOT operator is a unary operator that takes a Boolean expression as its operand and reverses its logical value. In other words, if the expression is true, the NOT operator returns false, and if the expression is false, the NOT operator returns true. The following is an If-Then statement using the NOT operator:

```
If NOT(temperature > 100) Then
 Display "This is below the maximum temperature."
End If
```

First, the expression (`temperature > 100`) is tested and a value of either true or false is the result. Then the NOT operator is applied to that value. If the expression (`temperature > 100`) is true, the NOT operator returns false. If the expression (`temperature > 100`) is false, the NOT operator returns true. The previous code is equivalent to asking: “Is the temperature not greater than 100?”



**NOTE:** In this example, we have put parentheses around the expression `temperature > 100`. The reason for this is that, in many languages, the NOT operator has higher precedence than the relational operators. Suppose we wrote the expression as follows:

```
NOT temperature > 100
```

In many languages this expression would not work correctly because the NOT operator would be applied to the `temperature` variable, not the expression `temperature > 100`. To make sure that the operator is applied to the expression, we enclose it in parentheses.

Table 3-7 shows a truth table for the NOT operator.

**Table 3-7** Truth table for the NOT operator

| Expression | Value of the Expression |
|------------|-------------------------|
| NOT true   | false                   |
| NOT false  | true                    |

## The Loan Qualifier Program Revisited

In some situations the AND operator can be used to simplify nested decision structures. For example, recall that the loan qualifier program in Program 3-5 uses the following nested If-Then-Else statements:

```
If salary >= 30000 Then
 If yearsOnJob >= 2 Then
 Display "You qualify for the loan."
 Else
 Display "You must have been on your current"
 Display "job for at least two years to qualify."
 End If
Else
 Display "You must earn at least $30,000"
 Display "per year to qualify."
End If
```

The purpose of this decision structure is to determine that a person's salary is at least \$30,000 and that they have been at their current job for at least two years. Program 3-9 shows a way to perform a similar task with simpler code.

### Program 3-9

```
1 // Declare variables
2 Declare Real salary, yearsOnJob
3
4 // Get the annual salary.
5 Display "Enter your annual salary."
6 Input salary
7
8 // Get the number of years on the current job.
9 Display "Enter the number of years on your ",
10 "current job."
11 Input yearsOnJob
12
13 // Determine whether the user qualifies.
14 If salary >= 30000 AND yearsOnJob >= 2 Then
15 Display "You qualify for the loan."
16 Else
17 Display "You do not qualify for this loan."
18 End If
```

### Program Output (with Input Shown in Bold)

```
Enter your annual salary.
35000 [Enter]
Enter the number of years on your current job.
1 [Enter]
You do not qualify for this loan.
```

### Program Output (with Input Shown in Bold)

```
Enter your annual salary.
25000 [Enter]
```

Enter the number of years on your current job.

5 [Enter]

You do not qualify for this loan.

### Program Output (with Input Shown in Bold)

Enter your annual salary.

35000 [Enter]

Enter the number of years on your current job.

5 [Enter]

You qualify for the loan.

The If-Then-Else statement in lines 14 through 18 tests the compound expression `salary >= 30000 AND yearsOnJob >= 2`. If both subexpressions are true, the compound expression is true and the message “You qualify for the loan” is displayed. If either of the subexpressions is false, the compound expression is false and the message “You do not qualify for this loan” is displayed.



**NOTE:** A careful observer will realize that Program 3-9 is similar to Program 3-5, but it is not equivalent. If the user does not qualify for the loan, Program 3-9 displays only the message “You do not qualify for this loan,” whereas Program 3-5 displays one of two possible messages explaining why the user did not qualify.

## Yet Another Loan Qualifier Program

Suppose the bank is losing customers to a competing bank that isn’t as strict about whom it loans money to. In response, the bank decides to change its loan requirements. Now, customers have to meet only one of the previous conditions, not both. Program 3-10 shows the pseudocode for the new loan qualifier program. The compound expression that is tested by the If-Then-Else statement in line 14 now uses the OR operator.

### Program 3-10

```
1 // Declare variables
2 Declare Real salary, yearsOnJob
3
4 // Get the annual salary.
5 Display "Enter your annual salary."
6 Input salary
7
8 // Get the number of years on the current job.
9 Display "Enter the number of years on your"
10 Display "current job."
11 Input yearsOnJob
12
13 // Determine whether the user qualifies.
14 If salary >= 30000 OR yearsOnJob >= 2 Then
15 Display "You qualify for the loan."
16 Else
17 Display "You do not qualify for this loan."
18 End If
```

**Program Output (with Input Shown in Bold)**

Enter your annual salary.  
**35000 [Enter]**  
 Enter the number of years on your  
 current job.  
**1 [Enter]**  
 You qualify for the loan.

**Program Output (with Input Shown in Bold)**

Enter your annual salary.  
**25000 [Enter]**  
 Enter the number of years on your  
 current job.  
**5 [Enter]**  
 You qualify for the loan.

**Program Output (with Input Shown in Bold)**

Enter your annual salary.  
**12000 [Enter]**  
 Enter the number of years on your  
 current job.  
**1 [Enter]**  
 You do not qualify for this loan.

## Checking Numeric Ranges with Logical Operators

Sometimes you will need to design an algorithm that determines whether a numeric value is within a specific range of values or outside a specific range of values. When determining whether a number is inside a range, it is best to use the AND operator. For example, the following If-Then statement checks the value in *x* to determine whether it is in the range of 20 through 40:

```
If x >= 20 AND x <= 40 Then
 Display "The value is in the acceptable range."
End If
```

The compound Boolean expression being tested by this statement will be true only when *x* is greater than or equal to 20 AND less than or equal to 40. The value in *x* must be within the range of 20 through 40 for this compound expression to be true.

When determining whether a number is outside a range, it is best to use the OR operator. The following statement determines whether *x* is outside the range of 20 through 40:

```
If x < 20 OR x > 40 Then
 Display "The value is outside the acceptable range."
End If
```

It is important not to get the logic of the logical operators confused when testing for a range of numbers. For example, the compound Boolean expression in the following pseudocode would never test true:

```
// This is an error!
If x < 20 AND x > 40 Then
 Display "The value is outside the acceptable range."
End If
```

Obviously, *x* cannot be less than 20 and at the same time be greater than 40.



## Checkpoint

- 3.21 What is a compound Boolean expression?
- 3.22 The following truth table shows various combinations of the values true and false connected by a logical operator. Complete the table by circling T or F to indicate whether the result of such a combination is true or false.
- | Logical Expression | Result (circle T or F) |   |
|--------------------|------------------------|---|
| True AND False     | T                      | F |
| True AND True      | T                      | F |
| False AND True     | T                      | F |
| False AND False    | T                      | F |
| True OR False      | T                      | F |
| True OR True       | T                      | F |
| False OR True      | T                      | F |
| False OR False     | T                      | F |
| NOT True           | T                      | F |
| NOT False          | T                      | F |
- 3.23 Assume the variables `a = 2`, `b = 4`, and `c = 6`. Circle the T or F for each of the following conditions to indicate whether its value is true or false.

|                                      |   |   |
|--------------------------------------|---|---|
| <code>a == 4 OR b &gt; 2</code>      | T | F |
| <code>6 &lt;= c AND a &gt; 3</code>  | T | F |
| <code>1 != b AND c != 3</code>       | T | F |
| <code>a &gt;= -1 OR a &lt;= b</code> | T | F |
| <code>NOT (a &gt; 2)</code>          | T | F |

- 3.24 Explain how short-circuit evaluation works with the AND and OR operators.
- 3.25 Write an If-Then statement that displays the message “The number is valid” if the variable speed is within the range 0 through 200.
- 3.26 Write an If-Then statement that displays the message “The number is not valid” if the variable speed is outside the range 0 through 200.

### 3.7

## Boolean Variables

**CONCEPT:** A Boolean variable can hold one of two values: true or false. Boolean variables are commonly used as flags, which indicate whether specific conditions exist.

So far in this book we have worked with `Integer`, `Real`, and `String` variables. In addition to numeric and string data types, most programming languages provide a `Boolean` data type. The `Boolean` data type allows you to create variables that may hold one of two possible values: `True` or `False`. Here is an example of the way we declare `Boolean` variables in this book:

```
Declare Boolean isHungry
```

Most programming languages have key words such as `True` and `False` that can be assigned to Boolean variables. Here are examples of how we assign values to a Boolean variable:

```
Set isHungry = True
Set isHungry = False
```

Boolean variables are most commonly used as flags. A *flag* is a variable that signals when some condition exists in the program. When the flag variable is set to `False`, it indicates the condition does not exist. When the flag variable is set to `True`, it means the condition does exist.

For example, suppose a salesperson has a quota of \$50,000. Assuming the `sales` variable holds the amount that the salesperson has sold, the following pseudocode determines whether the quota has been met:

```
If sales >= 50000 Then
 Set salesQuotaMet = True
Else
 Set salesQuotaMet = False
End If
```

As a result of this code, the `salesQuotaMet` variable can be used as a flag to indicate whether the sales quota has been met. Later in the program we might test the flag in the following way:

```
If salesQuotaMet Then
 Display "You have met your sales quota!"
End If
```

This code displays the message “You have met your sales quota!” if the Boolean variable `salesQuotaMet` equals `True`. Notice that we did not have to use the `==` operator to explicitly compare the `salesQuotaMet` variable with the value `True`. This code is equivalent to the following:

```
If salesQuotaMet == True Then
 Display "You have met your sales quota!"
End If
```



## Checkpoint

3.27 What values can you store in a Boolean variable?

3.28 What is a flag variable?

### 3.8

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter’s topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher’s website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

## Java

# Decision Structures and Boolean Logic in Java

### Relational Operators in Java

Java's relational operators, shown in Table 3-8, are the same as those used in our pseudocode programs earlier in this chapter.

**Table 3-8** Relational operators

| Operator | Meaning                  |
|----------|--------------------------|
| >        | Greater than             |
| <        | Less than                |
| >=       | Greater than or equal to |
| <=       | Less than or equal to    |
| ==       | Equal to                 |
| !=       | Not equal to             |

### The if Statement in Java

Here is the general format of the `if` statement in Java:

```
if (BooleanExpression)
{
 statement;
 statement;
 etc;
}
```

When the `if` statement executes, it evaluates the Boolean expression. If the expression is true, the statements inside the curly braces are executed. If the Boolean expression is false, the statements inside the curly braces are skipped.

If you are writing an `if` statement that has only one conditionally executed statement, you do not have to enclose the conditionally executed statement inside curly braces. Such an `if` statement can be written in the following general format:

```
if (BooleanExpression)
 statement;
```

When an `if` statement written in this format executes, the Boolean expression is tested. If it is true, the one statement that appears on the next line will be executed. If the Boolean expression is false, however, that one statement is skipped.

### The if-else Statement in Java

You use the `if-else` statement in Java to create a dual alternative decision structure. This is the format of the `if-else` statement:

```
if (BooleanExpression)
{
 statement;
 statement;
 etc;
}
```

```

 else
 {
 statement;
 statement;
 etc;
 }

```

The **if-else** statement tests a Boolean expression. If the expression is true, the block of statements following the **if** clause is executed, and then control of the program jumps to the statement that follows the **if-else** statement. If the Boolean expression is false, the block of statements following the **else** clause is executed, and then control of the program jumps to the statement that follows the **if-else** statement.

If either set of conditionally executed statements contains only one statement, the curly braces are not required. For example, the following general format shows only one statement following the **if** clause and only one statement following the **else** clause:

```

if (BooleanExpression)
 statement;
else
 statement;

```

### Comparing Strings in Java

In Java, you do not use the relational operators to compare strings. To determine whether **string1** is equal to **string2**, you use the following notation:

```
string1.equals(string2)
```

This is an expression that returns true if **string1** is equal to **string2**. Otherwise, it returns false. Here is an example:

```

String password = "Prospero";
if (password.equals("prospero"))
 System.out.println("Password accepted.");
else
 System.out.println("Sorry, that is not the correct password.");

```

You can also determine whether **string1** is less-than, equal-to, or greater-than **string2** using the following notation:

```
string1.compareTo(string2)
```

This expression returns an integer value that can be used in the following manner:

- If the expression's value is negative, then **string1** is less than **string2**.
- If the expression's value is 0, then **string1** and **string2** are equal.
- If the expression's value is positive, then **string1** is greater than **string2**.

For example, assume that **name1** and **name2** are **String** variables. The following **if** statement compares the strings:

```

if (name1.compareTo(name2) == 0)
 System.out.println("The names are the same.");

```

Also, the following statement compares **name1** to the string literal “Joe”:

```

if (name1.compareTo("Joe") == 0)
 System.out.println("The names are the same.");

```

### The switch Statement (Java's Case Structure)

In Java, case structures are written as switch statements. Here is the general format of the switch statement:

```

switch (testExpression) ← This is a variable or an expression.
{
 case value_1:
 statement
 statement
 etc.
 break;

 case value_2:
 statement
 statement
 etc.
 break;

 Insert as many case sections as necessary

 case value_N:
 statement
 statement
 etc.
 break;

 default:
 statement
 statement
 etc.
 }
} ← This is the end of the switch statement.

```

These statements are executed if the testExpression is equal to value\_1.

These statements are executed if the testExpression is equal to value\_2.

These statements are executed if the testExpression is equal to value\_N.

These statements are executed if the testExpression is not equal to any of the values listed after the Case statements.

For example, the following code performs the same operation as the flowchart in Figure 3-16:

```

switch (month)
{
 case 1:
 System.out.println("January");
 break;
 case 2:
 System.out.println("February");
 break;
 case 3:
 System.out.println("March");
 break;
 default:
 System.out.println("Error: Invalid month");
}

```

In this example, the *testExpression* is the `month` variable. If the value in the `month` variable is 1, the program will branch to the `case 1:` section and execute the `System.out.println("January")` statement that immediately follows it. If the value in the `month` variable is 2, the program will branch to the `case 2:` section and execute the `System.out.println("February")` statement that immediately follows it. If the value in the `month` variable is 3, the program will branch to the `case 3:` section and execute the `System.out.println("March")` statement that immediately follows it. If the value in the `month` variable is not 1, 2, or 3, the program will branch to the `default:` section and execute the `System.out.println("Error: Invalid month")` statement that immediately follows it.

Here are some important points to remember about the `switch` statement in Java:

- The *testExpression* must be a value or expression of one of these types: `char`, `byte`, `short`, `int`, or `String`.
- The value that follows a `case` statement must be a literal or a named constant of one of these types: `char`, `byte`, `short`, `int`, or `String`.
- The `break` statement that appears at the end of a `case` section is optional, but in most situations, you will need it. If the program executes a `case` section that does not end with a `break` statement, it will continue executing the code in the very next `case` section.
- The `default` section is optional, but in most situations, you should have one. The `default` section is executed when the *testExpression* does not match any of the `case` values.
- Because the `default` section appears at the end of the `switch` statement, it does not need a `break` statement.

### Logical Operators in Java

Java's logical operators look different than the ones used in this chapter's pseudocode, but they work in the same manner. Table 3-9 shows Java's logical operators.

**Table 3-9** Java's logical operators

| Operator                | Meaning     |
|-------------------------|-------------|
| <code>&amp;&amp;</code> | Logical AND |
| <code>  </code>         | Logical OR  |
| <code>!</code>          | Logical NOT |

For example, the following `if` statement checks the value in `x` to determine if it is in the range of 20 through 40:

```
if (x >= 20 && x <= 40)
 System.out.println(x + " is in the acceptable range.");
```

The Boolean expression in the `if` statement will be true only when `x` is greater than or equal to 20 AND less than or equal to 40. The value in `x` must be within the range of 20

through 40 for this expression to be true. The following statement determines whether `x` is outside the range of 20 through 40:

```
if (x < 20 || x > 40)
 System.out.println(x + " is outside the acceptable range.");
```

Here is an `if` statement using the `!` operator:

```
if (!(temperature > 100))
 System.out.println("This is below the maximum temperature.");
```

First, the expression `(temperature > 100)` is tested and a value of either true or false is the result. Then the `!` operator is applied to that value. If the expression `(temperature > 100)` is true, the `!` operator returns false. If the expression `(temperature > 100)` is false, the `!` operator returns true. The previous code is equivalent to asking: “Is the temperature not greater than 100?”

### Boolean Variables in Java

In Java, you use the `boolean` data type to create Boolean variables. A `boolean` variable can hold one of two possible values: `true` or `false`. Here is an example of a `boolean` variable declaration:

```
boolean highScore;
```

The variable might be used to signal that a high score has been achieved by the following code:

```
if (average > 95)
 highScore = true;
```

Later, the same program might use code similar to the following to test the `highScore` variable, in order to determine whether a high score has been achieved:

```
if (highScore)
 System.out.println("That's a high score!");
```

## Python

### Decision Structures and Boolean Logic in Python

#### Relational Operators in Python

Python’s relational operators, shown in Table 3-10, are the same as those used in our pseudocode programs earlier in this chapter.

**Table 3-10** Relational operators

| Operator           | Meaning                  |
|--------------------|--------------------------|
| <code>&gt;</code>  | Greater than             |
| <code>&lt;</code>  | Less than                |
| <code>&gt;=</code> | Greater than or equal to |
| <code>&lt;=</code> | Less than or equal to    |
| <code>==</code>    | Equal to                 |
| <code>!=</code>    | Not equal to             |

### The if Statement in Python

Here is the general format of the `if` statement in Python:

```
if BooleanExpression:
 statement
 statement
 etc.
```

For simplicity, we will refer to the first line as the `if clause`. The `if` clause begins with the word `if`, followed by a Boolean expression. A colon appears after the Boolean expression. Beginning at the next line is a block of statements. All of the statements in a block must be consistently indented. This indentation is required because the Python interpreter uses it to tell where the block begins and ends.

When the `if` statement executes, the Boolean expression is tested. If the Boolean expression is true, the statements that appear in the block following the `if` clause are executed. If the Boolean expression is false, the statements in the block are skipped.

### The if-else Statement (Python's Dual Alternative Decision Structure)

You use the `if-else` statement in Python to create a dual alternative decision structure. This is the format of the `if-else` statement:

```
if BooleanExpression:
 statement
 statement
 etc.
else:
 statement
 statement
 etc.
```

When this statement executes, the Boolean expression is tested. If it is true, the block of indented statements following the `if` clause is executed, and then control of the program jumps to the statement that follows the `if-else` statement. If the Boolean expression is false, the block of indented statements following the `else` clause is executed, and then control of the program jumps to the statement that follows the `if-else` statement.

### Comparing Strings in Python

The relational operators can be used to compare strings, as shown here:

```
name1 = 'Mary'
name2 = 'Mark'
if name1 == name2:
 print('The names are the same.')
else:
 print('The names are NOT the same.)
```

The `==` operator compares `name1` and `name2` to determine whether they are equal. Because the strings '`Mary`' and '`Mark`' are not equal, the `else` clause will display the message '`The names are NOT the same.`'

Let's look at another example. Assume the `month` variable references a string. The following code uses the `!=` operator to determine whether the value referenced by `month` is not equal to 'October'.

```
if month != 'October':
 print('This is the wrong time for Octoberfest!')
```



**NOTE:** Python does not prove a case structure, so we can't cover that topic in this section.

### Logical Operators in Python

Table 3-11 shows Python's logical operators, which work like the ones previously discussed in this chapter.

**Table 3-11** Python's logical operators

| Operator | Meaning     |
|----------|-------------|
| and      | Logical AND |
| or       | Logical OR  |
| not      | Logical NOT |

For example, the following `if` statement checks the value of `x` to determine if it is in the range of 20 through 40:

```
if x >= 20 and x <= 40:
 print(x, 'is in the acceptable range.')
```

The Boolean expression in the `if` statement will be true only when `x` is greater than or equal to 20 *AND* less than or equal to 40. The value in `x` must be within the range of 20 through 40 for this expression to be true. The following statement determines whether `x` is outside the range of 20 through 40:

```
if x < 20 or x > 40:
 print(x, 'is outside the acceptable range.')
```

Here is an `if` statement using the `not` operator:

```
if not (temperature > 100):
 print('This is below the maximum temperature.')
```

First, the expression `(temperature > 100)` is tested and a value of either true or false is the result. Then the `not` operator is applied to that value. If the expression `(temperature > 100)` is true, the `not` operator returns false. If the expression `(temperature > 100)` is false, the `not` operator returns true. The previous code is equivalent to asking: "Is the temperature not greater than 100?"

### Boolean Variables in Python

The `bool` data type allows you to create variables that may reference one of two possible values: `True` or `False`. Here are examples of how we assign values to a `bool` variable:

```
hungry = True
sleepy = False
```

Boolean variables are most commonly used as flags that signals when some condition exists in the program. When the flag variable is set to `False`, it indicates the condition does not exist. When the flag variable is set to `True`, it means the condition does exist.

For example, suppose a salesperson has a quota of \$50,000. Assuming sales references the amount that the salesperson has sold, the following code determines whether the quota has been met:

```
if sales >= 50000.0:
 sales_quota_met = True
else:
 sales_quota_met = False
```

## C++

### Decision Structures and Boolean Logic in C++

#### Relational Operators in C++

C++’s relational operators, shown in Table 3-12, are the same as those used in our pseudocode programs earlier in this chapter.

**Table 3-12** Relational operators

| Operator | Meaning                  |
|----------|--------------------------|
| >        | Greater than             |
| <        | Less than                |
| >=       | Greater than or equal to |
| <=       | Less than or equal to    |
| ==       | Equal to                 |
| !=       | Not equal to             |

#### The if Statement in C++

Here is the general format of the `if` statement in C++:

```
if (BooleanExpression)
{
 statement;
 statement;
 etc;
}
```

When the `if` statement executes, it evaluates the Boolean expression. If the expression is true, the statements inside the curly braces are executed. If the Boolean expression is false, the statements inside the curly braces are skipped.

If you are writing an `if` statement that has only one conditionally executed statement, you do not have to enclose the conditionally executed statement inside curly braces. Such an `if` statement can be written in the following general format:

```
if (BooleanExpression)
 statement;
```

When an `if` statement written in this format executes, the Boolean expression is tested. If it is true, the one statement that appears on the next line will be executed. If the Boolean expression is false, however, that one statement is skipped.

### The `if-else` Statement in C++

You use the `if-else` statement in C++ to create a dual alternative decision structure. This is the format of the `if-else` statement:

```
if (BooleanExpression)
{
 statement;
 statement;
 etc;
}
else
{
 statement;
 statement;
 etc;
}
```

The `if-else` statement tests a Boolean expression. If the expression is true, the block of statements following the `if` clause is executed, and then control of the program jumps to the statement that follows the `if-else` statement. If the Boolean expression is false, the block of statements following the `else` clause is executed, and then control of the program jumps to the statement that follows the `if-else` statement.

If either set of conditionally executed statements contains only one statement, the curly braces are not required. For example, the following general format shows only one statement following the `if` clause and only one statement following the `else` clause:

```
if (BooleanExpression)
 statement;
else
 statement;
```

### The `switch` Statement (C++'s Case Structure)

In C++, case structures are written as `switch` statements. Here is the general format of the `switch` statement:

```
switch (testExpression) ← This is an integer variable or an expression.
{
 case value_1:
 statement
 statement
 etc.
 break;
 case value_2:
 statement
 statement
 etc.
 break;
```

} These statements are executed if the testExpression is equal to value\_1.

} These statements are executed if the testExpression is equal to value\_2.

*Insert as many case sections as necessary*

```

case value_N:
 statement
 statement
 etc. } These statements are executed if the testExpression
 is equal to value_N.

 break;

default:
 statement
 statement
 etc. } These statements are executed if the testExpression
 is not equal to any of the values listed after the Case
 statements.

}
```

← This is the end of the switch statement.

When the `switch` statement executes, it compares the value of the `testExpression` with the values that follow each of the `case` statements (from top to bottom). When it finds a `case` value that matches the `testExpression`'s value, the program branches to the `case` statement. The statements that follow the `case` statement are executed, until a `break` statement is encountered. At that point, program jumps out of the `switch` statement. If the `testExpression` does not match any of the `case` values, the program branches to the `default` statement and executes the statements that immediately following it.

For example, the following code performs the same operation as the flowchart in Figure 3-16:

```

switch (month)
{
 case 1:
 cout << "January" << endl;
 break;
 case 2:
 cout << "February" << endl;
 break;
 case 3:
 cout << "March" << endl;
 break;
 default:
 cout << "Error: Invalid month" << endl;
}
```

Here are some important points to remember about the `switch` statement in C++:

- The `testExpression` must be a value or expression of one of the integer data types (including `char`).
- The value that follows a `case` statement must be a literal or a named constant of one of the integer data types (including `char`).
- The `break` statement that appears at the end of a `case` section is optional, but in most situations, you will need it. If the program executes a `case` section that does not end with a `break` statement, it will continue executing the code in the very next `case` section.
- The `default` section is optional, but in most situations, you should have one. The `default` section is executed when the `testExpression` does not match any of the `case` values.
- Because the `default` section appears at the end of the `switch` statement, it does not need a `break` statement.

### Logical Operators in C++

C++'s logical operators look different than the ones used in this chapter's pseudocode, but they work in the same manner. Table 3-13 shows C++'s logical operators.

**Table 3-13** C++'s logical operators

| Operator | Meaning     |
|----------|-------------|
| &&       | Logical AND |
|          | Logical OR  |
| !        | Logical NOT |

For example, the following `if` statement checks the value in `x` to determine if it is in the range of 20 through 40:

```
if (x >= 20 && x <= 40)
 cout << x << " is in the acceptable range." << endl;
```

The Boolean expression in the `if` statement will be true only when `x` is greater than or equal to 20 AND less than or equal to 40. The value in `x` must be within the range of 20 through 40 for this expression to be true. The following statement determines whether `x` is outside the range of 20 through 40:

```
if (x < 20 || x > 40)
 cout << x << " is outside the acceptable range." << endl;
```

Here is an `if` statement using the `!` operator:

```
if (!(temperature > 100))
 cout << "This is below the maximum temperature." << endl;
```

First, the expression `(temperature > 100)` is tested and a value of either true or false is the result. Then the `!` operator is applied to that value. If the expression `(temperature > 100)` is true, the `!` operator returns false. If the expression `(temperature > 100)` is false, the `!` operator returns true. The previous code is equivalent to asking: “Is the temperature not greater than 100?”

### bool Variables in C++

In C++, you use the `bool` data type to create Boolean variables. A `boolean` variable can hold one of two possible values: `true` or `false`. Here is an example of a `bool` variable declaration:

```
bool highScore;
```

Boolean variables are commonly used as flags that signal when some condition exists in the program. When the flag variable is set to false, it indicates the condition does not yet exist. When the flag variable is set to true, it means the condition does exist.

For example, suppose a test grading program has a `bool` variable named `highScore`. The variable might be used to signal that a high score has been achieved by the following code:

```
if (average > 95)
 highScore = true;
```

## Review Questions

### Multiple Choice

1. A \_\_\_\_\_ structure can execute a set of statements only under certain circumstances.
  - a. sequence
  - b. circumstantial
  - c. decision
  - d. Boolean
2. A \_\_\_\_\_ structure provides one alternative path of execution.
  - a. sequence
  - b. single alternative decision
  - c. one path alternative
  - d. single execution decision
3. In pseudocode, the **If-Then** statement is an example of a \_\_\_\_\_.
  - a. sequence structure
  - b. decision structure
  - c. pathway structure
  - d. class structure
4. A(n) \_\_\_\_\_ expression has a value of either true or false.
  - a. binary
  - b. decision
  - c. unconditional
  - d. Boolean
5. The symbols `>`, `<`, and `==` are all \_\_\_\_\_ operators.
  - a. relational
  - b. logical
  - c. conditional
  - d. ternary
6. A(n) \_\_\_\_\_ structure tests a condition and then takes one path if the condition is true, or another path if the condition is false.
  - a. **If-Then** statement
  - b. single alternative decision
  - c. dual alternative decision
  - d. sequence
7. You use a(n) \_\_\_\_\_ statement in pseudocode to write a single alternative decision structure.
  - a. **Test-Jump**
  - b. **If-Then**
  - c. **If-Then-Else**
  - d. **If-Call**

8. You use a(n) \_\_\_\_\_ statement in pseudocode to write a dual alternative decision structure.
  - a. Test-Jump
  - b. If-Then
  - c. If-Then-Else
  - d. If-Call
9. A \_\_\_\_\_ structure allows you to test the value of a variable or an expression and then use that value to determine which statement or set of statements to execute.
  - a. variable test decision
  - b. single alternative decision
  - c. dual alternative decision
  - d. multiple alternative decision
10. A(n) \_\_\_\_\_ section of a `Select Case` statement is branched to if none of the case values match the expression listed after the `Select` statement.
  - a. Else
  - b. Default
  - c. Case
  - d. Otherwise
11. AND, OR, and NOT are \_\_\_\_\_ operators.
  - a. relational
  - b. logical
  - c. conditional
  - d. ternary
12. A compound Boolean expression created with the \_\_\_\_\_ operator is true only if both of its subexpressions are true.
  - a. AND
  - b. OR
  - c. NOT
  - d. BOTH
13. A compound Boolean expression created with the \_\_\_\_\_ operator is true if either of its subexpressions is true.
  - a. AND
  - b. OR
  - c. NOT
  - d. EITHER
14. The \_\_\_\_\_ operator takes a Boolean expression as its operand and reverses its logical value.
  - a. AND
  - b. OR
  - c. NOT
  - d. EITHER

15. A \_\_\_\_\_ is a Boolean variable that signals when some condition exists in the program.
- flag
  - signal
  - sentinel
  - siren

### True or False

1. You can write any program using only sequence structures.
2. A program can be made of only one type of control structure. You cannot combine structures.
3. A single alternative decision structure tests a condition and then takes one path if the condition is true, or another path if the condition is false.
4. A decision structure can be nested inside another decision structure.
5. A compound Boolean expression created with the AND operator is true only when both subexpressions are true.

### Short Answer

1. Explain what is meant by the term *conditionally executed*.
2. You need to test a condition and then execute one set of statements if the condition is true. If the condition is false, you need to execute a different set of statements. What structure will you use?
3. If you need to test the value of a variable and use that value to determine which statement or set of statements to execute, which structure would be the most straightforward to use?
4. Briefly describe how the AND operator works.
5. Briefly describe how the OR operator works.
6. When determining whether a number is inside a range, which logical operator is it best to use?
7. What is a flag and how does it work?

### Algorithm Workbench

1. Design an If-Then statement (or a flowchart with a single alternative decision structure) that assigns 20 to the variable *y* and assigns 40 to the variable *z* if the variable *x* is greater than 100.
2. Design an If-Then statement (or a flowchart with a single alternative decision structure) that assigns 0 to the variable *b* and assigns 1 to the variable *c* if the variable *a* is less than 10.
3. Design an If-Then-Else statement (or a flowchart with a dual alternative decision structure) that assigns 0 to the variable *b* if the variable *a* is less than 10. Otherwise, it should assign 99 to the variable *b*.

4. The following pseudocode contains several nested **If-Then-Else** statements. Unfortunately, it was written without proper alignment and indentation. Rewrite the code and use the proper conventions of alignment and indentation.

```
If score < 60 Then
 Display "Your grade is F."
Else
 If score < 70 Then
 Display "Your grade is D."
 Else
 If score < 80 Then
 Display "Your grade is C."
 Else
 If score < 90 Then
 Display "Your grade is B."
 Else
 Display "Your grade is A."
 End If
 End If
 End If
End If
```

5. Design nested decision structures that perform the following: If **amount1** is greater than 10 and **amount2** is less than 100, display the greater of **amount1** and **amount2**.

6. Rewrite the following **If-Then-Else If** statement as a **Select Case** statement.

```
If selection == 1 Then
 Display "You selected A."
Else If selection == 2 Then
 Display "You selected 2."
Else If selection == 3 Then
 Display "You selected 3."
Else If selection == 4 Then
 Display "You selected 4."
Else
 Display "Not good with numbers, eh?"
End If
```

7. Design an **If-Then-Else** statement (or a flowchart with a dual alternative decision structure) that displays “Speed is normal” if the **speed** variable is within the range of 24 to 56. If **speed** holds a value outside this range, display “Speed is abnormal.”

8. Design an **If-Then-Else** statement (or a flowchart with a dual alternative decision structure) that determines whether the **points** variable is outside the range of 9 to 51. If the variable holds a value outside this range it should display “Invalid points.” Otherwise, it should display “Valid points.”

9. Design a case structure that tests the **month** variable and does the following:

- If the **month** variable is set to 1, it displays “January has 31 days.”
- If the **month** variable is set to 2, it displays “February has 28 days.”
- If the **month** variable is set to 3, it displays “March has 31 days.”
- If the **month** variable is set to anything else, it displays “Invalid selection.”

10. Write an **If-Then** statement that sets the variable **hours** to 10 when the flag variable **minimum** is set.

## Debugging Exercises

- Part of the following pseudocode is incompatible with the Java, Python, C, and C++ languages. Identify the problem. How would you fix the problem if you were to translate this pseudocode into one of the aforementioned languages?

```
If num1 = num2 Then
 Display "The values are equal."
Else
 Display "The values are NOT equal."
End If
```

- The intended purpose of the following pseudocode is to set the `temp` variable to the value 32.0 if it is not already equal to 32.0. This will not work as the programmer expects, however. Find the problem.

```
If NOT temp == 32.0 Then
 Set temp = 32.0
End If
```

- The intended purpose of the following pseudocode is to determine whether the `value` variable is within a specified range. The logic will not work, however. Find the problem.

```
If value < lower AND value > upper Then
 Display "The value is outside the range."
Else
 Display "The value is within the range."
End If
```

## Programming Exercises



VideoNote  
The Areas of Rectangles Problem

### 1. Roman Numerals

Design a program that prompts the user to enter a number within the range of 1 through 10. The program should display the Roman numeral version of that number. If the number is outside the range of 1 through 10, the program should display an error message.

### 2. Areas of Rectangles

The area of a rectangle is the rectangle's length times its width. Design a program that asks for the length and width of two rectangles. The program should tell the user which rectangle has the greater area, or whether the areas are the same.

### 3. Mass and Weight

Scientists measure an object's mass in kilograms and its weight in Newtons. If you know the amount of mass of an object, you can calculate its weight, in Newtons, with the following formula:

$$\text{Weight} = \text{Mass} \times 9.8$$

Design a program that asks the user to enter an object's mass, and then calculates its weight. If the object weighs more than 1,000 Newtons, display a message indicating that it is too heavy. If the object weighs less than 10 Newtons, display a message indicating that it is too light.

#### 4. Magic Dates

The date June 10, 1960, is special because when it is written in the following format, the month times the day equals the year:

6/10/60

Design a program that asks the user to enter a month (in numeric form), a day, and a two-digit year. The program should then determine whether the month times the day equals the year. If so, it should display a message saying the date is magic. Otherwise, it should display a message saying the date is not magic.

#### 5. Color Mixer

The colors red, blue, and yellow are known as the primary colors because they cannot be made by mixing other colors. When you mix two primary colors, you get a secondary color, as shown here:

- When you mix red and blue, you get purple.
- When you mix red and yellow, you get orange.
- When you mix blue and yellow, you get green.

Design a program that prompts the user to enter the names of two primary colors to mix. If the user enters anything other than "red," "blue," or "yellow," the program should display an error message. Otherwise, the program should display the name of the secondary color that results.

#### 6. Book Club Points

Serendipity Booksellers has a book club that awards points to its customers based on the number of books purchased each month. The points are awarded as follows:

- If a customer purchases 0 books, 0 points are awarded.
- If a customer purchases 1 book, 5 points are awarded.
- If a customer purchases 2 books, 15 points are awarded.
- If a customer purchases 3 books, 30 points are awarded.
- If a customer purchases 4 or more books, 60 points are awarded.

Design a program that asks the user to enter the number of books they have purchased this month and displays the number of points awarded.

#### 7. Software Sales

A software company sells a package that retails for \$99. Quantity discounts are given according to the following table:

| Quantity    | Discount |
|-------------|----------|
| 10–19       | 20%      |
| 20–49       | 30%      |
| 50–99       | 40%      |
| 100 or more | 50%      |

Design a program that asks the user to enter the number of packages purchased. The program should then display the amount of the discount (if any) and the total amount of the purchase after the discount.

#### 8. Change for a Dollar Game

Design a change-counting game that gets the user to enter the number of coins required to make exactly one dollar. The program should ask the user to enter the number of pennies, nickels, dimes, and quarters. If the total value of the coins entered is equal to one dollar, the program should congratulate the user for winning the game. Otherwise, the program should display a message indicating whether the amount entered was more than or less than one dollar.

#### 9. Shipping Charges

The Fast Freight Shipping Company charges the following rates:

| Weight of Package                         | Rate per Pound |
|-------------------------------------------|----------------|
| 2 pounds or less                          | \$1.10         |
| Over 2 pounds but not more than 6 pounds  | \$2.20         |
| Over 6 pounds but not more than 10 pounds | \$3.70         |
| Over 10 pounds                            | \$3.80         |

Design a program that asks the user to enter the weight of a package and then displays the shipping charges.

#### 10. Time Calculator

Design a program that asks the user to enter a number of seconds, and works as follows:

- There are 60 seconds in a minute. If the number of seconds entered by the user is greater than or equal to 60, the program should display the number of minutes in that many seconds.
- There are 3,600 seconds in an hour. If the number of seconds entered by the user is greater than or equal to 3,600, the program should display the number of hours in that many seconds.
- There are 86,400 seconds in a day. If the number of seconds entered by the user is greater than or equal to 86,400, the program should display the number of days in that many seconds.

#### 11. Leap Year Detector

Design a program that asks the user to enter a year, and then displays a message indicating whether that year is a leap year or not. Use the following logic to develop your algorithm:

- If the year is evenly divisible by 100 and is also evenly divisible by 400, then it is a leap year. For example, 2000 is a leap year but 2010 is not.
- If the year is not evenly divisible by 100, but it is evenly divisible by 4, it is a leap year. For example, 2008 is a leap year but 2009 is not.

## TOPICS

- |                                                                  |                                                  |
|------------------------------------------------------------------|--------------------------------------------------|
| 4.1 Introduction to Repetition Structures                        | 4.4 Calculating a Running Total                  |
| 4.2 Condition-Controlled Loops: While,<br>Do-While, and Do-Until | 4.5 Sentinels                                    |
| 4.3 Count-Controlled Loops and the For<br>Statement              | 4.6 Nested Loops                                 |
|                                                                  | 4.7 Focus on Languages: Java, Python,<br>and C++ |

## 4.1

## Introduction to Repetition Structures

**CONCEPT:** A repetition structure causes a statement or set of statements to execute repeatedly.

Programmers commonly have to write code that performs the same task over and over. For example, suppose you have been asked to write a program that calculates a 10 percent sales commission for several salespeople. Although it would not be a good design, one approach would be to write the code to calculate one salesperson's commission, and then repeat that code for each salesperson. For example, look at the following pseudocode:

```
// Variables for sales and commission.
Declare Real sales, commission

// Constant for the commission rate.
Constant Real COMMISSION_RATE = 0.10

// Get the amount of sales.
Display "Enter the amount of sales."
Input sales

// Calculate the commission.
Set commission = sales * COMMISSION_RATE

// Display the commission
Display "The commission is $", commission
```

This calculates the first salesperson's commission.

```

// Get the amount of sales.
Display "Enter the amount of sales."
Input sales

// Calculate the commission.
Set commission = sales * COMMISSION_RATE

// Display the commission
Display "The commission is $", commission

```

} This calculates the second salesperson's commission.

**And this code goes on and on . . .**

As you can see, this is one long sequence structure containing a lot of duplicated code. There are several disadvantages to this approach, including the following:

- The duplicated code makes the program large.
- Writing a long sequence of statements can be time consuming.
- If part of the duplicated code has to be corrected or changed, then the correction or change has to be done many times.

Instead of writing the same sequence of statements over and over, a better way to repeatedly perform an operation is to write the code for the operation once, and then place that code in a structure that makes the computer repeat it as many times as necessary. This can be done with a *repetition structure*, which is more commonly known as a *loop*.

## Condition-Controlled and Count-Controlled Loops

In this chapter, we will look at two broad categories of loops: condition-controlled and count-controlled. A *condition-controlled loop* uses a true/false condition to control the number of times that it repeats. A *count-controlled loop* repeats a specific number of times. We will also discuss the specific ways that most programming languages allow you to construct these types of loops.



### Checkpoint

- 4.1 What is a repetition structure?
- 4.2 What is a condition-controlled loop?
- 4.3 What is a count-controlled loop?

**4.2**

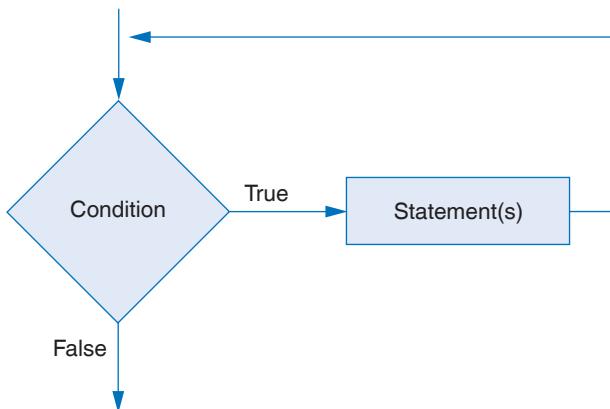
## Condition-Controlled Loops: While , Do-While , and Do-Until

**CONCEPT:** Both the While and Do-While loops cause a statement or set of statements to repeat as long as a condition is true. The Do-Until loop causes a statement or set of statements to repeat until a condition is true.

## The While Loop

The `While` loop gets its name from the way it works: *While a condition is true, do some task*. The loop has two parts: (1) a condition that is tested for a true or false value, and (2) a statement or set of statements that is repeated as long as the condition is true. Figure 4-1 shows the logic of a `While` loop.

**Figure 4-1** The logic of a `While` loop



The diamond symbol represents the condition that is tested. Notice what happens if the condition is true: one or more statements are executed and the program's execution flows back to the point just above the diamond symbol. The condition is tested again, and if it is true, the process repeats. If the condition is false, the program exits the loop. In a flowchart, you will always recognize a loop when you see a flow line going back to a previous part of the flowchart.

## Writing a While Loop in Pseudocode

In pseudocode, we will use the `While` statement to write a `While` loop. Here is the general format of the `While` statement:

```
While condition
 statement
 statement
 etc.
End While
```

} These statements are the body of the loop. They are repeated while the condition is true.

In the general format, the *condition* is a Boolean expression, and the statements that appear on the lines between the `While` and the `End While` clauses are called the *body of the loop*. When the loop executes, the *condition* is tested. If it is true, the statements that appear in the body of the loop are executed, and then the loop starts over. If the *condition* is false, the program exits the loop.

As shown in the general format, you should use the following conventions when you write a `While` statement:

- Make sure the `While` clause and the `End While` clause are aligned.
- Indent the statements in the body of the loop.

By indenting the statements in the body of the loop you visually set them apart from the surrounding code. This makes your program easier to read and debug. Also, this is similar to the style that most programmers follow when writing loops in actual code.

Program 4-1 shows how we might use a `While` loop to write the commission calculating program that was described at the beginning of this chapter.

### Program 4-1

```
1 // Variable declarations
2 Declare Real sales, commission
3 Declare String keepGoing = "y"
4
5 // Constant for the commission rate
6 Constant Real COMMISSION_RATE = 0.10
7
8 While keepGoing == "y"
9 // Get the amount of sales.
10 Display "Enter the amount of sales."
11 Input sales
12
13 // Calculate the commission.
14 Set commission = sales * COMMISSION_RATE
15
16 // Display the commission
17 Display "The commission is $", commission
18
19 Display "Do you want to calculate another"
20 Display "commission? (Enter y for yes.)"
21 Input keepGoing
22 End While
```

### Program Output (with Input Shown in Bold)

```
Enter the amount of sales.
10000.00 [Enter]
The commission is $1000
Do you want to calculate another
commission? (Enter y for yes.)
y [Enter]
Enter the amount of sales.
5000.00 [Enter]
The commission is $500
Do you want to calculate another
commission? (Enter y for yes.)
y [Enter]
Enter the amount of sales.
12000.00 [Enter]
The commission is $1200
Do you want to calculate another
commission? (Enter y for yes.)
n [Enter]
```

In line 2, we declare the `sales` variable, which will hold the amount of sales, and the `commission` variable, which will hold the amount of commission. Then, in line 3 we declare a `String` variable named `keepGoing`. Notice that the variable is initialized with the value “y.” This initialization value is important, and in a moment you will see why. In line 6 we declare a constant, `COMMISSION_RATE`, which is initialized with the value 0.10. This is the commission rate that we will use in our calculation.

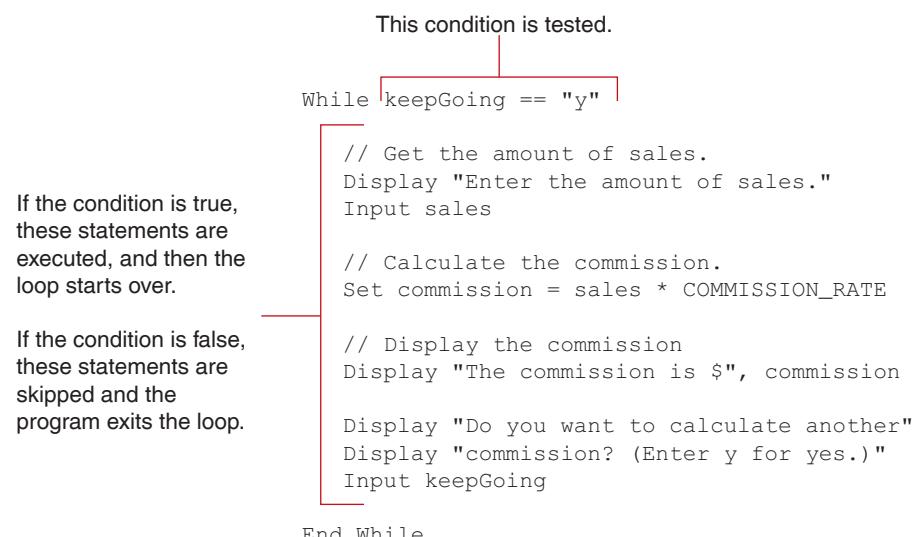
Line 8 is the beginning of a `While` loop, which starts like this:

```
While keepGoing == "y"
```

Notice the condition that is being tested: `keepGoing == "y"`. The loop tests this condition, and if it is true, the statements in the body of the loop (lines 9 through 21) are executed. Then, the loop starts over at line 8. It tests the expression `keepGoing == "y"` and if it is true, the statements in the body of the loop are executed again. This cycle repeats until the expression `keepGoing == "y"` is tested in line 8 and found to be false. When that happens, the program exits the loop. This is illustrated in Figure 4-2.

In order for this loop to stop executing, something has to happen inside the loop to make the expression `keepGoing == "y"` false. The statements in lines 19 through 21 take care of this. Lines 19 and 20 display a message asking “Do you want to calculate another commission? (Enter y for yes.)” Then, the `Input` statement in line 21 reads the user’s input and stores it in the `keepGoing` variable. If the user enters y (and it must be a lowercase y), then the expression `keepGoing == "y"` will be true when the loop starts over. This will cause the statements in the body of the loop to execute again. But, if the user enters anything other than lowercase y, the expression will be false when the loop starts over, and the program will exit the loop.

**Figure 4-2** The `While` loop

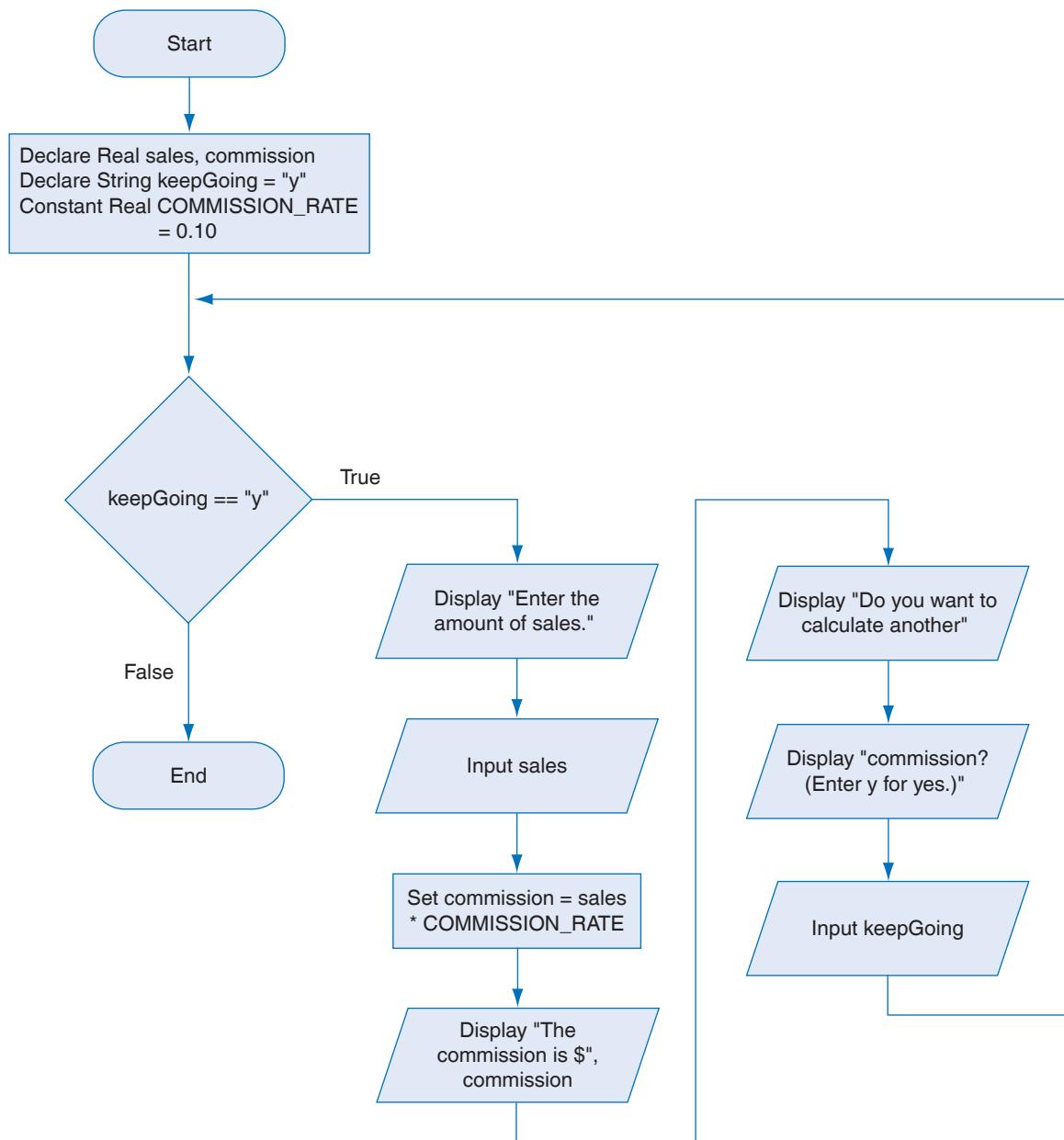


Now that you have examined the pseudocode, look at the program output in the sample run. First, the program prompted the user to enter the amount of sales. The user entered 10000.00, and then the program displayed the commission for that amount, which is \$1000.00. Then, the user is prompted “Do you want to calculate another commission?

(Enter y for yes.)” The user entered y, and the loop started the steps over. In the sample run, the user went through this process three times. Each execution of the body of a loop is known as an *iteration*. In the sample run, the loop iterated three times.

Figure 4-3 shows a flowchart for Program 4-1. By looking at this flowchart you can see that we have a repetition structure (the `While` loop) with a sequence structure (the body of the loop) nested inside it. The fundamental structure of the `While` loop is still present, however. A condition is tested, and if it is true one or more statements are executed and the flow of execution returns to the point just above the conditional test.

**Figure 4-3** Flowchart for Program 4-1



## The While Loop Is a Pretest Loop

The `While` loop is known as a *pretest* loop, which means it tests its condition *before* performing an iteration. Because the test is done at the beginning of the loop, you usually have to perform some steps prior to the loop to make sure that the loop executes at least once. For example, the loop in Program 4-1 starts like this:

```
While keepGoing == "y"
```

The loop will perform an iteration only if the expression `keepGoing == "y"` is true. To make sure the expression is true the first time that the loop executes, we declared and initialized the `keepGoing` variable in line 3 as follows:

```
Declare String keepGoing = "y"
```

If `keepGoing` had been initialized with any other value (or not initialized at all), the loop would never execute. This is an important characteristic of the `While` loop: it will never execute if its condition is false to start with. In some programs, this is exactly what you want. The following *In the Spotlight* section gives an example.

### In the Spotlight: Designing a While Loop



A project currently underway at Chemical Labs, Inc. requires that a substance be continually heated in a vat. A technician must check the substance's temperature every 15 minutes. If the substance's temperature does not exceed 102.5, then the technician does nothing. However, if the temperature is greater than 102.5, the technician must turn down the vat's thermostat, wait five minutes, and check the temperature again. The technician repeats these steps until the temperature does not exceed 102.5. The director of engineering has asked you to design a program that guides the technician through this process.

Here is the algorithm:

1. Get the substance's temperature.
2. Repeat the following steps as long as the temperature is greater than 102.5:
  - a. Tell the technician to turn down the thermostat, wait five minutes, and check the temperature again.
  - b. Get the substance's temperature.
3. After the loop finishes, tell the technician that the temperature is acceptable and to check it again in 15 minutes.

After reviewing this algorithm, you realize that steps 2(a) and 2(b) should not be performed if the test condition (temperature is greater than 102.5) is false to begin with. The `While` loop will work well in this situation, because it will not execute even once if its condition is false. Program 4-2 shows the pseudocode for the program, and Figure 4-4 shows a flowchart.

**Program 4-2**

```

1 // Variable to hold the temperature
2 Declare Real temperature
3
4 // Constant for the maximum temperature
5 Constant Real MAX_TEMP = 102.5
6
7 // Get the substance's temperature.
8 Display "Enter the substance's temperature."
9 Input temperature
10
11 // If necessary, adjust the thermostat.
12 While temperature > MAX_TEMP
13 Display "The temperature is too high."
14 Display "Turn the thermostat down and wait"
15 Display "five minutes. Take the temperature"
16 Display "again and enter it here."
17 Input temperature
18 End While
19
20 // Remind the user to check the temperature
21 // again in 15 minutes.
22 Display "The temperature is acceptable."
23 Display "Check it again in 15 minutes."

```

**Program Output (with Input Shown in Bold)**

Enter the substance's temperature.

**104.7 [Enter]**

The temperature is too high.

Turn the thermostat down and wait  
five minutes. Take the temperature  
again and enter it here.

**103.2 [Enter]**

The temperature is too high.

Turn the thermostat down and wait  
five minutes. Take the temperature  
again and enter it here.

**102.1 [Enter]**

The temperature is acceptable.

Check it again in 15 minutes.

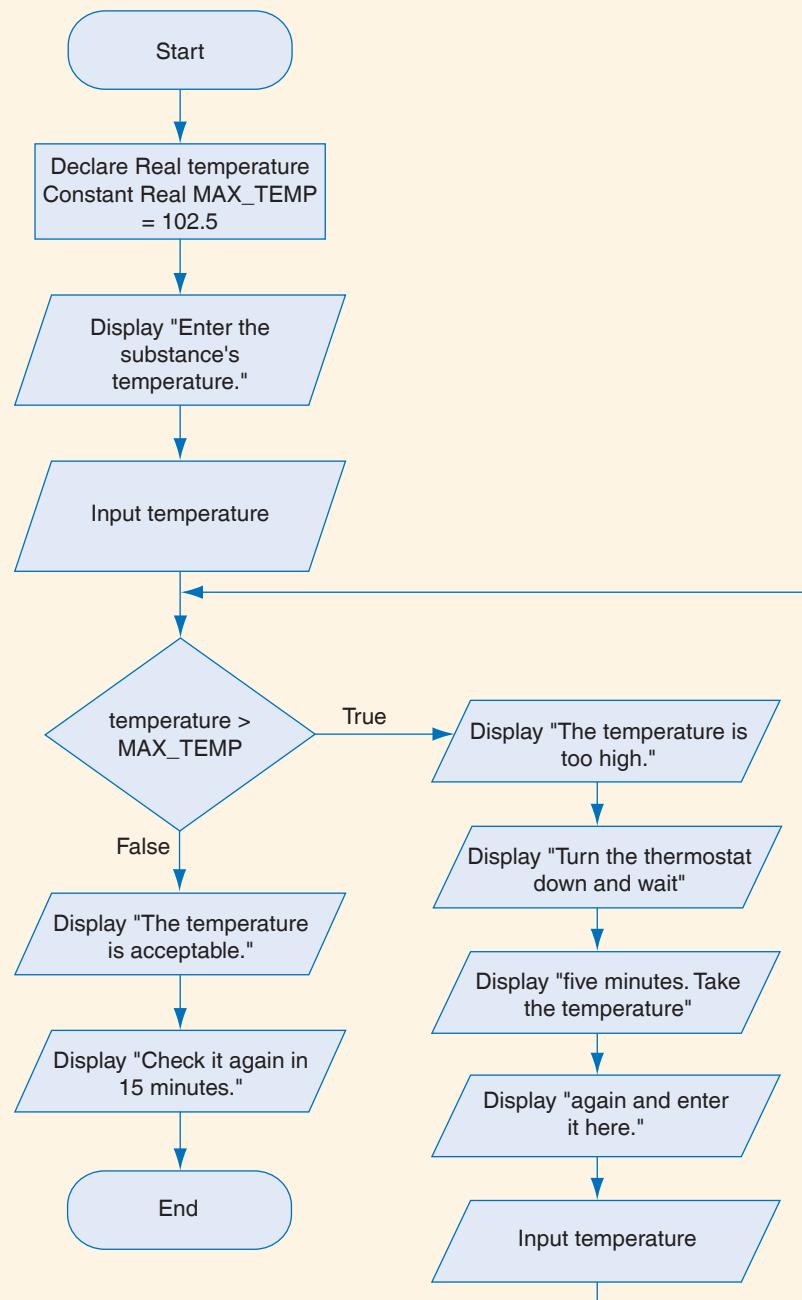
**Program Output (with Input Shown in Bold)**

Enter the substance's temperature.

**102.1 [Enter]**

The temperature is acceptable.

Check it again in 15 minutes.

**Figure 4-4** Flowchart for Program 4-2

## Infinite Loops

In all but rare cases, loops must contain within themselves a way to terminate. This means that something inside the loop must eventually make the test condition false. The loop in Program 4-1 stops when the expression `keepGoing == "y"` is false. If a loop does not have a way of stopping, it is called an infinite loop. An *infinite loop* continues to repeat until the program is interrupted. Infinite loops usually occur when the programmer forgets to write code inside the loop that makes the test condition false. In most circumstances you should avoid writing infinite loops.

The pseudocode in Program 4-3 demonstrates an infinite loop. This is a modified version of the commission calculating program. In this version, we have removed the code that modifies the `keepGoing` variable in the body of the loop. Each time the expression `keepGoing == "y"` is tested in line 9, `keepGoing` will contain the string "y". As a consequence, the loop has no way of stopping.

### Program 4-3

```

1 // Variable declarations
2 Declare Real sales, commission
3 Declare String keepGoing = "y"
4
5 // Constant for the commission rate
6 Constant Real COMMISSION_RATE = 0.10
7
8 // Warning! Infinite loop!
9 While keepGoing == "y"
10 // Get the amount of sales.
11 Display "Enter the amount of sales."
12 Input sales
13
14 // Calculate the commission.
15 Set commission = sales * COMMISSION_RATE
16
17 // Display the commission
18 Display "The commission is $", commission
19 End While

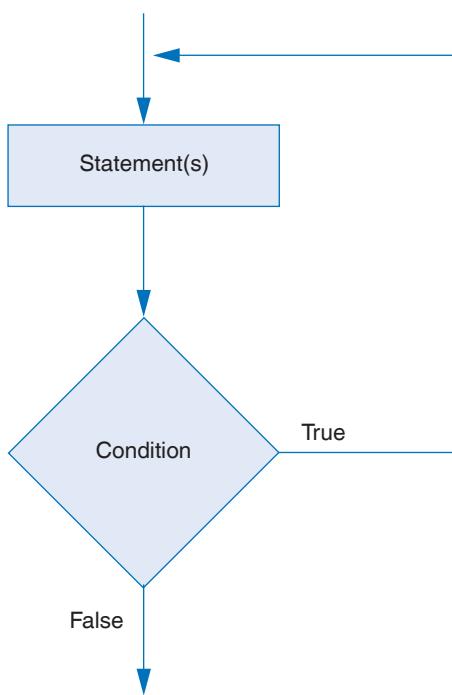
```



VideoNote  
The Do-While Loop

## The Do-While Loop

You have learned that the `While` loop is a *pretest* loop, which means it tests its condition before performing an iteration. The `Do-While` loop is a *posttest* loop. This means it performs an iteration before testing its condition. As a result, the `Do-While` loop always performs at least one iteration, even if its condition is false to begin with. The logic of a `Do-While` loop is shown in Figure 4-5.

**Figure 4-5** The logic of a Do-While loop

In the flowchart, one or more statements are executed, and then a condition is tested. If the condition is true, the program's execution flows back to the point just above the first statement in the body of the loop, and this process repeats. If the condition is false, the program exits the loop.

## Writing a Do-While Loop in Pseudocode

In pseudocode, we will use the Do-While statement to write a Do-While loop. Here is the general format of the Do-While statement:

```
Do
 statement
 statement
 etc.
} These statements are the body of the loop. They are always
performed once, and then repeated while the condition is true.
 While condition
```

In the general format, the statements that appear in the lines between the `Do` and the `While` clauses are the body of the loop. The *condition* that appears after the `While` clause is a Boolean expression. When the loop executes, the statements in the body of the loop are executed, and then the *condition* is tested. If the *condition* is true, the loop starts over and the statements in the body are executed again. If the condition is false, however, the program exits the loop.

As shown in the general format, you should use the following conventions when you write a Do-While statement:

- Make sure the `Do` clause and the `While` clause are aligned.
- Indent the statements in the body of the loop.

As shown in Program 4-4, the commission calculating program can be easily modified to use a **Do-While** loop instead of a **While** loop. Notice that in this version of the program, in line 3, we do not initialize the `keepGoing` variable with the string "y". It isn't necessary because the **Do-While** loop, in lines 7 through 15, will always execute at least once. This means that the `Input` statement in line 14 will read a value into the `keepGoing` variable before the condition is ever tested in line 15.

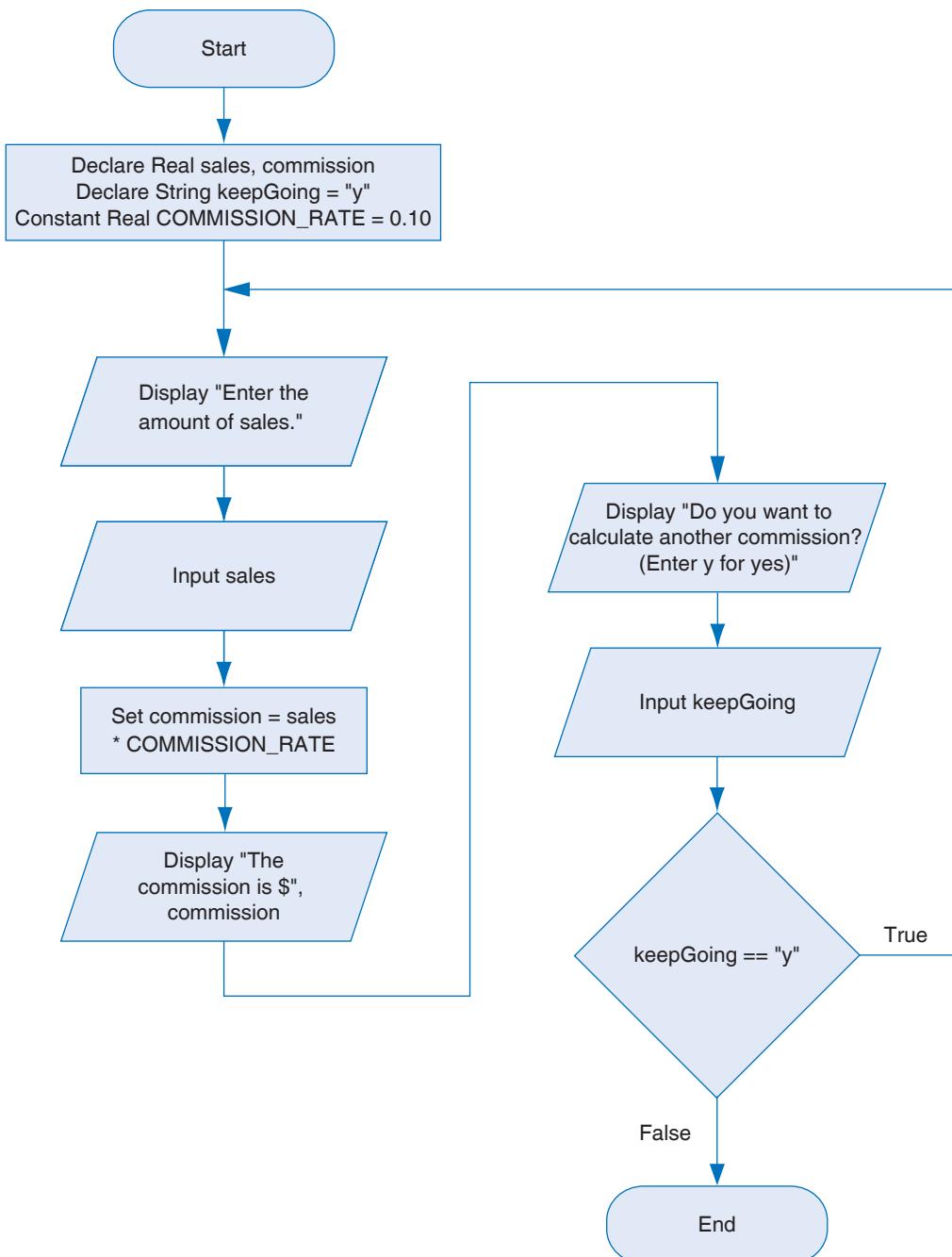
Figure 4-6 shows a flowchart for the program.

#### Program 4-4

```
1 // Variable declarations
2 Declare Real sales, commission
3 Declare String keepGoing = "y"
4
5 // Constant for the commission rate
6 Constant Real COMMISSION_RATE = 0.10
7
8 Do
9 // Get the amount of sales.
10 Display "Enter the amount of sales."
11 Input sales
12
13 // Calculate the commission.
14 Set commission = sales * COMMISSION_RATE
15
16 // Display the commission
17 Display "The commission is $", commission
18
19 // Do it again?
20 Display "Do you want to calculate another"
21 Display "commission? (Enter y for yes.)"
22 Input keepGoing
23 While keepGoing == "y"
```

#### Program Output (with Input Shown in Bold)

```
Enter the amount of sales.
10000.00 [Enter]
The commission is $1000
Do you want to calculate another
commission? (Enter y for yes.)
y [Enter]
Enter the amount of sales.
5000.00 [Enter]
The commission is $500
Do you want to calculate another
commission? (Enter y for yes.)
y [Enter]
Enter the amount of sales.
12000.00 [Enter]
The commission is $1200
Do you want to calculate another
commission? (Enter y for yes.)
n [Enter]
```

**Figure 4-6** Flowchart for Program 4-4

Although the Do-While loop is convenient to use in some circumstances, it is never required. Any loop that can be written as a Do-While loop can also be written as a While loop. As previously mentioned, some circumstances require that you initialize data prior to executing a While loop, to ensure that it executes at least once.

## In the Spotlight: Designing a Do-While Loop



Samantha owns an import business and she calculates the retail prices of her products with the following formula:

$$\text{Retail Price} = \text{Wholesale Cost} \times 2.5$$

She has asked you to design a program to do this calculation for each item that she receives in a shipment. You learn that each shipment contains various numbers of items, so you decide to use a loop that calculates the price for one item, and then asks her whether she has another item. The loop will iterate as long as she indicates that she has another item. Program 4-5 shows the pseudocode for the program, and Figure 4-7 shows the flowchart.

### Program 4-5

```

1 // Variable declarations
2 Declare Real wholesale, retail
3 Declare String doAnother
4
5 // Constant for the markup percentage
6 Constant Real MARKUP = 2.50
7
8 Do
9 // Get the wholesale cost.
10 Display "Enter an item's wholesale cost."
11 Input wholesale
12
13 // Calculate the retail price.
14 Set retail = wholesale * MARKUP
15
16 // Display the retail price.
17 Display "The retail price is $", retail
18
19 // Do this again?
20 Display "Do you have another item? (Enter y for yes.)"
21 Input doAnother
22 While doAnother == "y" OR doAnother == "Y"
```

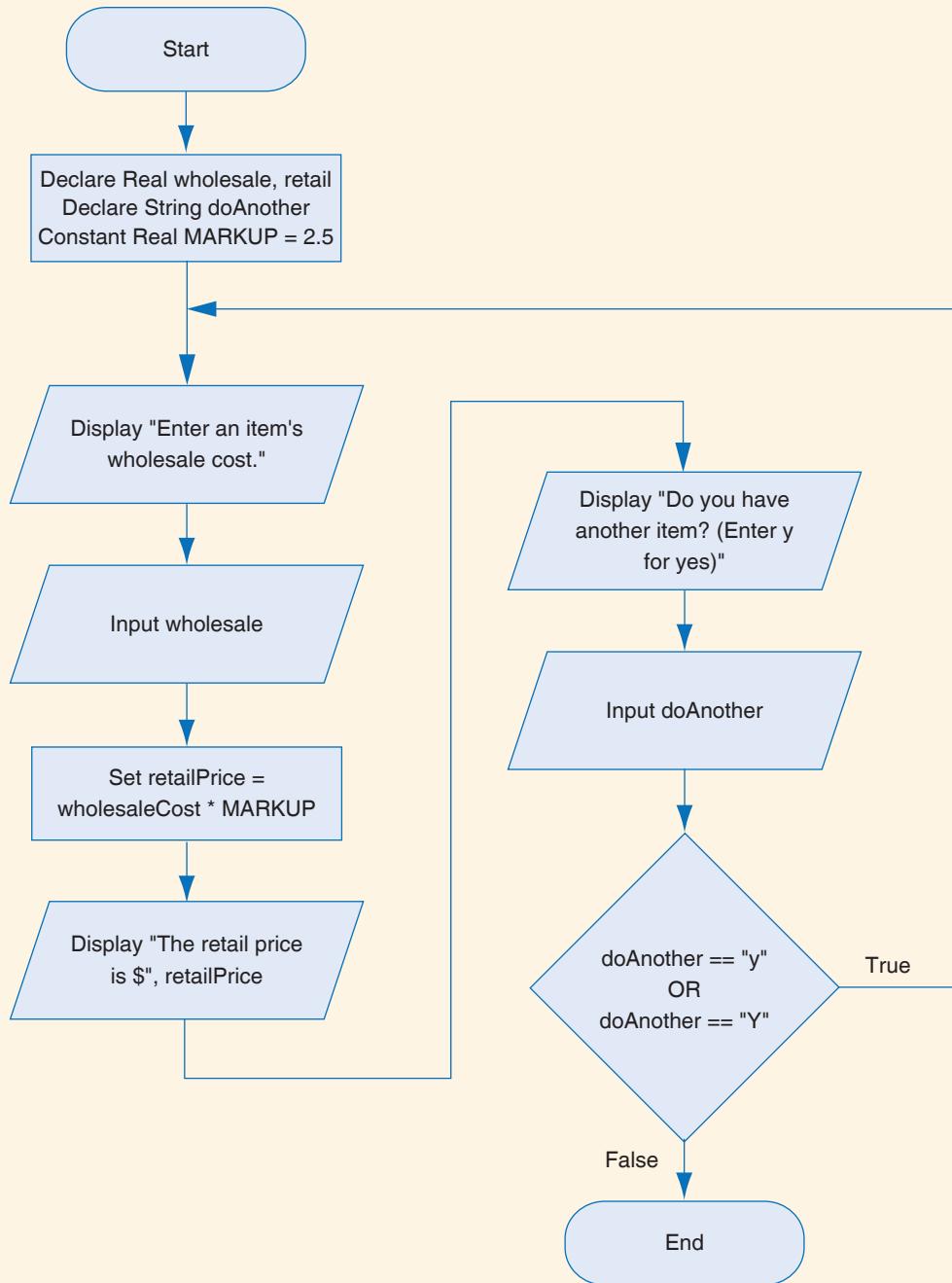
### Program Output (with Input Shown in Bold)

```

Enter an item's wholesale cost.
10.00 [Enter]
The retail price is $25
Do you have another item? (Enter y for yes.)
y [Enter]
Enter an item's wholesale cost.
15.00 [Enter]
The retail price is $37.50
```

```
Do you have another item? (Enter y for yes.)
y [Enter]
Enter an item's wholesale cost.
12.50 [Enter]
The retail price is $31.25
Do you have another item? (Enter y for yes.)
n [Enter]
```

**Figure 4-7** Flowchart for Program 4-5



In the pseudocode, a **Do-While** loop appears in lines 8 through 22. Inside the loop, lines 10 through 11 get an item's wholesale cost, line 14 calculates the item's retail price, and line 17 displays the item's retail price. Then, in line 20, the user is prompted “Do you have another item? (Enter *y* for yes.)” In line 21, the user’s input is stored in the **doAnother** variable. In line 22, the following statement is the end of the **Do-While** loop:

```
While doAnother == "y" OR doAnother == "Y"
```

Notice that we are using the logical **OR** operator to test a compound Boolean expression. The expression on the left side of the **OR** operator will be true if **doAnother** is equal to lowercase “*y*”. The expression on the right side of the **OR** operator will be true if **doAnother** is equal to uppercase “*Y*”. If either of these subexpressions is true, the loop will iterate. This is a simple way to make a case insensitive comparison, which means that it does not matter whether the user enters uppercase or lowercase letters.

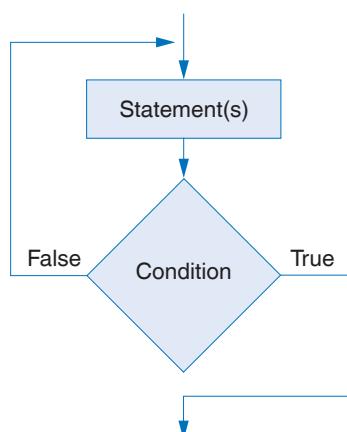
## The Do-Until Loop

Both the **While** and the **Do-While** loops iterate as long as a condition is true. Sometimes, however, it is more convenient to write a loop that iterates *until* a condition is true—that is, a loop that iterates as long as a condition is false, and then stops when the condition becomes true.

For example, consider a machine in an automobile factory that paints cars as they move down the assembly line. When there are no more cars to paint, the machine stops. If you were programming such a machine, you would want to design a loop that causes the machine to paint cars until there are no more cars on the assembly line.

A loop that iterates until a condition is true is known as a **Do-Until** loop. Figure 4-8 shows the general logic of a **Do-Until** loop.

**Figure 4-8** The logic of a Do-Until loop



Notice that the Do-Until loop is a posttest loop. First, one or more statements are executed, and then a condition is tested. If the condition is false, the program's execution flows back to the point just above the first statement in the body of the loop, and this process repeats. If the condition is true, the program exits the loop.



**NOTE:** Because the Do-Until loop is a posttest loop, it will always iterate at least one time.

## Writing a Do-Until Loop in Pseudocode

In pseudocode, we will use the Do-Until statement to write a Do-Until loop. Here is the general format of the Do-Until statement:

```
Do
 statement
 statement
 etc.
} These statements are the body of the loop. They are always
performed once, and then repeated until the condition is true.
Until condition
```

In the general format, the statements that appear in the lines between the Do and the Until clauses are the body of the loop. The *condition* that appears after the Until clause is a Boolean expression. When the loop executes, the statements in the body of the loop are executed, and then the *condition* is tested. If the *condition* is true, the program exits the loop. If the *condition* is false, the loop starts over and the statements in the body are executed again.

As shown in the general format, you should use the following conventions when you write a Do-Until statement:

- Make sure the Do clause and the Until clause are aligned.
- Indent the statements in the body of the loop.

The pseudocode in Program 4-6 shows an example of the Do-Until loop. The loop in lines 6 through 16 repeatedly asks the user to enter a password until the string "prospero" is entered. Figure 4-9 shows a flowchart for the program.

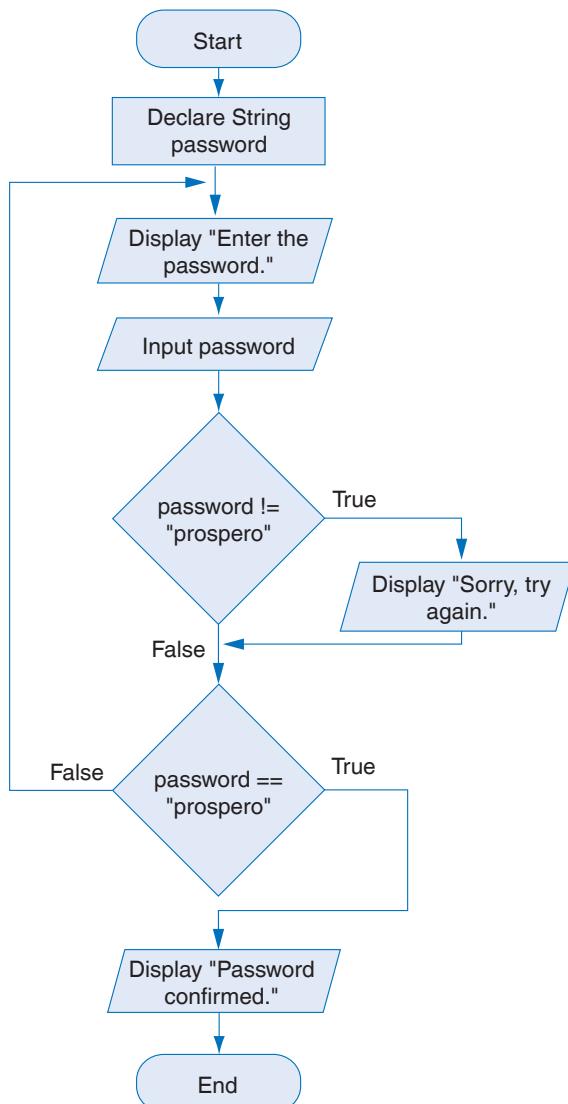
### Program 4-6

```
1 // Declare a variable to hold the password.
2 Declare String password
3
4 // Repeatedly ask the user to enter a password
5 // until the correct one is entered.
6 Do
7 // Prompt the user to enter the password.
8 Display "Enter the password."
9 Input password
10
11 // Display an error message if the wrong
12 // password was entered.
13 If password != "prospero" Then
14 Display "Sorry, try again."
15 End If
16 Until password == "prospero"
```

```
17
18 // Indicate that the password is confirmed.
19 Display "Password confirmed."
```

**Program Output (with Input Shown in Bold)**

Enter the password.  
**ariel [Enter]**  
Sorry, try again.  
Enter the password.  
**caliban [Enter]**  
Sorry, try again.  
Enter the password.  
**prospero [Enter]**  
Password confirmed.

**Figure 4-9** Flowchart for Program 4-6



**NOTE:** Not all programming languages provide a Do-Until loop because you can write a Do-While loop that is logically equivalent to any Do-Until loop.

## Deciding Which Loop to Use

In this section, we have introduced three different types of condition-controlled loop: the `While` loop, the `Do-While` loop, and the `Do-Until` loop. When you write a program that requires a condition-controlled loop, you will have to decide which loop to use.

You want to use the `While` loop to repeat a task as long as a condition is true. The `While` loop is a pretest loop, so it is ideal in situations where the condition might be false to start with, and in such cases you do not want the loop to iterate at all. The pseudocode that you saw in Program 4-2 is a good example.

The `Do-While` loop is also a candidate in situations where a task must be repeated as long as a condition is true. It is a posttest loop, so it is the best choice when you always want the task to be performed at least once, regardless of whether the condition is true or false to start with.

The `Do-Until` loop is also a posttest loop, so it performs a task at least once. It is the best choice when you want to perform a task *until* a condition is true. The `Do-Until` loop will repeat as long as its condition is false. When the condition is true, the `Do-Until` loop stops.



## Checkpoint

- 4.4 What is a loop iteration?
- 4.5 What is the difference between a pretest loop and a posttest loop?
- 4.6 Does the `While` loop test its condition before or after it performs an iteration?
- 4.7 Does the `Do-While` loop test its condition before or after it performs an iteration?
- 4.8 What is an infinite loop?
- 4.9 What is the difference between a `Do-While` loop and a `Do-Until` loop?

4.3

## Count-Controlled Loops and the For Statement

**CONCEPT:** A count-controlled loop iterates a specific number of times. Although you can write the logic of a condition-controlled loop so it iterates a specific number of times, most languages provide a loop known as the `For` loop, which is specifically designed as a count-controlled loop.

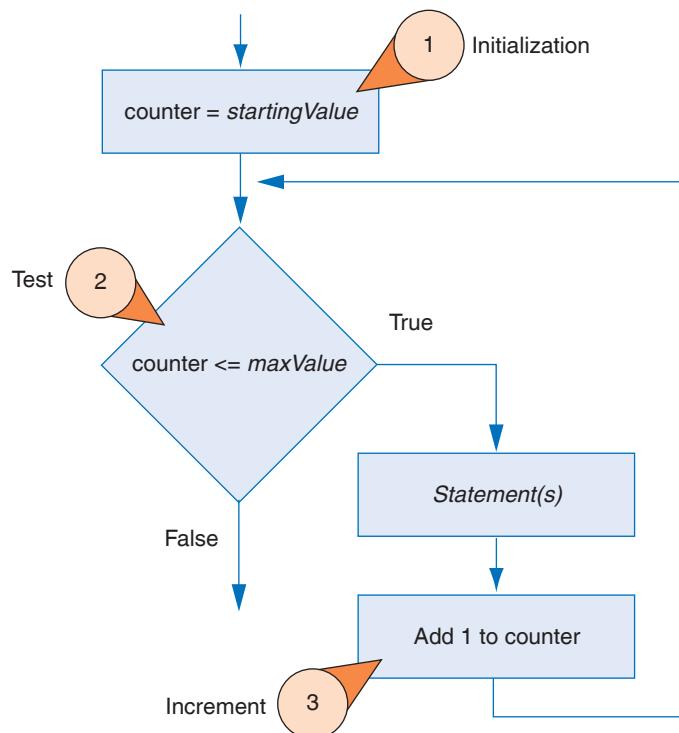
As mentioned at the beginning of this chapter, a count-controlled loop iterates a specific number of times. Count-controlled loops are commonly used in programs. For example, suppose a business is open six days per week, and you are going to write a program that calculates the total sales for a week. You will need a loop that iterates exactly six times. Each time the loop iterates, it will prompt the user to enter the sales for one day.

The way that a count-controlled loop works is simple: the loop keeps a count of the number of times that it iterates, and when the count reaches a specified amount, the loop stops. A count-controlled loop uses a variable known as a *counter variable*, or simply *counter*, to store the number of iterations that it has performed. Using the counter variable, the loop typically performs the following three actions: *initialization*, *test*, and *increment*:

1. **Initialization:** Before the loop begins, the counter variable is initialized to a starting value. The starting value that is used will depend on the situation.
2. **Test:** The loop tests the counter variable by comparing it to a maximum value. If the counter variable is less than or equal to the maximum value, the loop iterates. If the counter is greater than the maximum value, the program exits the loop.
3. **Increment:** To *increment* a variable means to increase its value. During each iteration, the loop increments the counter variable by adding 1 to it.

Figure 4-10 shows the general logic of a count-controlled loop. The initialization, test, and increment operations are indicated with the ①, ②, and ③ callouts.

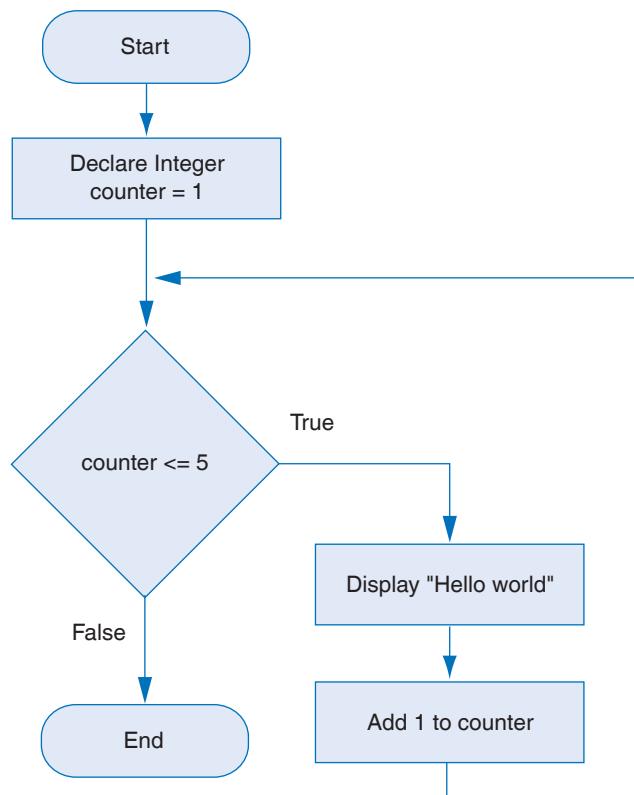
**Figure 4-10** Logic of a count-controlled loop



In the flowchart, assume that `counter` is an `Integer` variable. The first step is to set `counter` to the appropriate starting value. Then, determine whether `counter` is less than or equal to the maximum value. If this is true, the body of the loop executes. Otherwise, the program exits the loop. Notice that in the body of the loop one or more statements are executed, and then 1 is added to `counter`.

For example, look at the flowchart in Figure 4-11. First, an `Integer` variable named `counter` is declared and initialized with the starting value 1. Then, the expression `counter <= 5` is tested. If this expression is true the message “Hello world” is displayed and 1 is added to `counter`. Otherwise, the program exits the loop. If you follow the logic of this program you will see that the loop will iterate five times.

**Figure 4-11** A count-controlled loop



## The For Statement



Count-controlled loops are so common in programming that most languages provide a statement just for them. This is usually called the `For` statement. The `For` statement is specifically designed to initialize, test, and increment a counter variable. Here is the general format that we will use to write the `For` statement in pseudocode:

```

For counterVariable = startingValue To maxValue
 statement
 statement
 statement
 etc.
}
End For

```

These statements are the body of the loop.

In the general format, *counterVariable* is the name of a variable that is used as a counter, *startingValue* is the value that the counter will be initially set to, and *maxValue* is the maximum value that the counter can contain. When the loop executes, the following actions are performed:

1. The *counterVariable* is set to the *startingValue*.
2. The *counterVariable* is compared to the *maxValue*. If the *counterVariable* is greater than *maxValue*, the loop stops. Otherwise:
  - a. The statements that appear in the body of the loop are executed.
  - b. The *counterVariable* is incremented.
  - c. The loop starts over again at Step 2.

An actual For loop is easy to understand, so let's look at one. The pseudocode in Program 4-7 uses a For loop to display "Hello world" five times. The flowchart in Figure 4-12 shows the logic of the program.

### Program 4-7



```

1 Declare Integer counter
2 Constant Integer MAX_VALUE = 5
3
4 For counter = 1 To MAX_VALUE
5 Display "Hello world"
6 End For

```

### Program Output

```

Hello world
Hello world
Hello world
Hello world
Hello world

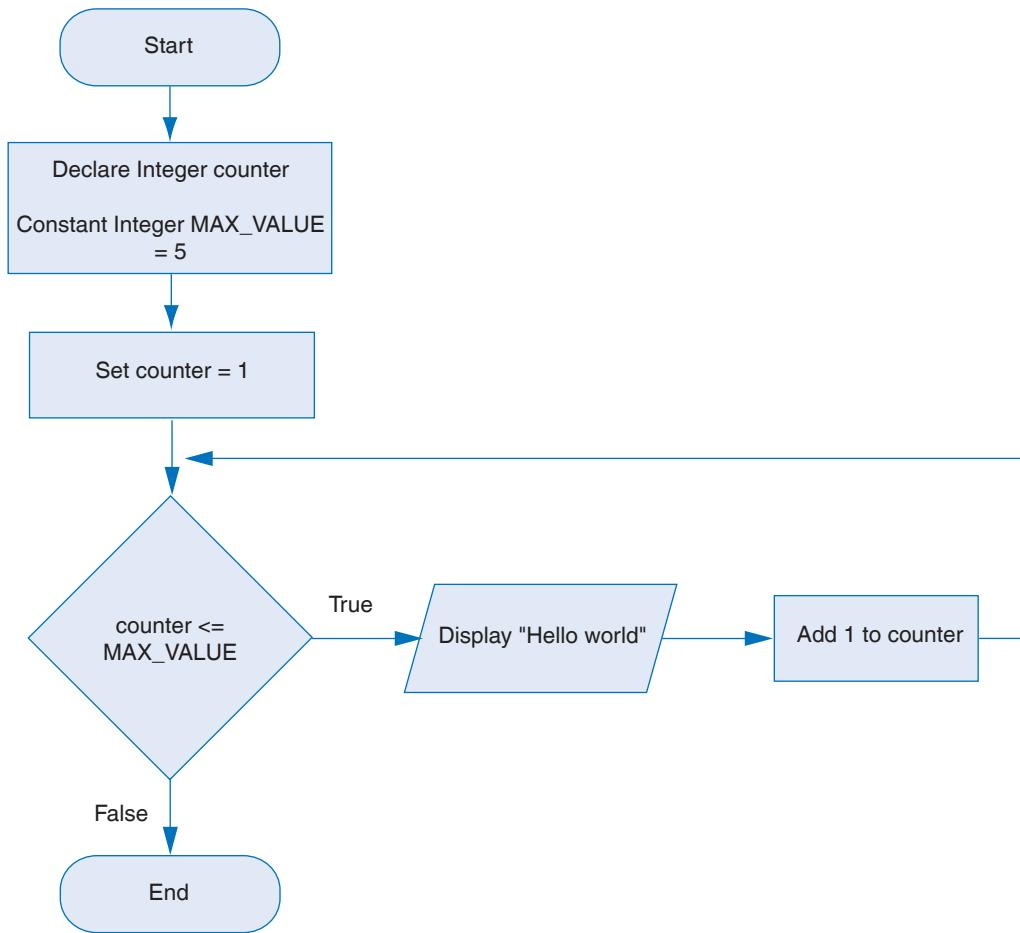
```

Line 1 declares an Integer variable that will be used as the counter variable. You do not have to name the variable *counter* (you are free to name it anything you wish), but in many cases that is an appropriate name. Line 2 declares a constant named *MAX\_VALUE* that will be used as the counter's maximum value. The For loop begins in line 4 with the statement *For counter = 1 To MAX\_VALUE*. This specifies that the *counter* variable will start with the value 1 and will end with the value 5. At the end of each loop iteration, the *counter* variable will be incremented by 1, so this loop will iterate five times. Each time it iterates, it displays "Hello world."

Notice that the loop does not contain a statement to increment the *counter* variable. This happens automatically in a For loop, at the end of each iteration. For

that reason, you should be careful not to place a statement that modifies the counter variable inside the body of a For loop. Doing so will usually disrupt the way the For loop works.

**Figure 4-12** Flowchart for Program 4-7



**TIP:** Program 4-7 has a constant, MAX\_VALUE, that represents the counter variable's maximum value. The first line of the loop could have been written as follows, to achieve the same result:

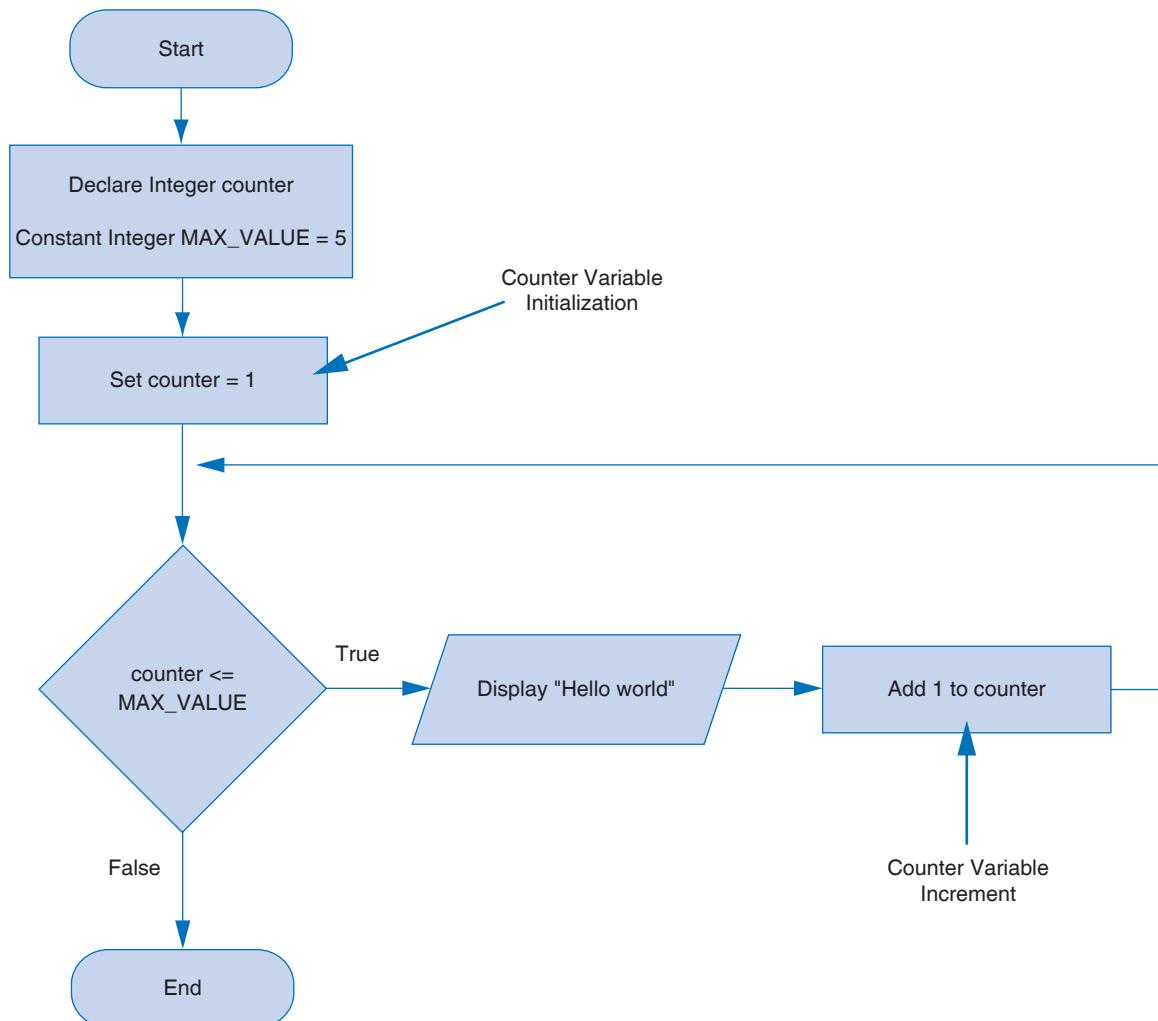
```
For counter = 1 To 5
```

Although creating the named constant is not necessary for this simple program, creating named constants to represent important values is a good habit. Recall from Chapter 2 that named constants make a program easier to read and easier to maintain.

## Flowcharting the For Statement

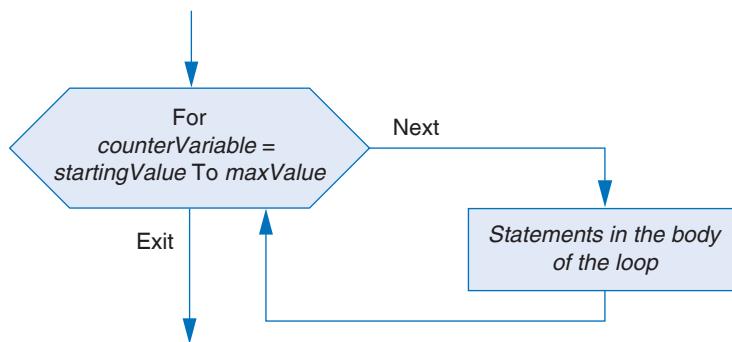
Perhaps you noticed that the flowchart in Figure 4-12 shows some statements that do not appear in the pseudocode shown in Program 4-7. Specifically, the flowchart shows a statement that initializes the counter variable, and a statement that increments the counter variable. Figure 4-13 shows the flowchart again, pointing out where these operations appear.

**Figure 4-13** The counter variable's initialization and increment

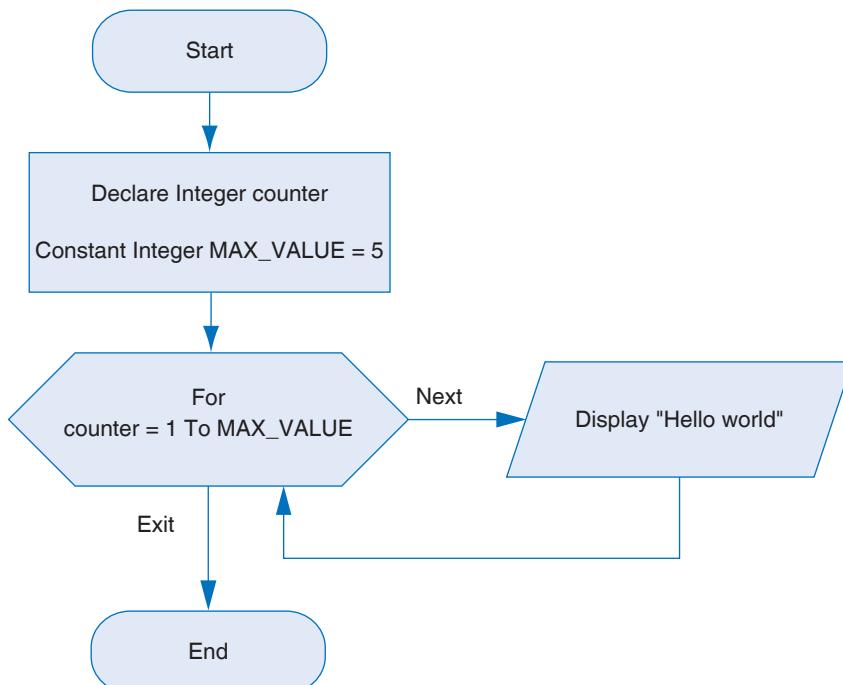


These statements do not appear in the pseudocode because they are implied by the For statement. When we read the pseudocode statement `For counter = 1 To MAX_VALUE`, we understand that `counter` is initialized with the value 1, and that `counter` is incremented each time the loop iterates.

To make the flowchart match the pseudocode, we introduce a new symbol to represent the For statement. The new symbol is a hexagon, as shown in Figure 4-14.

**Figure 4-14** Flowcharting symbol for the For statement

Inside the hexagon, we write the For statement that shows the name of the counter variable, the counter variable's starting value, and the counter variable's maximum value. Notice that the hexagon has two branches: *Next* and *Exit*. Each time the loop iterates, the program follows the *Next* branch to execute the statements inside the body of the loop. When the loop has finished, the program follows the *Exit* branch. When we use this symbol in our flowcharts, we do not have to show the steps for initializing the counter variable and incrementing the counter variable. It is understood that these steps happen as part of the For statement. Figure 4-15 shows a flowchart for Program 4-7 using this new symbol for the For statement.

**Figure 4-15** Another flowchart for Program 4-7

## Using the Counter Variable in the Body of the Loop

In a count-controlled loop, the primary purpose of the counter variable is to store the number of times that the loop has iterated. In some situations, it is also helpful to use the counter variable in a calculation or other task within the body of the loop. For example, suppose you need to write a program that displays the numbers 1 through 10 and their squares, in a table similar to the following:

| Number | Square |
|--------|--------|
| 1      | 1      |
| 2      | 4      |
| 3      | 9      |
| 4      | 16     |
| 5      | 25     |
| 6      | 36     |
| 7      | 49     |
| 8      | 64     |
| 9      | 81     |
| 10     | 100    |

This can be accomplished by writing a count-controlled loop that iterates 10 times. During the first iteration, the counter variable will be set to 1, during the second iteration it will be set to 2, and so forth. Because the counter variable will take on the values 1 through 10 during the loop's execution, you can use it in the calculation inside the loop.

The flowchart in Figure 4-16 shows the logic of such a program. Notice that in the body of the loop, the counter variable is used in the following calculation:

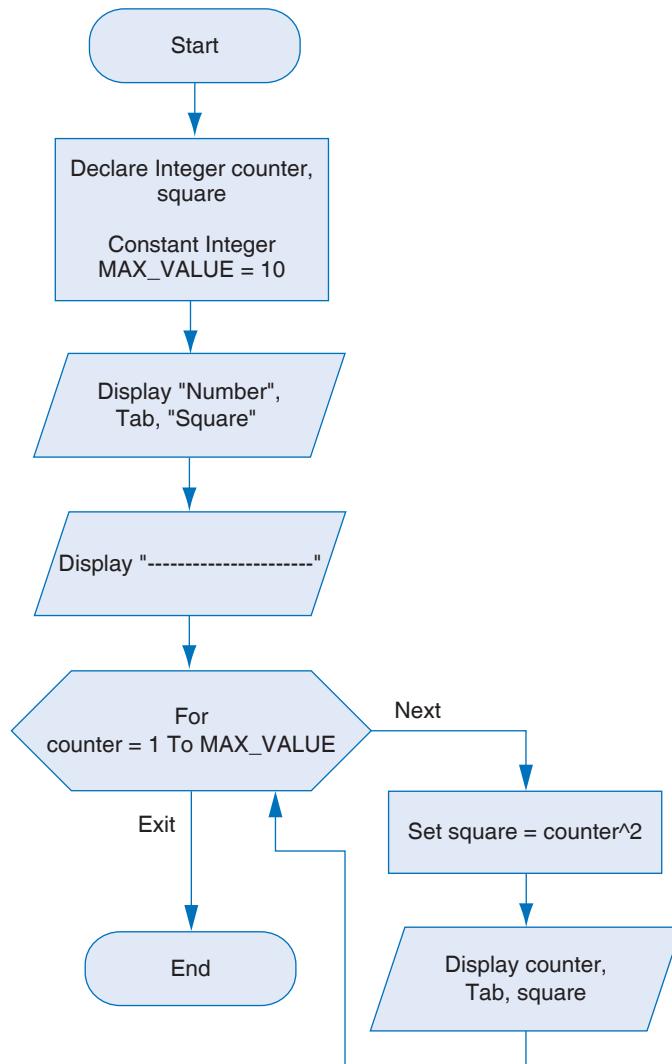
```
Set square = counter^2
```

This assigns the result of `counter^2` to the `square` variable. After performing this calculation, the contents of the `counter` variable and the `square` variable are displayed. Then, 1 is added to `counter` and the loop starts over again.

Program 4-8 shows the pseudocode for the program. Notice that the word `Tab` is used in the `Display` statements in lines 8 and 18. This is simply a way of indicating in pseudocode that we are indenting the screen output. For example, look at the following statement, which appears in line 18:

```
Display counter, Tab, square
```

This statement displays the contents of the `counter` variable, indents (or “tabs over”), and then displays the contents of the `square` variable. As a result, the numbers that are displayed will be aligned in two columns. Most programming languages provide a way to indent, or tab, screen output.

**Figure 4-16** Displaying the numbers 1 through 10 and their squares**Program 4-8**

```

1 // Variables
2 Declare Integer counter, square
3
4 // Constant for the maximum value
5 Constant Integer MAX_VALUE = 10
6
7 // Display table headings.
8 Display "Number", Tab, "Square"
9 Display "-----"
10
11 // Display the numbers 1 through 10 and
12 // their squares.
13 For counter = 1 To MAX_VALUE

```

```

14 // Calculate number squared.
15 Set square = counter^2
16
17 // Display number and number squared.
18 Display counter, Tab, square
19 End For

```

### Program Output

| Number | Square |
|--------|--------|
| 1      | 1      |
| 2      | 4      |
| 3      | 9      |
| 4      | 16     |
| 5      | 25     |
| 6      | 36     |
| 7      | 49     |
| 8      | 64     |
| 9      | 81     |
| 10     | 100    |

## Incrementing by Values Other Than 1

The amount by which the counter variable is incremented in a For loop is known as the *step amount*. By default, the step amount is 1. Most languages provide a way to change the step amount. This gives you the ability to increment the counter variable by any value you wish.

In pseudocode, we will use the optional Step clause to specify a step value in a For loop. For example, look at the following pseudocode:

```

For counter = 0 To 100 Step 10
 Display counter
End For

```

In this loop, the starting value of the counter variable is 0, and its ending value is 100. The Step clause specifies a step value of 10, which means that 10 is added to the counter variable at the end of each iteration. During the first iteration, counter is 0, during the second iteration, counter is 10, during the third iteration, counter is 20, and so forth.

The pseudocode in Program 4-9 gives another demonstration. The program displays all of the odd numbers from 1 through 11. Figure 4-17 shows a flowchart for the program. Notice that the step value is shown in the hexagon symbol for the For statement.

### Program 4-9



```

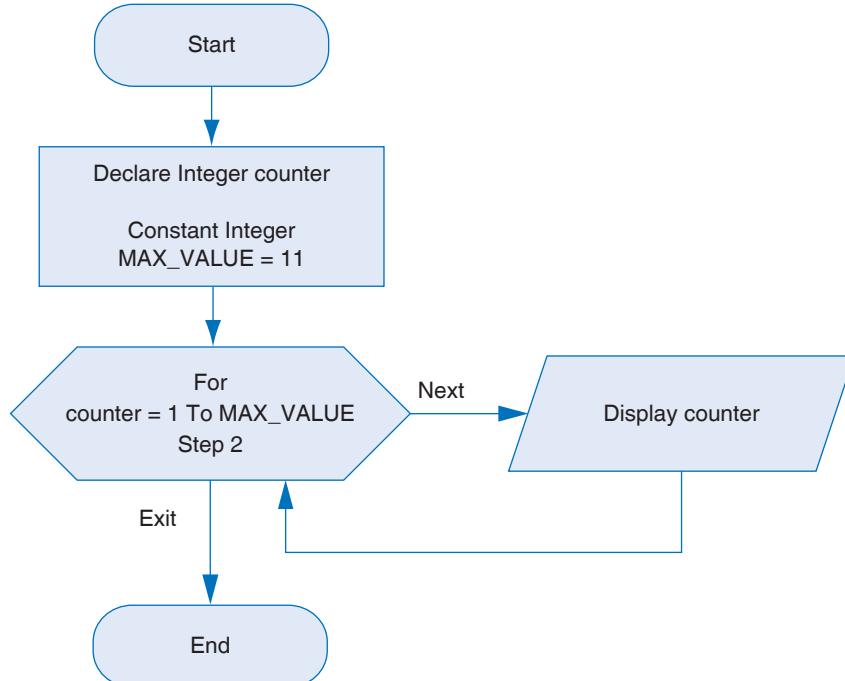
1 // Declare a counter variable
2 Declare Integer counter
3
4 // Constant for the maximum value
5 Constant Integer MAX_VALUE = 11
6

```

```
7 // Display the odd numbers from 1 through 11.
8 For counter = 1 To MAX_VALUE Step 2
9 Display counter
10 End For
```

**Program Output**

```
1
3
5
7
9
11
```

**Figure 4-17** Flowchart for Program 4-9**In the Spotlight:**  
Designing a Count-Controlled  
Loop with the For Statement

Your friend Amanda just inherited a European sports car from her uncle. Amanda lives in the United States, and she is afraid she will get a speeding ticket because the car's speedometer works in kilometers per hour. She has asked you to write a program that displays a table of speeds in kilometers per hour with their values converted to miles per hour. The formula for converting kilometers per hour to miles per hour is:

$$MPH = KPH \times 0.6214$$

In the formula, *MPH* is the speed in miles per hour and *KPH* is the speed in kilometers per hour.

The table that your program displays should show speeds from 60 kilometers per hour through 130 kilometers per hour, in increments of 10, along with their values converted to miles per hour. The table should look something like this:

| KPH             | MPH    |
|-----------------|--------|
| 60              | 37.284 |
| 70              | 43.498 |
| 80              | 49.712 |
| <i>etc. . .</i> |        |
| 130             | 80.782 |

After thinking about this table of values, you decide that you will write a For loop that uses a counter variable to hold the kilometer-per-hour speeds. The counter's starting value will be 60, its ending value will be 130, and a step value of 10 will be used. Inside the loop you will use the counter variable to calculate a speed in miles-per-hour. Program 4-10 shows the pseudocode for the program, and Figure 4-18 shows a flowchart.

### Program 4-10

```

1 // Declare variables to hold speeds in MPH and KPH.
2 Declare Real mph
3 Declare Integer kph
4
5 // Display the table headings.
6 Display "KPH", Tab, "MPH"
7 Display "-----"
8
9 // Display the speeds.
10 For kph = 60 To 130 Step 10
11 // Calculate the miles-per-hour.
12 Set mph = kph * 0.6214
13
14 // Display KPH and MPH.
15 Display kph, Tab, mph
16 End For

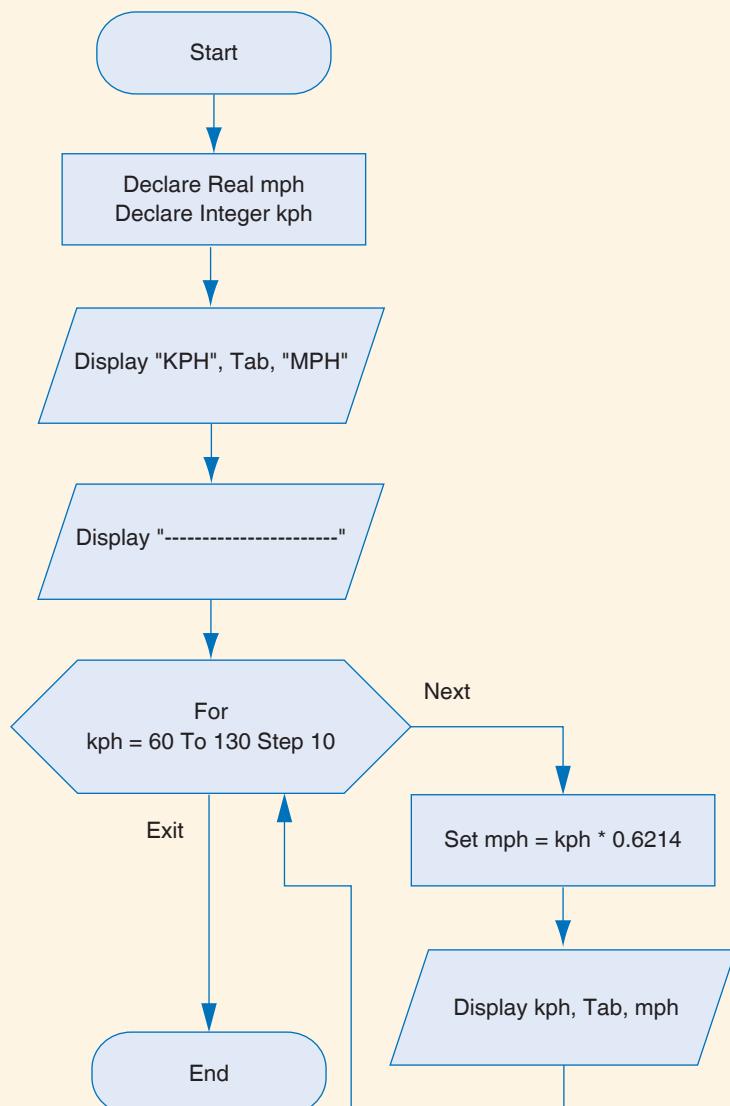
```

### Program Output

| KPH | MPH    |
|-----|--------|
| 60  | 37.284 |
| 70  | 43.498 |
| 80  | 49.712 |
| 90  | 55.926 |
| 100 | 62.14  |
| 110 | 68.354 |
| 120 | 74.568 |
| 130 | 80.782 |

Notice that a variable named kph is used as the counter. Until now we have used the name counter for our counter variables. In this program, however, kph is a better name for the counter because it will hold speeds in kilometers-per-hour.

**Figure 4-18** Flowchart for Program 4-10



## Counting Backward by Decrementing the Counter Variable

Although the counter variable is usually incremented in a count-controlled loop, you can alternatively decrement the counter variable. To *decrement* a variable means to decrease its value. In a For statement, you specify a negative step value to decrement the counter variable. For example, look at the following loop:

```
For counter = 10 To 1 Step -1
 Display counter
End For
```

In this loop, the starting value of the counter variable is 10, and its ending value is 1. The step value is  $-1$ , which means that 1 is subtracted from counter at the end of each iteration. During the first iteration, counter is 10; during the second iteration, counter is 9; and so forth. If this were an actual program, it would display the numbers 10, 9, 8, and so forth, down to 1.

## Letting the User Control the Number of Iterations

In many cases, the programmer knows the exact number of iterations that a loop must perform. For example, recall Program 4-8, which displays a table showing the numbers 1 through 10 and their squares. When the pseudocode was written, the programmer knew that the loop had to iterate 10 times. A constant named `MAX_VALUE` was initialized with the value 10, and the loop was written as follows:

```
For counter = 1 To MAX_VALUE
```

As a result, the loop iterates exactly 10 times. Sometimes, however, the programmer needs to let the user decide the number of times that a loop should iterate. For example, what if you want Program 4-8 to be a bit more versatile by allowing the user to specify the maximum value displayed by the loop? The pseudocode in Program 4-11 shows how you can accomplish this.

### Program 4-11

```

1 // Variables
2 Declare Integer counter, square, upperLimit
3
4 // Get the upper limit.
5 Display "This program displays numbers, starting at 1,"
6 Display "and their squares. How high should I go?"
7 Input upperLimit
8
9 // Display table headings.
10 Display "Number", Tab, "Square"
11 Display "-----"
12
13 // Display the numbers and their squares.
14 For counter = 1 To upperLimit
15 // Calculate number squared.
16 Set square = counter^2
17
18 // Display number and number squared.
19 Display counter, Tab, square
20 End For
```

### Program Output

This program displays numbers, starting at 1, and their squares. How high should I go?

5 [Enter]

| Number | Square |
|--------|--------|
| 1      | 1      |
| 2      | 4      |
| 3      | 9      |
| 4      | 16     |
| 5      | 25     |

Lines 5 and 6 ask the user how high the numbers in the table should go, and the statement in line 7 stores the user's input in the `upperLimit` variable. Then, the `For` loop uses the `upperLimit` variable as the counter's ending value:

```
For counter = 1 To upperLimit
```

As a result, the `counter` variable starts with 1, and ends with the value in `upperLimit`. In addition to specifying the counter's ending value, you can also specify its starting value. The pseudocode in Program 4-12 shows an example. In this program, the user specifies both the starting value and the ending value of the numbers displayed in the table. Notice that in line 20 the `For` loop uses variables to specify both the starting and ending values of the `counter` variable.

### Program 4-12

```

1 // Variables
2 Declare Integer counter, square,
3 lowerLimit, upperLimit
4
5 // Get the lower limit.
6 Display "This program displays numbers and"
7 Display "their squares. What number should"
8 Display "I start with?"
9 Input lowerLimit
10
11 // Get the upper limit.
12 Display "What number should I end with?"
13 Input upperLimit
14
15 // Display table headings.
16 Display "Number", Tab, "Square"
17 Display "-----"
18
19 // Display the numbers and their squares.
20 For counter = lowerLimit To upperLimit
21 // Calculate number squared.
22 Set square = counter^2
23
24 // Display number and number squared.
25 Display counter, Tab, square
26 End For

```

### Program Output

This program displays numbers and their squares. What number should I start with?

3 [Enter]

What number should I end with?

7 [Enter]

| Number | Square |
|--------|--------|
| 3      | 9      |
| 4      | 16     |
| 5      | 25     |
| 6      | 36     |
| 7      | 49     |

| Number | Square |
|--------|--------|
| 3      | 9      |
| 4      | 16     |
| 5      | 25     |
| 6      | 36     |
| 7      | 49     |

## Designing a Count-Controlled While Loop

In most situations, it is best to use the `For` statement to write a count-controlled loop. Most languages, however, make it possible to use any looping mechanism to create a count-controlled loop. For example, you can create a count-controlled `While` loop, a count-controlled `Do-While` loop, or a count-controlled `Do-Until` loop. Regardless of the type of mechanism that you use, all count-controlled loops perform an initialization, test, and increment operation on a counter variable.

In pseudocode, you can use the following general format to write a count-controlled `While` loop:

```

① Declare Integer counter = startingValue ← Initialize a counter variable
 to the starting value.

② While counter <= maxValue ← Compare the counter to the
 maximum value.

 statement
 statement
 statement

③ Set counter = counter + 1 ← Add 1 to the counter variable
 during each iteration.

End While

```

The ①, ②, and ③ callouts show where the initialization, test, and increment actions are performed.

- ① shows the declaration of an `Integer` variable that will be used as the counter. The variable is initialized with the appropriate starting value.
- ② shows where the `While` loop tests the expression `counter <= maxValue`. In this general format, `maxValue` is the maximum value that the counter variable can be set to.
- ③ shows where 1 is added to the counter variable. In a `While` loop, the counter variable will not automatically be incremented. You have to explicitly write a statement that performs this action. It's important that you understand how this statement works, so let's take a closer look at it:

Set counter = counter + 1

This is how the statement would be executed by the computer: First, the computer would get the value of the expression on the right side of the = operator which is counter + 1. Then, that value would be assigned to the counter variable. The effect of the statement is that 1 is added to the counter variable.



**WARNING!** If you forget to increment the counter variable in a count-controlled While loop, the loop will iterate an infinite number of times.

The pseudocode in Program 4-13 shows an example of a count-controlled While loop. This program follows the same logic that you previously saw in Figure 4-11, and displays “Hello world” five times. Figure 4-19 points out where the counter variable’s initialization, test, and increment occur in the pseudocode.

### Program 4-13

```

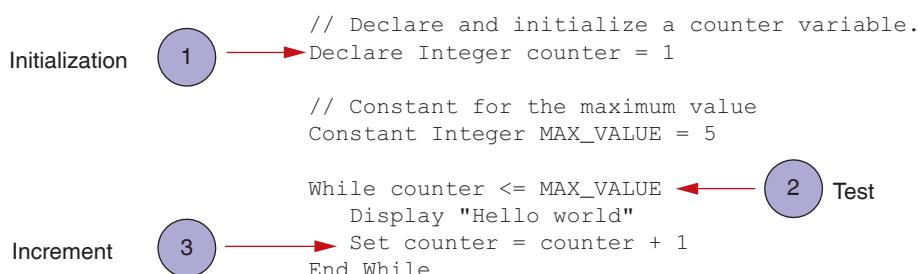
1 // Declare and initialize a counter variable.
2 Declare Integer counter = 1
3
4 // Constant for the maximum value
5 Constant Integer MAX_VALUE = 5
6
7 While counter <= MAX_VALUE
8 Display "Hello world"
9 Set counter = counter + 1
10 End While

```

### Program Output

```
Hello world
Hello world
Hello world
Hello world
Hello world
```

**Figure 4-19** The initialization, test, and increment of the counter variable



The pseudocode in Program 4-14 shows another example. This program produces the same output that was produced by Program 4-8: the numbers 1 through 10 and their squares. The flowchart that you previously saw in Figure 4-16 shows the logic of this program.

**Program 4-14**

```

1 // Variables
2 Declare Integer counter = 1
3 Declare Integer square
4
5 // Constant for the maximum value
6 Constant Integer MAX_VALUE = 10
7
8 // Display table headings.
9 Display "Number", Tab, "Square"
10 Display "-----"
11
12 // Display the numbers 1 through 10 and
13 // their squares.
14 While counter <= MAX_VALUE
15 // Calculate the square of a number.
16 Set square = counter^2
17
18 // Display the number and its square.
19 Display counter, Tab, square
20
21 // Increment counter.
22 Set counter = counter + 1
23 End While

```

**Program Output**

| Number | Square |
|--------|--------|
| 1      | 1      |
| 2      | 4      |
| 3      | 9      |
| 4      | 16     |
| 5      | 25     |
| 6      | 36     |
| 7      | 49     |
| 8      | 64     |
| 9      | 81     |
| 10     | 100    |

**Incrementing by Values Other Than 1**

In Programs 4-13 and 4-14 the counter variable is incremented by 1 during each loop iteration, with a statement such as this:

```
Set counter = counter + 1
```

This statement can be easily modified to increment the counter variable by values other than 1. For example, you could add 2 to the counter variable with the following statement:

```
Set counter = counter + 2
```

The pseudocode in Program 4-15 demonstrates how you can use this statement in a count-controlled **While** loop. The program displays all of the odd numbers from 1 through 11.

### Program 4-15

```
1 // Declare a counter variable
2 Declare Integer counter = 1
3
4 // Constant for the maximum value
5 Constant Integer MAX_VALUE = 11
6
7 // Display the odd numbers from 1
8 // through 11.
9 While counter <= MAX_VALUE
10 Display counter
11 Set counter = counter + 2
12 End While
```

### Program Output

```
1
3
5
7
9
11
```

### Counting Backward by Decrementing

Previously you saw how a negative step value can be used to decrement the counter variable in a **For** statement. In a count-controlled **While** loop, you decrement the counter variable with a statement such as the following:

```
Set counter = counter - 1
```

This statement subtracts 1 from the counter variable. If the counter variable is set to the value 5 before this statement executes, it will be set to 4 after the statement executes. The pseudocode in Program 4-16 demonstrates how you can use this statement in a **While** loop. The program counts backward from 10 down to 1.

### Program 4-16

```
1 // Declare a counter variable
2 Declare Integer counter = 10
3
4 // Constant for the minimum value
5 Constant Integer MIN_VALUE = 1
6
7 // Display a count-down.
8 Display "And the countdown begins..."
```

```

9 While counter >= MIN_VALUE
10 Display counter
11 Set counter = counter - 1
12 End While
13 Display "Blast off!"
```

### Program Output

And the countdown begins...

```

10
9
8
7
6
5
4
3
2
1
Blast off!
```

Let's take a closer look at this program. Notice that line 11 subtracts 1 from the counter variable. Because we are counting backward, we have to reverse many parts of the logic. For example, in line 2 the counter variable must be initialized with the value 10 instead of 1. This is because 10 is the counter's starting value in this program. Also, in line 5 we create a constant to represent the counter's minimum value (which is 1) instead of the maximum value. Because we are counting down, we want the loop to stop when it reaches 1. Finally, notice that we are using the `>=` relational operator in line 9. In this program we want the loop to iterate as long as the counter is greater than or equal to 1. When the counter becomes less than 1, the loop should stop.



### Checkpoint

- 4.10 What is a counter variable?
- 4.11 What three actions do count-controlled loops typically perform using the counter variable?
- 4.12 When you increment a variable, what are you doing? When you decrement a variable, what are you doing?
- 4.13 Look at the following pseudocode. If it were a real program, what would it display?

```

Declare Integer number = 5
Set number = number + 1
Display number
```

- 4.14 Look at the following pseudocode. If it were a real program, what would it display?

```

Declare Integer counter
For counter = 1 To 5
 Display counter
End For
```

- 4.15 Look at the following pseudocode. If it were a real program, what would it display?

```
Declare Integer counter
For counter = 0 To 500 Step 100
 Display counter
End For
```

- 4.16 Look at the following pseudocode. If it were a real program, what would it display?

```
Declare Integer counter = 1
Constant Integer MAX = 8
While counter <= MAX
 Display counter
 Set counter = counter + 1
End While
```

- 4.17 Look at the following pseudocode. If it were a real program, what would it display?

```
Declare Integer counter = 1
Constant Integer MAX = 7
While counter <= MAX
 Display counter
 Set counter = counter + 2
End While
```

- 4.18 Look at the following pseudocode. If it were a real program, what would it display?

```
Declare Integer counter
Constant Integer MIN = 1
For counter = 5 To MIN Step -1
 Display counter
End For
```

## 4.4

# Calculating a Running Total

**CONCEPT:** A running total is a sum of numbers that accumulates with each iteration of a loop. The variable used to keep the running total is called an accumulator.

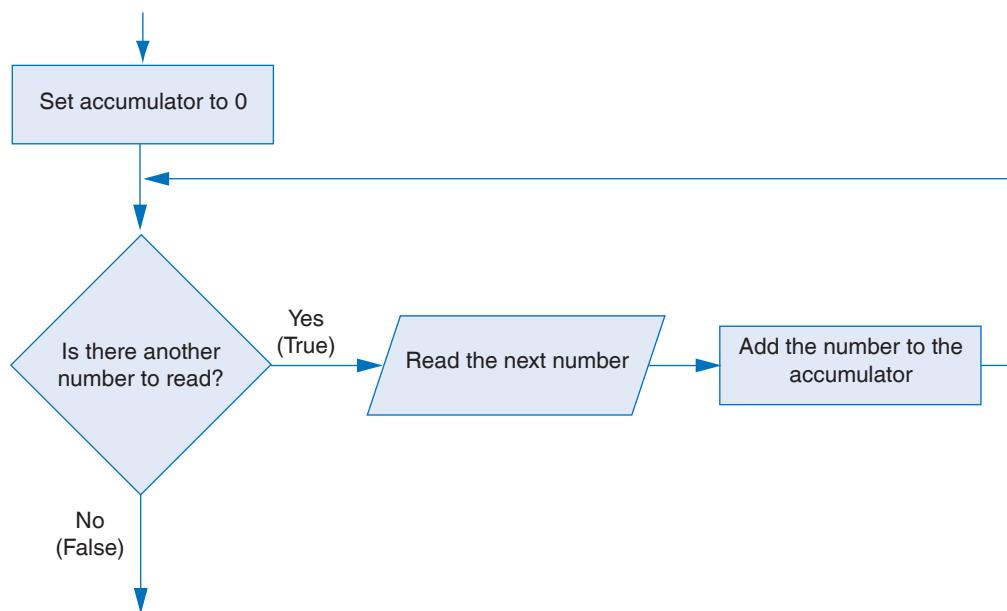
Many programming tasks require you to calculate the total of a series of numbers. For example, suppose you are writing a program that calculates a business's total sales for a week. The program would read the sales for each day as input and calculate the total of those numbers.

Programs that calculate the total of a series of numbers typically use two elements:

- A loop that reads each number in the series.
- A variable that accumulates the total of the numbers as they are read.

The variable that is used to accumulate the total of the numbers is called an *accumulator*. It is often said that the loop keeps a *running total* because it accumulates the total as it reads each number in the series. Figure 4-20 shows the general logic of a loop that calculates a running total.

**Figure 4-20** General logic for calculating a running total



When the loop finishes, the accumulator will contain the total of the numbers that were read by the loop. Notice that the first step in the flowchart is to set the accumulator variable to 0. This is a critical step. Each time the loop reads a number, it adds it to the accumulator. If the accumulator starts with any value other than 0, it will not contain the correct total when the loop finishes.

Let's look at the design of a program that calculates a running total. The pseudocode shown in Program 4-17 allows the user to enter five numbers, and it displays the total of the numbers entered.

### Program 4-17



```

1 // Declare a variable to hold each number
2 // entered by the user.
3 Declare Integer number
4
5 // Declare an accumulator variable,
6 // initialized with 0.
7 Declare Integer total = 0
8
9 // Declare a counter variable for the loop.
10 Declare Integer counter

```

```
11
12 // Explain what we are doing.
13 Display "This program calculates the"
14 Display "total of five numbers."
15
16 // Get five numbers and accumulate them.
17 For counter = 1 To 5
18 Display "Enter a number."
19 Input number
20 Set total = total + number
21 End For
22
23 // Display the total of the numbers.
24 Display "The total is ", total
```

### Program Output (with Input Shown in Bold)

This program calculates the  
total of five numbers.

Enter a number.

**2** [Enter]

Enter a number.

**4** [Enter]

Enter a number.

**6** [Enter]

Enter a number.

**8** [Enter]

Enter a number.

**10** [Enter]

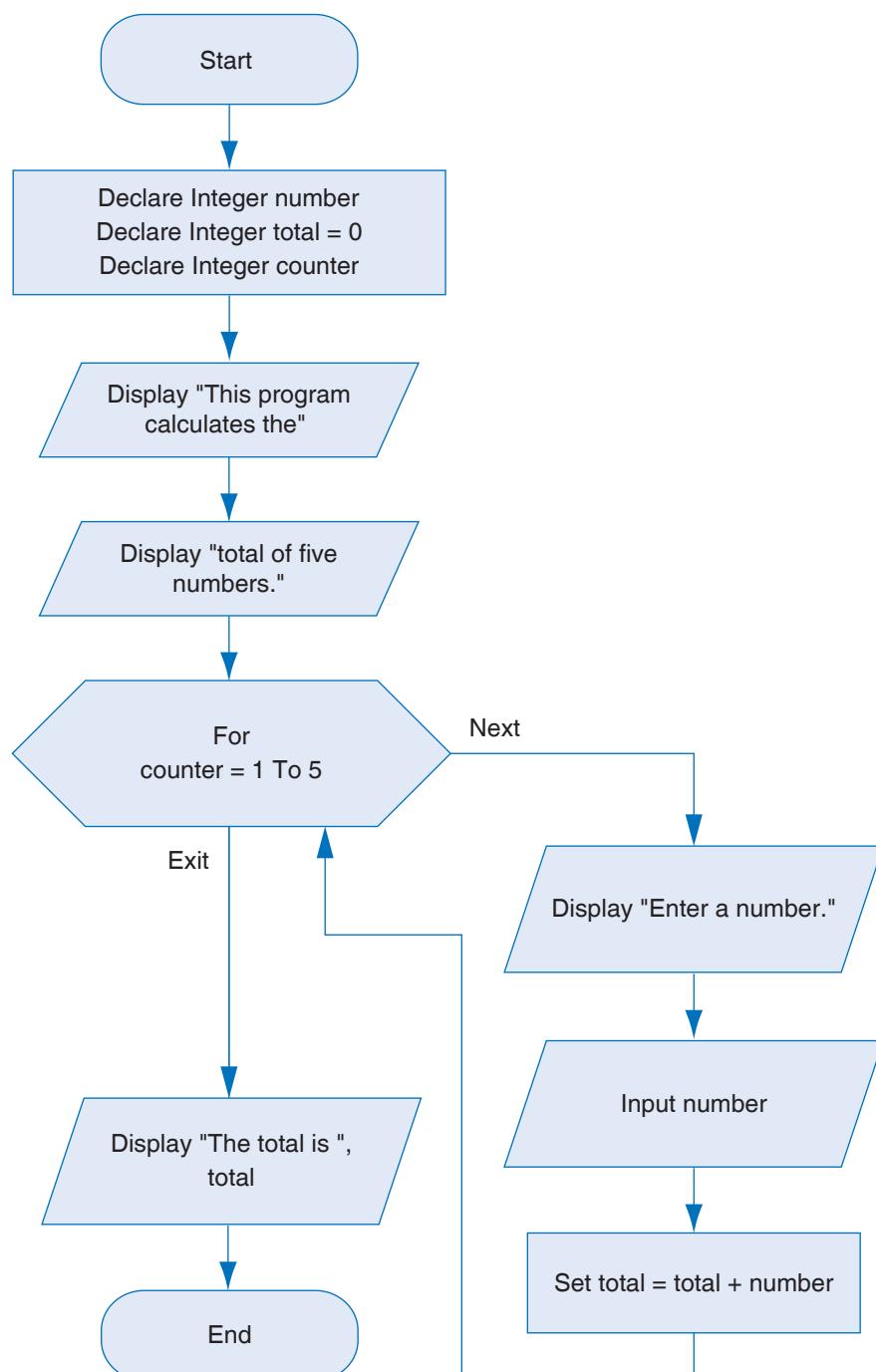
The total is 30

First, let's look at the variable declarations. The `number` variable, declared in line 3, will be used to hold a number entered by the user. The `total` variable, declared in line 7, is the accumulator. Notice that it is initialized with the value 0. The `counter` variable, declared in line 10, will be used as a counter by the loop.

The `For` loop, in lines 17 through 21, does the work of getting the numbers from the user and calculating their total. Line 18 prompts the user to enter a number, and line 19 gets the user's input and stores it in the `number` variable. Then, the following statement in line 20 adds `number` to `total`:

Set `total` = `total` + `number`

After this statement executes, the value in the `number` variable will be added to the value in the `total` variable. When the loop finishes, the `total` variable will hold the sum of all the numbers that were added to it. This value is displayed in line 24. Figure 4-21 shows a flowchart for the Program 4-17.

**Figure 4-21** Flowchart for Program 4-17



## Checkpoint

4.19 A program that calculates the total of a series of numbers typically has what two elements?

4.20 What is an accumulator?

4.21 Should an accumulator be initialized to any specific value? Why or why not?

4.22 Look at the following pseudocode. If it were a real program, what would it display?

```
Declare Integer number1 = 10, number2 = 5
Set number1 = number1 + number2
Display number1
Display number2
```

4.23 Look at the following pseudocode. If it were a real program, what would it display?

```
Declare Integer counter, total = 0
For counter = 1 To 5
 Set total = total + counter
End For
Display total
```

4.5

## Sentinels

**CONCEPT:** A sentinel is a special value that marks the end of a list of values.

Consider the following scenario: You are designing a program that will use a loop to process a long list of values. At the time you are designing the program, you do not know the number of values that will be in the list. In fact, the number of values in the list could be different each time the program is executed. What is the best way to design such a loop? Here are some techniques that you have seen already in this chapter, along with the disadvantages of using them when processing a long list of values:

- Simply ask the user, at the end of each loop iteration, whether there is another value to process. If the list of values is long, however, asking this question at the end of each loop iteration might make the program cumbersome for the user.
- Ask the user at the beginning of the program how many items the list contains. This might also inconvenience the user, however. If the list is very long, and the user does not know the number of items in the list, it will require the user to count them.

When processing a long list of values with a loop, perhaps a better technique is to use a sentinel. A *sentinel* is a special value that marks the end of a list of items. When a

program reads the sentinel value, it knows it has reached the end of the list, so the loop terminates. For example, suppose a doctor wants a program to calculate the average weight of patients. The program might work like this: A loop prompts the user to enter either a patient's weight, or 0 if there are no more weights. When the program reads 0 as a weight, it interprets this as a signal that there are no more weights. The loop ends and the program displays the average weight.

A sentinel value must be unique enough that it will not be mistaken as a regular value in the list. In the example cited above, the doctor (or their medical assistant) enters 0 to signal the end of the list of weights. Because no patient's weight will be 0, this is a good value to use as a sentinel.

### In the Spotlight: Using a Sentinel



The county tax office calculates the annual taxes on property using the following formula:

$$\text{Property Tax} = \text{Property Value} \times 0.0065$$

Every day, a clerk in the tax office gets a list of properties and has to calculate the tax for each property on the list. You have been asked to design a program that the clerk can use to perform these calculations.

In your interview with the tax clerk, you learn that each property is assigned a lot number, and all lot numbers are 1 or greater. You decide to write a loop that uses the number 0 as a sentinel value. During each loop iteration, the program will ask the clerk to enter either a property's lot number, or 0 to end. Program 4-18 shows the pseudocode for the program, and Figure 4-22 shows a flowchart.

#### Program 4-18

```
1 // Declare variables.
2 Declare Real propertyValue, tax
3 Declare Integer lotNumber
4
5 // Constant for the tax factor.
6 Constant Real TAX_FACTOR = 0.0065
7
8 // Get the first lot number.
9 Display "Enter the property's lot number"
10 Display "(or enter 0 to end)."
11 Input lotNumber
12
```

```
13 // Continue processing as long as the user
14 // does not enter lot number 0.
15 While lotNumber != 0
16 // Get the property's value.
17 Display "Enter the property's value."
18 Input propertyValue
19
20 // Calculate the property's tax.
21 Set tax = propertyValue * TAX_FACTOR
22
23 // Display the tax.
24 Display "The property's tax is $", tax
25
26 // Get the next lot number.
27 Display "Enter the lot number for the"
28 Display "next property (or 0 to end)."
29 Input lotNumber
30 End While
```

### Program Output (with Input Shown in Bold)

Enter the property's lot number  
(or enter 0 to end).

**417 [Enter]**

Enter the property's value.

**100000 [Enter]**

The property's tax is \$650  
Enter the lot number for the  
next property (or 0 to end).

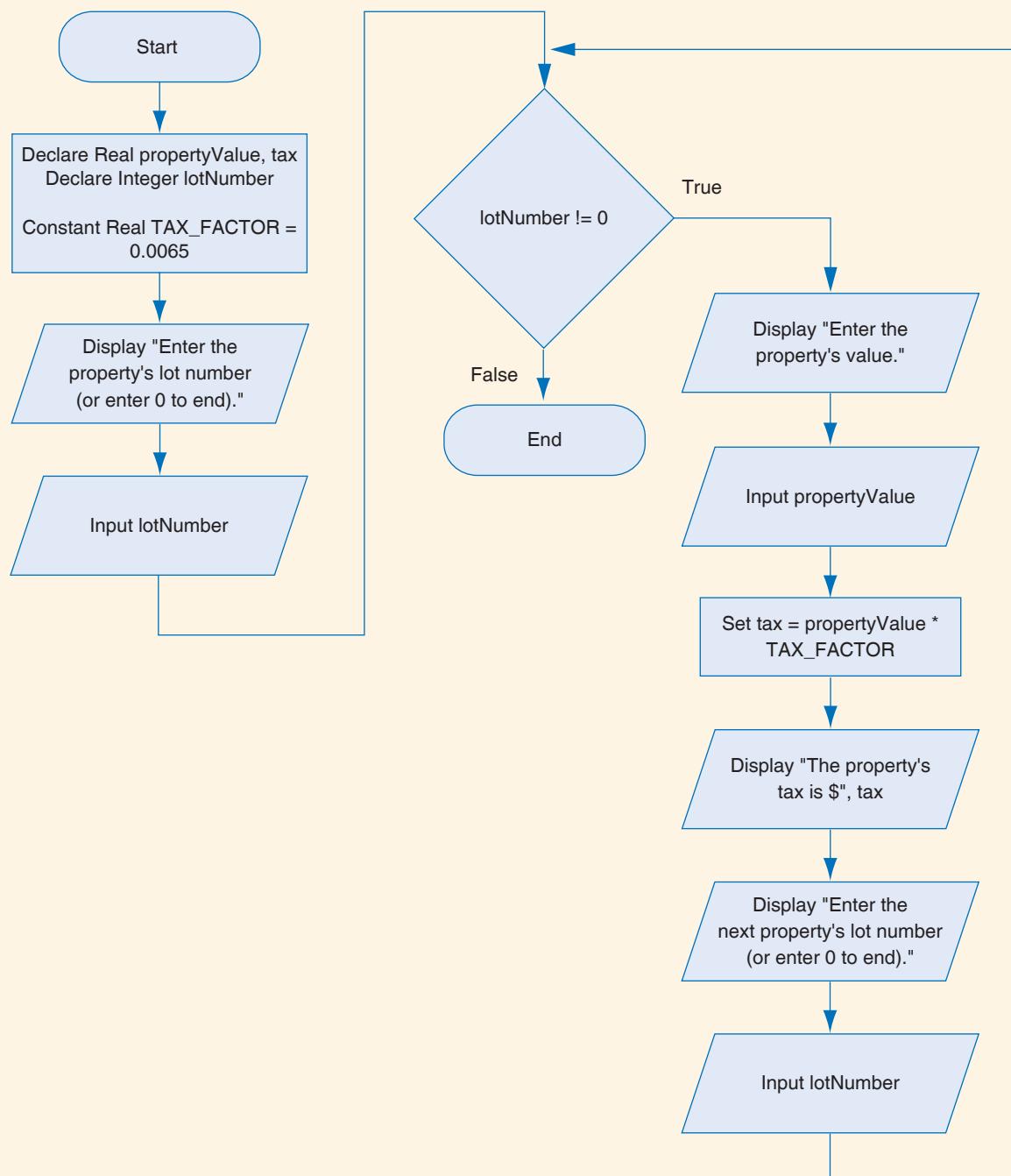
**692 [Enter]**

Enter the property's value.

**60000 [Enter]**

The property's tax is \$390  
Enter the lot number for the  
next property (or 0 to end).

**0 [Enter]**

**Figure 4-22** Flowchart for Program 4-18**Checkpoint**

4.24 What is a sentinel?

4.25 Why should you take care to choose a unique value as a sentinel?

**4.6**

## Nested Loops

**CONCEPT:** A loop that is inside another loop is called a **nested loop**.

A nested loop is a loop that is inside another loop. A clock is a good example of something that works like a nested loop. The second hand, minute hand, and hour hand all spin around the face of the clock. The hour hand, however, only makes 1 revolution for every 12 of the minute hand's revolutions. And it takes 60 revolutions of the second hand for the minute hand to make 1 revolution. This means that for every complete revolution of the hour hand, the second hand has revolved 720 times. Here is pseudocode with a loop that partially simulates a digital clock. It displays the seconds from 0 to 59:

```
Declare Integer seconds
For seconds = 0 To 59
 Display seconds
End For
```

We can add a `minutes` variable and nest the loop above inside another loop that cycles through 60 minutes:

```
Declare Integer minutes, seconds
For minutes = 0 To 59
 For seconds = 0 To 59
 Display minutes, ":", seconds
 End For
End For
```

To make the simulated clock complete, another variable and loop can be added to count the hours:

```
Declare Integer hours, minutes, seconds
For hours = 0 To 23
 For minutes = 0 To 59
 For seconds = 0 To 59
 Display hours, ":", minutes, ":", seconds
 End For
 End For
End For
```

If this were a real program, its output would be:

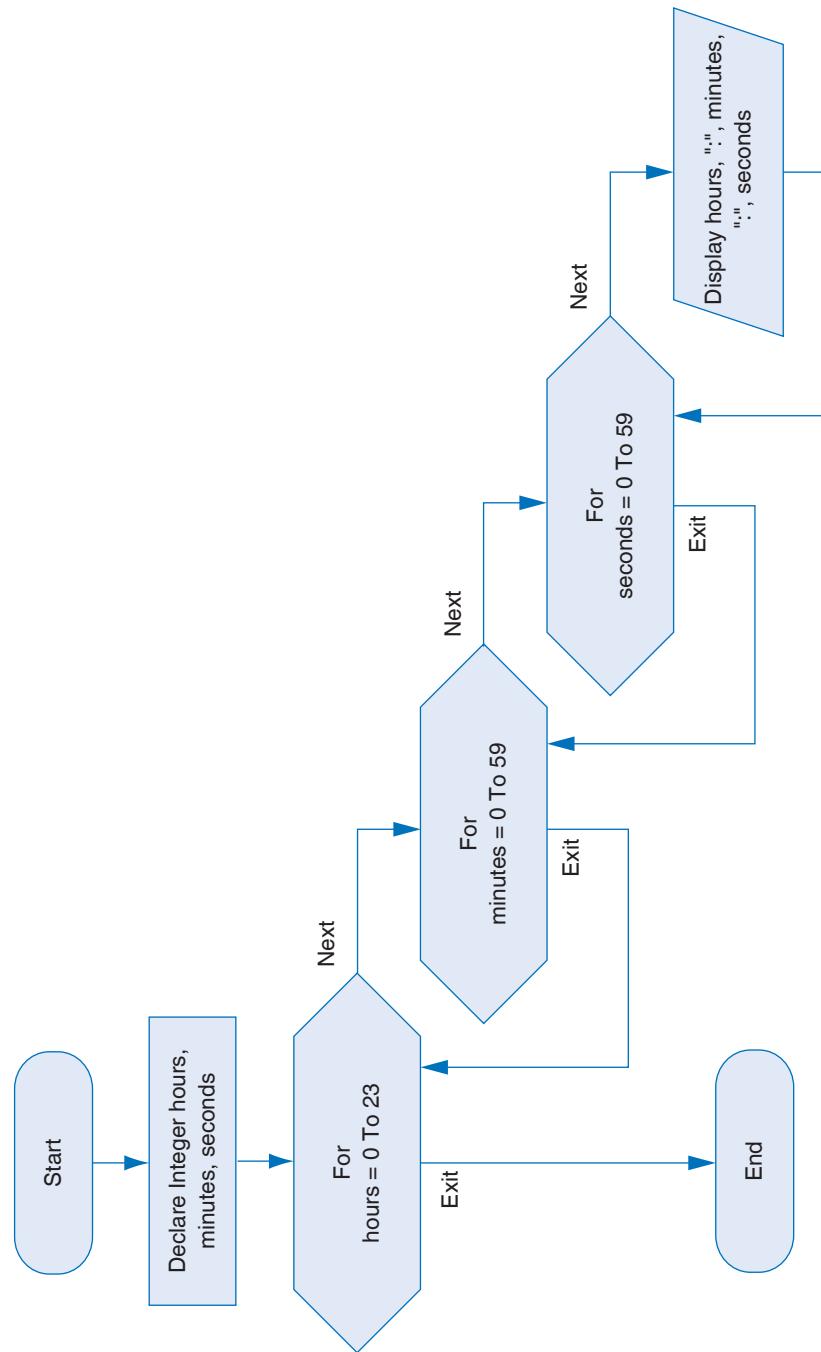
```
0:0:0
0:0:1
0:0:2
```

(The program will count through each second of 24 hours.)

23:59:59

The innermost loop will iterate 60 times for each iteration of the middle loop. The middle loop will iterate 60 times for each iteration of the outermost loop. When the outermost loop has iterated 24 times, the middle loop will have iterated 1,440 times and the innermost loop will have iterated 86,400 times! Figure 4-23 shows a flowchart for the complete clock simulation program previously shown.

**Figure 4-23** Flowchart for a clock simulator



The simulated clock example brings up a few points about nested loops:

- An inner loop goes through all of its iterations for every single iteration of an outer loop.
- Inner loops complete their iterations faster than outer loops.
- To get the total number of iterations of a nested loop, multiply the number of iterations of all the loops.

Program 4-19 shows another example in pseudocode. It is a program that a teacher might use to get the average of each student's test scores. The statement in line 13 gets the number of students, and the statement in line 17 gets the number of test scores per student. The For loop that begins in line 20 iterates once for each student. The nested inner loop, in lines 27 through 31, iterates once for each test score.

### Program 4-19

```
1 // This program averages test scores. It asks the user for the
2 // number of students and the number of test scores per student.
3 Declare Integer numStudents
4 Declare Integer numTestScores
5 Declare Integer total
6 Declare Integer student
7 Declare Integer testNum
8 Declare Real score
9 Declare Real average
10
11 // Get the number of students.
12 Display "How many students do you have?"
13 Input numStudents
14
15 // Get the number of test scores per student.
16 Display "How many test scores per student?"
17 Input numTestScores
18
19 // Determine each student's average test score.
20 For student = 1 To numStudents
21 // Initialize an accumulator for test scores.
22 Set total = 0
23
24 // Get a student's test scores.
25 Display "Student number ", student
26 Display "-----"
27 For testNum = 1 To numTestScores
28 Display "Enter test number ", testNum, ":"
29 Input score
30 Set total = total + score
31 End For
32
33 // Calculate the average test score for this student.
34 Set average = total / numTestScores
35
36 // Display the average.
37 Display "The average for student ", student, " is ", average
38 Display
39 End For
```

**Program Output (with Input Shown in Bold)**

```
How many students do you have?
3 [Enter]
How many test scores per student?
3 [Enter]
Student number 1

Enter test number 1:
100 [Enter]
Enter test number 2:
95 [Enter]
Enter test number 3:
90 [Enter]
The average for student number 1 is 95.0

Student number 2

Enter test number 1:
80 [Enter]
Enter test number 2:
81 [Enter]
Enter test number 3:
82 [Enter]
The average for student number 2 is 81.0

Student number 3

Enter test number 1:
75 [Enter]
Enter test number 2:
85 [Enter]
Enter test number 3:
80 [Enter]
The average for student number 3 is 80.0
```

**4.7****Focus on Languages: Java, Python, and C++**

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

## Java

### Repetition Structures in Java

#### Incrementing and Decrementing Variables in Java

To increment a variable means to increase its value and to decrement a variable means to decrease its value. Incrementing and decrementing is so commonly done in programs that Java provides a set of simple unary operators designed just for incrementing and decrementing variables. The increment operator is `++` and the decrement operator is `--`. The following statement uses the `++` operator to add 1 to `num`:

```
num++;
```

After this statement executes, the value of `num` will increased by 1. The following statement uses the `--` operator to subtract 1 from `num`:

```
num--;
```

In these examples, we have written the `++` and `--` operators after their operands (or, on the right side of their operands). This is called *postfix mode*. The operators can also be written before (or, on the left side) of their operands, which is called *prefix mode*. Here are examples:

```
++num;
--num;
```

When you write a simple statement to increment or decrement a variable, such as the ones shown here, it doesn't matter if you use prefix mode or postfix mode. The operators do the same thing in either mode. However, if you write statements that mix these operators with other operators or with other operations, there is a difference in the way the two modes work. Such complex code can be difficult to understand and debug. In this book, we use the increment and decrement operators only in ways that are straightforward and easy to understand, such as the statements previously shown. We introduce these operators at this point because they are commonly used in certain types of loops.

#### The while Loop in Java

In Java, the `while` loop is written in the following general format:

```
while (BooleanExpression)
{
 statement;
 statement;
 etc;
}
```

When the `while` loop executes, the Boolean expression is tested. If the Boolean expression is true, the statements that appear inside the curly braces are executed, and then the loop starts over. If the Boolean expression is false, the loop ends and the program resumes execution at the statement immediately following the loop.

If you are writing a `while` loop that has only one statement in its body, you do not have to enclose the statement inside curly braces. Such a loop can be written in the following general format:

```
while (BooleanExpression)
 statement;
```

When a `while` loop written in this format executes, the Boolean expression is tested. If it is true, the one statement that appears on the next line will be executed, and then the loop starts over. If the Boolean expression is false, however, the loop ends.

The following code shows an example of a `while` loop that prints “Hello” five times:

```
int count = 0;
while (count < 5)
{
 System.out.println("Hello");
 count++;
}
```

### The do-while Loop in Java

Here is the general format of the `do-while` loop:

```
do
{
 statement;
 statement;
 etc;
} while (BooleanExpression);
```

As with the `while` loop, the braces are optional if there is only one statement in the body of the loop. This is the general format of the `do-while` loop with only one conditionally executed statement:

```
do
 statement;
while (BooleanExpression);
```

Notice that a semicolon appears at the very end of the `do-while` statement. This semicolon is required, and leaving it out is a common error.

The following code shows an example of a `do-while` loop that prints “Hello” five times:

```
int count = 0;
do
{
 System.out.println("Hello");
 count++;
} while (count < 5);
```



**NOTE:** Java does not provide a loop that is equivalent to the Do-Until loop that is discussed earlier in this chapter.

### The for Loop in Java

The `for` loop is specifically designed to initialize, test, and increment a counter variable. Here is the general format of the `for` loop:

```
for (InitializationExpression; TestExpression; IncrementExpression)
{
 statement;
 statement;
 etc.
}
```

The statements that appear inside the curly braces are executed each time the loop iterates. The curly braces are optional if the body of the loop contains only one statement, as shown in the following general format:

```
for (InitializationExpression; TestExpression; IncrementExpression)
 statement;
```

The first line of the `for` loop is the *loop header*. After the key word `for`, there are three expressions inside the parentheses, separated by semicolons. (Notice there is not a semicolon after the third expression.)

The first expression is the *initialization expression*. It is normally used to initialize a counter variable to its starting value. This is the first action performed by the loop, and it is only done once. The second expression is the *test expression*. This is a Boolean expression that controls the execution of the loop. As long as this expression is true, the body of the `for` loop will repeat. The `for` loop is a pretest loop, so it evaluates the test expression before each iteration. The third expression is the *increment expression*. It executes at the end of each iteration. Typically, this is a statement that increments the loop's counter variable.

Here is an example of a simple `for` loop that prints “Hello” five times:

```
for (count = 1; count <= 5; count++)
{
 System.out.println("Hello");
}
```

In this loop, the initialization expression is `count = 1`, the test expression is `count <= 5`, and the increment expression is `count++`. The body of the loop has one statement, which is the call to `System.out.println`. This is a summary of what happens when this loop executes:

1. The initialization expression `count = 1` is executed. This assigns 1 to the `count` variable.
2. The expression `count <= 5` is tested. If the expression is true, continue with step 3. Otherwise, the loop is finished.
3. The statement `System.out.println("Hello");` is executed.
4. The increment expression `count++` is executed. This adds 1 to the `count` variable.
5. Go back to step 2.

## Python

### Repetition Structures in Python

#### The while Loop in Python

In Python, the `while` loop is written in the following general format:

```
while condition:
 statement
 statement
 etc.
```

The `while` clause begins with the word `while`, followed by a Boolean *condition* that will be evaluated as either true or false. A colon appears after the *condition*. Beginning at the next line is a block of statements. All of the statements in a block must be consistently indented. This indentation is required because the Python interpreter uses it to tell where the block begins and ends.

When the `while` loop executes, the *condition* is tested. If the *condition* is true, the statements that appear in the block following the `while` clause are executed, and then the loop starts over. If the *condition* is false, the program exits the loop. The following code shows an example of a `while` loop that prints “Hello” five times:

```
count = 0
while count < 5:
 print('Hello')
 count = count + 1
```



**NOTE:** Python does not provide a loop that is equivalent to the Do-While or Do-Until loops that are discussed earlier in this chapter.

#### The for Loop in Python

In Python, the `for` statement is designed to work with a sequence of data items. When the statement executes, it iterates once for each item in the sequence. We will use the `for` statement in the following general format:

```
for variable in [value1, value2, etc.]:
 statement
 statement
 etc.
```

In the `for` clause, *variable* is the name of a variable. Inside the brackets, a sequence of values appears, with a comma separating each value. (In Python, a comma-separated sequence of data items that are enclosed in a set of brackets is called a *list*.) Beginning at the next line is a block of statements that is executed each time the loop iterates.

The `for` statement executes in the following manner: The *variable* is assigned the first value in the list, and then the statements that appear in the block are executed. Then, *variable* is assigned the next value in the list, and the statements in the block are executed again. This continues until *variable* has been assigned the last value in the list. The following code shows a simple example that uses a `for` loop to display the numbers 1 through 5:

```
for num in [1, 2, 3, 4, 5]:
 print(num)
```

### Using the range Function with the for Loop in Python

Python provides a built-in function named `range` that simplifies the process of writing a count-controlled `for` loop. Here is an example of a `for` loop that uses the `range` function:

```
for num in range(5):
 print(num)
```

Notice that instead of using a list of values, we call to the `range` function passing 5 as an argument. In this statement the `range` function will generate a list of integers in the range of 0 up to (but not including) 5. This code works the same as the following:

```
for num in [0, 1, 2, 3, 4]:
 print(num)
```

As you can see, the list contains five numbers, so the loop will iterate five times. The following code uses the `range` function with a `for` loop to display *Hello world* five times:

```
for x in range(5):
 print('Hello world!')
```

If you pass one argument to the `range` function, as previously demonstrated, that argument is used as the ending limit of the list. If you pass two arguments to the `range` function, the first argument is used as the starting value of the list and the second argument is used as the ending limit. Here is an example:

```
for num in range(1, 5):
 print(num)
```

This code will display the following:

```
1
2
3
4
```

By default, the `range` function produces a list of numbers that increase by 1 for each successive number in the list. If you pass a third argument to the `range` function, that argument is used as *step value*. Instead of increasing by 1, each successive number in the list will increase by the step value. The following code shows an example:

```
for num in range(1, 12, 2):
 print(num)
```

This code will display the following:

```
1
3
5
7
9
11
```

**C++****Repetition Structures in C++****Incrementing and Decrementing Variables in C++**

To increment a variable means to increase its value and to decrement a variable means to decrease its value. Incrementing and decrementing is so commonly done in programs that C++ provides a set of simple unary operators designed just for incrementing and decrementing variables. The increment operator is `++` and the decrement operator is `--`. The following statement uses the `++` operator to add 1 to `num`:

```
num++;
```

After this statement executes, the value of `num` will increased by 1. The following statement uses the `--` operator to subtract 1 from `num`:

```
num--;
```

In these examples, we have written the `++` and `--` operators after their operands (or, on the right side of their operands). This is called *postfix mode*. The operators can also be written before (or, on the left side) of their operands, which is called *prefix mode*. Here are examples:

```
++num;
--num;
```

When you write a simple statement to increment or decrement a variable, such as the ones shown here, it doesn't matter if you use prefix mode or postfix mode. The operators do the same thing in either mode. However, if you write statements that mix these operators with other operators or with other operations, there is a difference in the way the two modes work. Such complex code can be difficult to understand and debug. In this book, we use the increment and decrement operators only in ways that are straightforward and easy to understand, such as the statements previously shown. We introduce these operators at this point because they are commonly used in certain types of loops.

**The while Loop in C++**

In C++, the `while` loop is written in the following general format:

```
while (BooleanExpression)
{
 statement;
 statement;
 etc;
}
```

When the `while` loop executes, the Boolean expression is tested. If the Boolean expression is true, the statements that appear inside the curly braces are executed, and then the loop starts over. If the Boolean expression is false, the loop ends and the program resumes execution at the statement immediately following the loop.

If you are writing a `while` loop that has only one statement in its body, you do not have to enclose the statement inside curly braces. Such a loop can be written in the following general format:

```
while (BooleanExpression)
 statement;
```

When a `while` loop written in this format executes, the Boolean expression is tested. If it is true, the one statement that appears on the next line will be executed, and then the loop starts over. If the Boolean expression is false, however, the loop ends.

The following code shows an example of a `while` loop that prints *Hello* five times:

```
int count = 0;
while (count < 5)
{
 cout << "Hello" << endl;
 count++;
}
```

### The do-while Loop in C++

Here is the general format of the `do-while` loop:

```
do
{
 statement;
 statement;
 etc;
} while (BooleanExpression);
```

As with the `while` loop, the braces are optional if there is only one statement in the body of the loop. This is the general format of the `do-while` loop with only one conditionally executed statement:

```
do
 statement;
while (BooleanExpression);
```

Notice that a semicolon appears at the very end of the `do-while` statement. This semicolon is required, and leaving it out is a common error.

The following code shows an example of a `do-while` loop that prints *Hello* five times:

```
int count = 0;
do
{
 cout << "Hello" << endl;
 count++;
} while (count < 5);
```



**NOTE:** C++ does not provide a loop that is equivalent to the Do-Until loop that is discussed earlier in this chapter.

### The for Loop in C++

The `for` loop is specifically designed to initialize, test, and increment a counter variable. Here is the general format of the `for` loop:

```
for (InitializationExpression; TestExpression; IncrementExpression)
{
 statement;
 statement;
 etc.
}
```

The statements that appear inside the curly braces are executed each time the loop iterates. The curly braces are optional if the body of the loop contains only one statement, as shown in the following general format:

```
for (InitializationExpression; TestExpression; IncrementExpression)
statement;
```

The first line of the `for` loop is the *loop header*. After the key word `for`, there are three expressions inside the parentheses, separated by semicolons. (Notice there is not a semicolon after the third expression.)

The first expression is the *initialization expression*. It is normally used to initialize a counter variable to its starting value. This is the first action performed by the loop, and it is only done once. The second expression is the *test expression*. This is a Boolean expression that controls the execution of the loop. As long as this expression is true, the body of the `for` loop will repeat. The `for` loop is a pretest loop, so it evaluates the test expression before each iteration. The third expression is the *increment expression*. It executes at the end of each iteration. Typically, this is a statement that increments the loop's counter variable.

Here is an example of a simple `for` loop that prints “Hello” five times:

```
for (count = 1; count <= 5; count++)
{
 cout << "Hello" << endl;
}
```

In this loop, the initialization expression is `count = 1`, the test expression is `count <= 5`, and the increment expression is `count++`. The body of the loop has one statement. This is a summary of what happens when this loop executes:

1. The initialization expression `count = 1` is executed. This assigns 1 to the `count` variable.
2. The expression `count <= 5` is tested. If the expression is true, continue with step 3. Otherwise, the loop is finished.
3. The statement `cout << "Hello" << endl;` is executed.
4. The increment expression `count++` is executed. This adds 1 to the `count` variable.
5. Go back to step 2.

## Review Questions

### Multiple Choice

1. A \_\_\_\_\_-controlled loop uses a true/false condition to control the number of times that it repeats.
  - a. Boolean
  - b. condition
  - c. decision
  - d. count
2. A \_\_\_\_\_-controlled loop repeats a specific number of times.
  - a. Boolean
  - b. condition
  - c. decision
  - d. count
3. Each repetition of a loop is known as a(n) \_\_\_\_\_.
  - a. cycle
  - b. revolution
  - c. orbit
  - d. iteration
4. The `While` loop is a \_\_\_\_\_ type of loop.
  - a. pretest
  - b. posttest
  - c. prequalified
  - d. post iterative
5. The `Do-While` loop is a \_\_\_\_\_ type of loop.
  - a. pretest
  - b. posttest
  - c. prequalified
  - d. post iterative
6. The `For` loop is a \_\_\_\_\_ type of loop.
  - a. pretest
  - b. posttest
  - c. prequalified
  - d. post iterative
7. A(n) \_\_\_\_\_ loop has no way of ending and repeats until the program is interrupted.
  - a. indeterminate
  - b. interminable
  - c. infinite
  - d. timeless
8. A \_\_\_\_\_ loop always executes at least once.
  - a. pretest
  - b. posttest
  - c. condition-controlled
  - d. count-controlled

9. A(n) \_\_\_\_\_ variable keeps a running total.
  - a. sentinel
  - b. sum
  - c. total
  - d. accumulator
10. A(n) \_\_\_\_\_ is a special value that signals when there are no more items from a list of items to be processed. This value cannot be mistaken as an item from the list.
  - a. sentinel
  - b. flag
  - c. signal
  - d. accumulator

### True or False

1. A condition-controlled loop always repeats a specific number of times.
2. The `While` loop is a pretest loop.
3. The `Do-While` loop is a pretest loop.
4. You should not write code that modifies the contents of the counter variable in the body of a `For` loop.
5. You cannot display the contents of the counter variable in the body of a loop.
6. It is not possible to increment a counter variable by any value other than 1.
7. The following statement decrements the variable `x`: `Set x = x - 1`.
8. It is not necessary to initialize accumulator variables.
9. In a nested loop, the inner loop goes through all of its iterations for every single iteration of the outer loop.
10. To calculate the total number of iterations of a nested loop, add the number of iterations of all the loops.

### Short Answer

1. Why should you indent the statements in the body of a loop?
2. Describe the difference between pretest loops and posttest loops.
3. What is a condition-controlled loop?
4. What is a count-controlled loop?
5. What three actions do count-controlled loops typically perform using the counter variable?
6. What is an infinite loop? Write the code for an infinite loop.
7. A `For` loop looks like what other loop in a flowchart?
8. Why is it critical that accumulator variables are properly initialized?
9. What is the advantage of using a sentinel?
10. Why must the value chosen for use as a sentinel be carefully selected?

### Algorithm Workbench

1. Design a **While** loop that lets the user enter a number. The number should be multiplied by 10, and the result stored in a variable named **product**. The loop should iterate as long as **product** contains a value less than 100.
2. Design a **Do-While** loop that asks the user to enter two numbers. The numbers should be added and the sum displayed. The loop should ask the user whether they wish to perform the operation again. If so, the loop should repeat; otherwise it should terminate.
3. Design a **For** loop that displays the following set of numbers:  
0, 10, 20, 30, 40, 50, . . . , 1000
4. Design a loop that asks the user to enter a number. The loop should iterate 10 times and keep a running total of the numbers entered.
5. Design a **For** loop that calculates the total of the following series of numbers:

$$\frac{1}{30} + \frac{2}{29} + \frac{3}{28} + \cdots + \frac{30}{1}$$

6. Design a nested loop that displays 10 rows of # characters. There should be 15 # characters in each row.
7. Convert the **While** loop in the following code to a **Do-While** loop:

```
Declare Integer x = 1
While x > 0
 Display "Enter a number."
 Input x
End While
```

8. Convert the **Do-While** loop in the following code to a **While** loop:

```
Declare String sure
Do
 Display "Are you sure you want to quit?"
 Input sure
 While sure != "Y" AND sure != "y"
```

9. Convert the following **While** loop to a **For** loop:

```
Declare Integer count = 0
While count < 50
 Display "The count is ", count
 Set count = count + 1
End While
```

10. Convert the following **For** loop to a **While** loop:

```
Declare Integer count
For count = 1 To 50
 Display count
End For
```

## Debugging Exercises

1. Find the error in the following pseudocode.

```

Declare Boolean finished = False
Declare Integer value, cube

While NOT finished
 Display "Enter a value to be cubed."
 Input value;
 Set cube = value^3
 Display value, " cubed is ", cube
End While

```

2. The programmer intended the following pseudocode to display the numbers 1 through 60, and then display the message “Time’s up!” It will not function as intended, however. Find the error.

```

Declare Integer counter = 1
Const Integer TIME_LIMIT = 60
While counter < TIME_LIMIT
 Display counter
 Set counter = counter + 1
End While
Display "Time's up!"

```

3. The programmer intended the following pseudocode to get five sets of two numbers each, calculate the sum of each set, and calculate the sum of all the numbers entered. It will not function as intended, however. Find the error.

```

// This program calculates the sum of five sets of two numbers.
Declare Integer number, sum, total
Declare Integer sets, numbers

Constant Integer MAX_SETS = 5
Constant Integer MAX_NUMBERS = 2

Set sum = 0;
Set total = 0;

For sets = 1 To MAX_SETS
 For numbers = 1 To MAX_NUMBERS
 Display "Enter number ", numbers, " of set ", sets, "."
 Input number;
 Set sum = sum + number
 End For
 Display "The sum of set ", sets, " is ", sum, "."
 Set total = total + sum
 Set sum = 0
End For
Display "The total of all the sets is ", total, "."

```

## Programming Exercises



VideoNote  
The Bug Collector  
Problem

### 1. Bug Collector

A bug collector collects bugs every day for seven days. Design a program that keeps a running total of the number of bugs collected during the seven days. The loop should ask for the number of bugs collected for each day, and when the loop is finished, the program should display the total number of bugs collected.

### 2. Candy Factory

A machine at a candy factory can produce 80 chocolate bars per minute. Design a program that uses a loop to display the number of chocolate bars the machine can produce in 10, 15, 20, 25, and 30 minutes.

### 3. Budget Analysis

Design a program that asks the user to enter the amount they have to spend for a month. A loop should then prompt the user to enter each expense for the month, and keep a running total. When the loop finishes, the program should display the amount that the user is over or under budget.

### 4. Sum of Numbers

Design a program with a loop that asks the user to enter a series of positive numbers. The user should enter a negative number to signal the end of the series. After all the positive numbers have been entered, the program should display their sum.

### 5. Tuition Increase

At one college, the tuition for a full-time student is \$6,000 per semester. It has been announced that the tuition will increase by 2 percent each year for the next five years. Design a program with a loop that displays the projected semester tuition amount for the next five years.

### 6. Distance Traveled

The distance a vehicle travels can be calculated as follows:

$$\text{Distance} = \text{Speed} \times \text{Time}$$

For example, if a train travels 40 miles per hour for three hours, the distance traveled is 120 miles. Design a program that asks the user for the speed of a vehicle (in miles per hour) and how many hours it has traveled. It should then use a loop to display the distance the vehicle has traveled for each hour of that time period. Here is an example of the output:

What is the speed of the vehicle in mph? **40 [Enter]**  
How many hours has it traveled? **3 [Enter]**

| Hour | Distance Traveled |
|------|-------------------|
| 1    | 40                |
| 2    | 80                |
| 3    | 120               |

**7. Average Rainfall**

Design a program that uses nested loops to collect data and calculate the average rainfall over a period of years. The program should first ask for the number of years. The outer loop will iterate once for each year. The inner loop will iterate twelve times, once for each month. Each iteration of the inner loop will ask the user for the inches of rainfall for that month. After all iterations, the program should display the number of months, the total inches of rainfall, and the average rainfall per month for the entire period.

**8. Celsius to Fahrenheit Table**

Design a program that displays a table of the Celsius temperatures 0 through 20 and their Fahrenheit equivalents. The formula for converting a temperature from Celsius to Fahrenheit is

$$F = \frac{9}{5}C + 32$$

where  $F$  is the Fahrenheit temperature and  $C$  is the Celsius temperature. Your program must use a loop to display the table.

**9. Pennies for Pay**

Design a program that calculates the amount of money a person would earn over a period of time if their salary is one penny the first day, two pennies the second day, and continues to double each day. The program should ask the user for the number of days. Display a table showing what the salary was for each day, and then show the total pay at the end of the period. The output should be displayed in a dollar amount, not the number of pennies.

**10. Largest and Smallest**

Design a program with a loop that lets the user enter a series of numbers. The user should enter  $-99$  to signal the end of the series. After all the numbers have been entered, the program should display the largest and smallest numbers entered.

**11. First and Last**

Design a program that asks the user for a series of names (in no particular order). After the final person's name has been entered, the program should display the name that is first alphabetically and the name that is last alphabetically. For example, if the user enters the names Kumiko, Joel, Adam, Samara, Zeb, and Darius, the program would display Adam and Zeb.

**12. Calculating the Factorial of a Number**

In mathematics, the notation  $n!$  represents the factorial of the nonnegative integer  $n$ . The factorial of  $n$  is the product of all the nonnegative integers from 1 up through  $n$ . For example:

$$7! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 = 5,040$$

and

$$4! = 1 \times 2 \times 3 \times 4 = 24$$

Design a program that asks the user to enter a nonnegative integer and then displays the factorial of that number.

### 13. Multiplication Table

Design a program that uses nested loops to display a multiplication table for the numbers 1 through 12. The program's output should look like this:

1 \* 0 = 0

1 \* 1 = 1

1 \* 2 = 2

1 \* 3 = 3

*and so forth...*

12 \* 9 = 108

12 \* 10 = 120

12 \* 11 = 132

12 \* 12 = 144

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**TOPICS**

- |                                   |                                               |
|-----------------------------------|-----------------------------------------------|
| 5.1 Introduction to Modules       | 5.4 Passing Arguments to Modules              |
| 5.2 Defining and Calling a Module | 5.5 Global Variables and Global Constants     |
| 5.3 Local Variables               | 5.6 Focus on Languages: Java, Python, and C++ |

**5.1**

## Introduction to Modules

**CONCEPT:** A module is a group of statements that exist for the purpose of performing a specific task within a program.

In Chapter 2 you saw a simple program that performs the task of calculating an employee’s pay. Recall that the program multiplied the number of hours that the employee worked by the employee’s hourly pay rate. A more realistic payroll program, however, would do much more than this. In a real-world application, the overall task of calculating an employee’s pay would consist of several subtasks, such as the following:

- Getting the employee’s hourly pay rate
- Getting the number of hours worked
- Calculating the employee’s gross pay
- Calculating overtime pay
- Calculating withholdings for taxes and benefits
- Calculating the net pay
- Printing the paycheck

Most programs perform tasks that are large enough to be broken down into several subtasks. For this reason, programmers usually break down their programs into modules. A *module* is a group of statements that exist within a program for the purpose of performing a specific task. Instead of writing a large program as one long sequence of statements, it

can be written as several small modules, each one performing a specific part of the task. These small modules can then be executed in the desired order to perform the overall task.

This approach is sometimes called *divide and conquer* because a large task is divided into several smaller tasks that are easily performed. Figure 5-1 illustrates this idea by comparing two programs: one that uses a long, complex sequence of statements to perform a task, and another that divides a task into smaller tasks, each of which is performed by a separate module.

When using modules in a program, you generally isolate each task within the program in its own module. For example, a realistic pay calculating program might have the following modules:

- A module that gets the employee's hourly pay rate
- A module that gets the number of hours worked
- A module that calculates the employee's gross pay
- A module that calculates the overtime pay
- A module that calculates the withholdings for taxes and benefits
- A module that calculates the net pay
- A module that prints the paycheck

Although every modern programming language allows you to create modules, they are not always referred to as modules. Modules are commonly called *procedures*, *subroutines*, *subprograms*, *methods*, and *functions*. (A function is a special type of module that we will discuss in Chapter 6.)

## Benefits of Using Modules

A program benefits in the following ways when it is modularized:

### Simpler Code

A program's code tends to be simpler and easier to understand when it is modularized. Several small modules are much easier to read than one long sequence of statements.

### Code Reuse

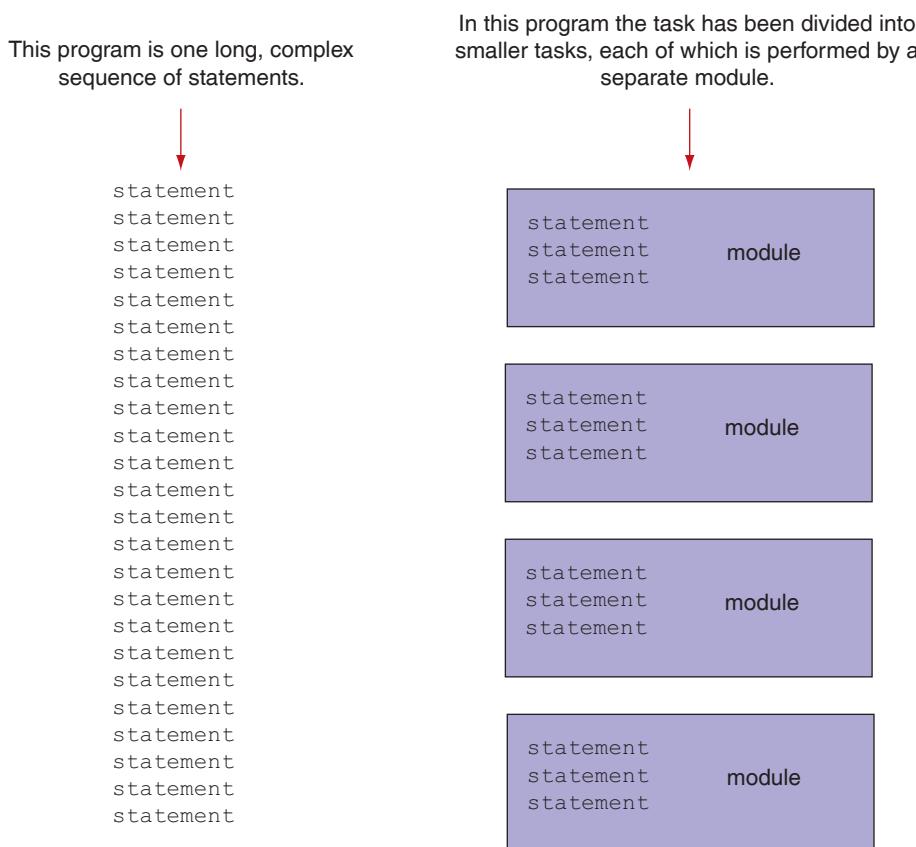
Modules also reduce the duplication of code within a program. If a specific operation is performed in several places in a program, a module can be written once to perform that operation, and then be executed any time it is needed. This benefit of using modules is known as *code reuse* because you are writing the code to perform a task once and then reusing it each time you need to perform the task.

### Better Testing

When each task within a program is contained in its own module, testing and debugging become simpler. Programmers can test each module in a program individually, to determine whether it correctly performs its operation. This makes it easier to isolate and fix errors.

### Easier Maintenance

Most programs must be periodically modified to correct logic errors, improve performance, and provide a better experience for the user. Such modifications are known as *maintenance*. A modularized program is easier to maintain than an unmodularized program because its code tends to be simpler, smaller, and easier to understand.

**Figure 5-1** Using modules to divide and conquer a large task

### Faster Development

Suppose a programmer or a team of programmers is developing multiple programs. They discover that each of the programs performs several common tasks, such as asking for a username and a password, displaying the current time, and so on. It doesn't make sense to write the code for these tasks multiple times. Instead, modules can be written for the commonly needed tasks, and those modules can be incorporated into each program that needs them.

### Easier Facilitation of Teamwork

Modules also make it easier for programmers to work in teams. When a program is developed as a set of modules that each perform an individual task, then different programmers can be assigned the job of writing different modules.

## Checkpoint

- 5.1 What is a module?
- 5.2 What is meant by the phrase “divide and conquer”?
- 5.3 How do modules help you reuse code in a program?

- 5.4 How can modules make the development of multiple programs faster?
- 5.5 How can modules make it easier for programs to be developed by teams of programmers?

## 5.2

## Defining and Calling a Module

**CONCEPT:** The code for a module is known as a **module definition**. To execute the module, you write a statement that calls it.

### Module Names

Before we discuss the process of creating and using modules, we should mention a few things about module names. Just as you name the variables that you use in a program, you also name the modules. A module's name should be descriptive enough so that anyone reading your code can reasonably guess what the module does.

Because modules perform actions, most programmers prefer to use verbs in module names. For example, a module that calculates gross pay might be named `calculateGrossPay`. This name would make it evident to anyone reading the code that the module calculates something. What does it calculate? The gross pay, of course. Other examples of good module names would be `getHours`, `getPayRate`, `calculateOvertime`, `printCheck`, and so on. Each module name describes what the module does.

When naming a module, most languages require that you follow the same rules that you follow when naming variables. This means that module names cannot contain spaces, cannot typically contain punctuation characters, and usually cannot begin with a number. These are only general rules, however. The specific rules for naming a module will vary slightly with each programming language.



VideoNote  
Defining and  
Calling a Module

### Defining and Calling a Module

To create a module you write its *definition*. In most languages, a module definition has two parts: a header and a body. The *header* indicates the starting point of the module, and the *body* is a list of statements that belong to the module. Here is the general format that we will follow when we write a module definition in pseudocode:

```
Module name()
 statement
 statement
 etc.
}
} These statements are the body of the module.
End Module
```

The first line is the module header. In our pseudocode the header begins with the word `Module`, followed by the name of the module, followed by a set of parentheses. It is a common practice in most programming languages to put a set of parentheses after a

module name. Later in this chapter, you will see the actual purpose of the parentheses, but for now, just remember that they come after the module name.

Beginning at the line after the module header, one or more statements will appear. These statements are the module's body, and are performed any time the module is executed. The last line of the definition, after the body, reads `End Module`. This line marks the end of the module definition.

Let's look at an example. Keep in mind that this is not a complete program. We will show the entire pseudocode program in a moment.

```
Module showMessage()
 Display "Hello world."
End Module
```

This pseudocode defines a module named `showMessage`. As its name implies, the purpose of this module is to show a message on the screen. The body of the `showMessage` module contains one statement: a `Display` statement that displays the message “Hello world.”

Notice in the previous example that the statement in the body of the module is indented. Indenting the statements in the body of a module is not usually required,<sup>1</sup> but it makes your code much easier to read. By indenting the statements inside a module, you visually set them apart. As a result, you can tell at a glance which statements are inside the module. This practice is a programming style convention that virtually all programmers follow.

### Calling a Module

A module definition specifies what a module does, but it does not cause the module to execute. To execute a module, we must *call* it. In pseudocode we will use the word `Call` to call a module. This is how we would call the `showMessage` module:

```
Call showMessage()
```

When a module is called, the computer jumps to that module and executes the statements in the module's body. Then, when the end of the module is reached, the computer jumps back to the part of the program that called the module, and the program resumes execution at that point.

To fully demonstrate how module calling works, we will look at Program 5-1.

#### Program 5-1



```
1 Module main()
2 Display "I have a message for you."
3 Call showMessage()
4 Display "That's all, folks!"
5 End Module
6
```

<sup>1</sup> The Python language requires you to indent the statements inside a function, which is the equivalent of a module as described in this chapter.

```

7 Module showMessage()
8 Display "Hello world"
9 End Module

```

### Program Output

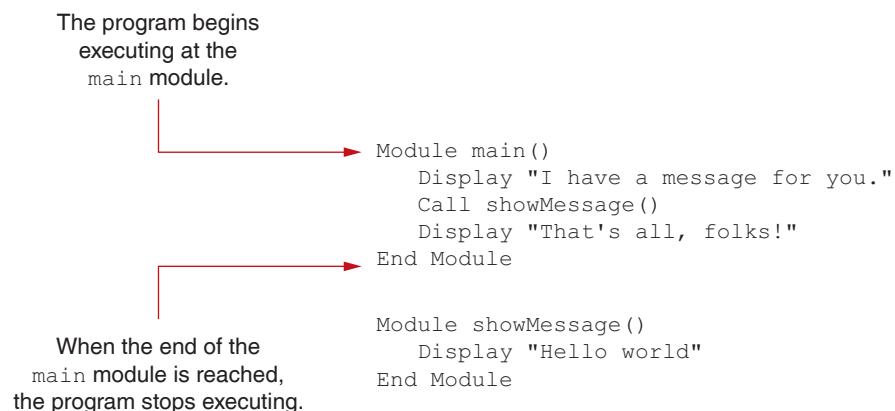
```

I have a message for you.
Hello world
That's all, folks!

```

First, notice that Program 5-1 has two modules: a module named `main` appears in lines 1 through 5, and the `showMessage` module appears in lines 7 through 9. Many programming languages require that programs have a *main module*. The `main` module is the program's starting point, and it generally calls other modules. When the end of the `main` module is reached, the program stops executing. In this book, any time you see a pseudocode program with a module named `main`, we are using that module as the program's starting point. Likewise, when the end of the `main` module is reached, the program will stop executing. This is shown in Figure 5-2.

**Figure 5-2** The main module



**NOTE:** Many languages, including Java, C, and C++, require that the `main` module actually be named `main`, as we have shown in Program 5-1.

Let's step through the program. When the program runs, the `main` module starts and the statement in line 2 displays “I have a message for you.” Then, line 3 calls the `showMessage` module. As shown in Figure 5-3, the computer jumps to the `showMessage` module and executes the statements in its body. There is only one statement in the body of the `showMessage` module: the `Display` statement in line 8. This statement displays “Hello world” and then the module ends. As shown in Figure 5-4, the computer jumps back to the part of the program that called `showMessage`, and resumes execution from that point. In this case, the program resumes execution at line 4, which displays “That's all, folks!” The `main` module ends at line 5, so the program stops executing.

**Figure 5-3** Calling the showMessage module

```

Module main()
 Display "I have a message for you."
 Call showMessage()
 Display "That's all, folks!"
End Module

The computer jumps to
the showMessage module
and executes the statements
in its body.

→ Module showMessage()
 Display "Hello world"
End Module

```

**Figure 5-4** The showMessage module returns

```

Module main()
 Display "I have a message for you."
 Call showMessage()
 → Display "That's all, folks!"
End Module

When the showMessage module
ends, the computer jumps back
to the part of the program that
called it, and resumes execution
from that point.

→ Module showMessage()
 Display "Hello world"
End Module

```

When the computer encounters a module call, such as the one in line 3 of Program 5-1, it has to perform some operations “behind the scenes” so it will know where to return after the module ends. First, the computer saves the memory address of the location that it should return to. This is typically the statement that appears immediately after the module call. This memory location is known as the *return point*. Then, the computer jumps to the module and executes the statements in its body. When the module ends, the computer jumps back to the return point and resumes execution.



**NOTE:** When a program calls a module, programmers commonly say that the *control* of the program transfers to that module. This simply means that the module takes control of the program’s execution.

Modules may be called by statements in control structures, such as loops and If statements. For example, Program 5-2 uses a For loop to repeatedly call the showMessage module.

### Program 5-2

```

1 Module main()
2 // Declare a counter variable.
3 Declare Integer counter
4
5 // Constant for the counter's maximum value
6 Constant Integer MAX_VALUE = 5
7
8 // Call the showMessage module 5 times.
9 Display "I have some messages for you."

```

```

10 For counter = 1 To MAX_VALUE
11 Call showMessage()
12 End For
13 Display "That's all, folks!"
14 End Module
15
16 Module showMessage()
17 Display "Hello world"
18 End Module

```

### Program Output

I have some messages for you.  
 Hello world  
 Hello world  
 Hello world  
 Hello world  
 Hello world  
 Hello world  
 That's all, folks!

Program 5-3 shows another example. It asks the user to enter a test score. The program then determines whether the user passed or failed the test. One of two modules, `pass` or `fail`, is called to display a message.

### Program 5-3

```

1 Module main()
2 // Variable to hold a test score.
3 Declare Real testScore
4
5 // Get the user's test score.
6 Display "Enter your test score."
7 Input testScore
8
9 // Determine whether the user passed the test.
10 If testScore >= 60 Then
11 Call pass()
12 Else
13 Call fail()
14 End If
15 End Module
16
17 Module pass()
18 Display "You passed the test."
19 End Module
20
21 Module fail()
22 Display "You did not pass the test."
23 End Module

```

### Program Output (with Input Shown in Bold)

Enter your test score.  
**75 [Enter]**  
 You passed the test.

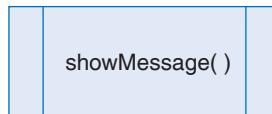
**Program Output (with Input Shown in Bold)**

Enter your test score.  
**50 [Enter]**  
You did not pass the test.

## Flowcharting a Program with Modules

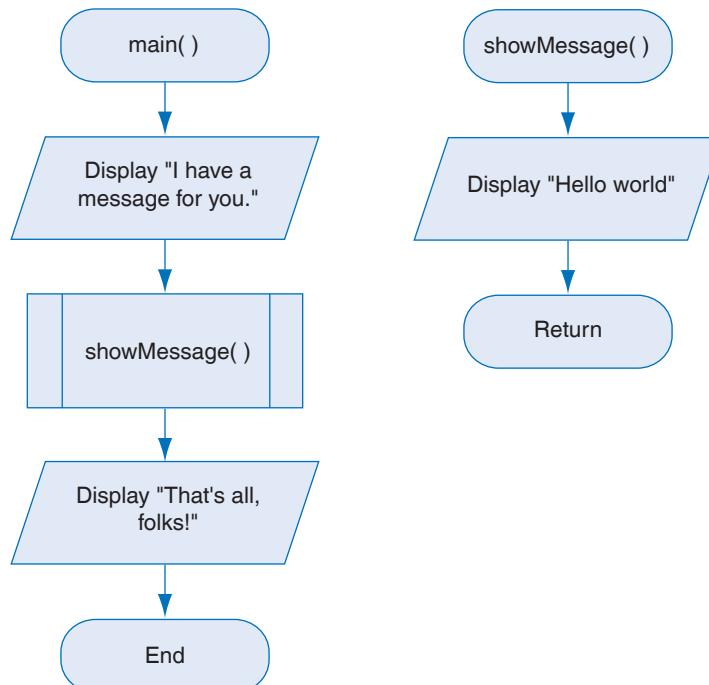
In a flowchart, a module call is shown with a rectangle that has vertical bars at each side, as shown in Figure 5-5. The name of the module that is being called is written on the symbol. The example shown in Figure 5-5 shows how we would represent a call to the `showMessage` module.

**Figure 5-5** Module call symbol



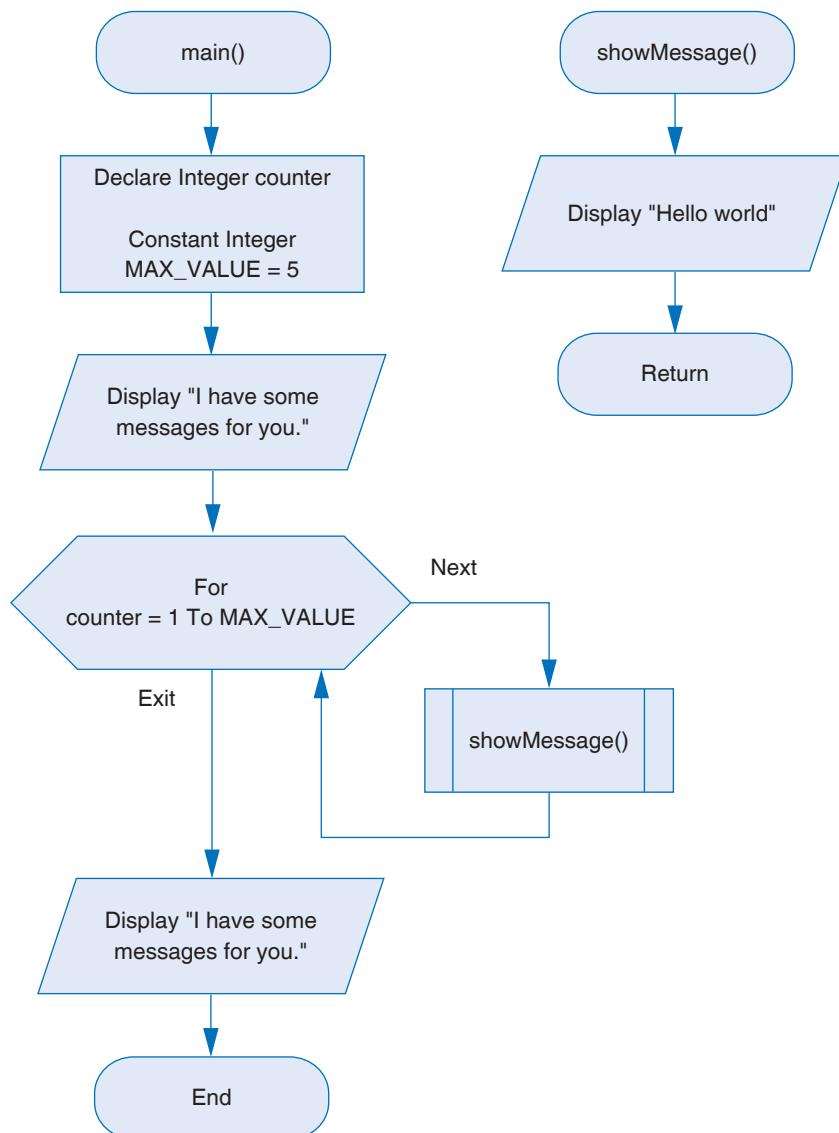
Programmers typically draw a separate flowchart for each module in a program. For example, Figure 5-6 shows how Program 5-1 would be flowcharted. Notice that the figure shows two flowcharts: one for the `main` module and another for the `showMessage` module.

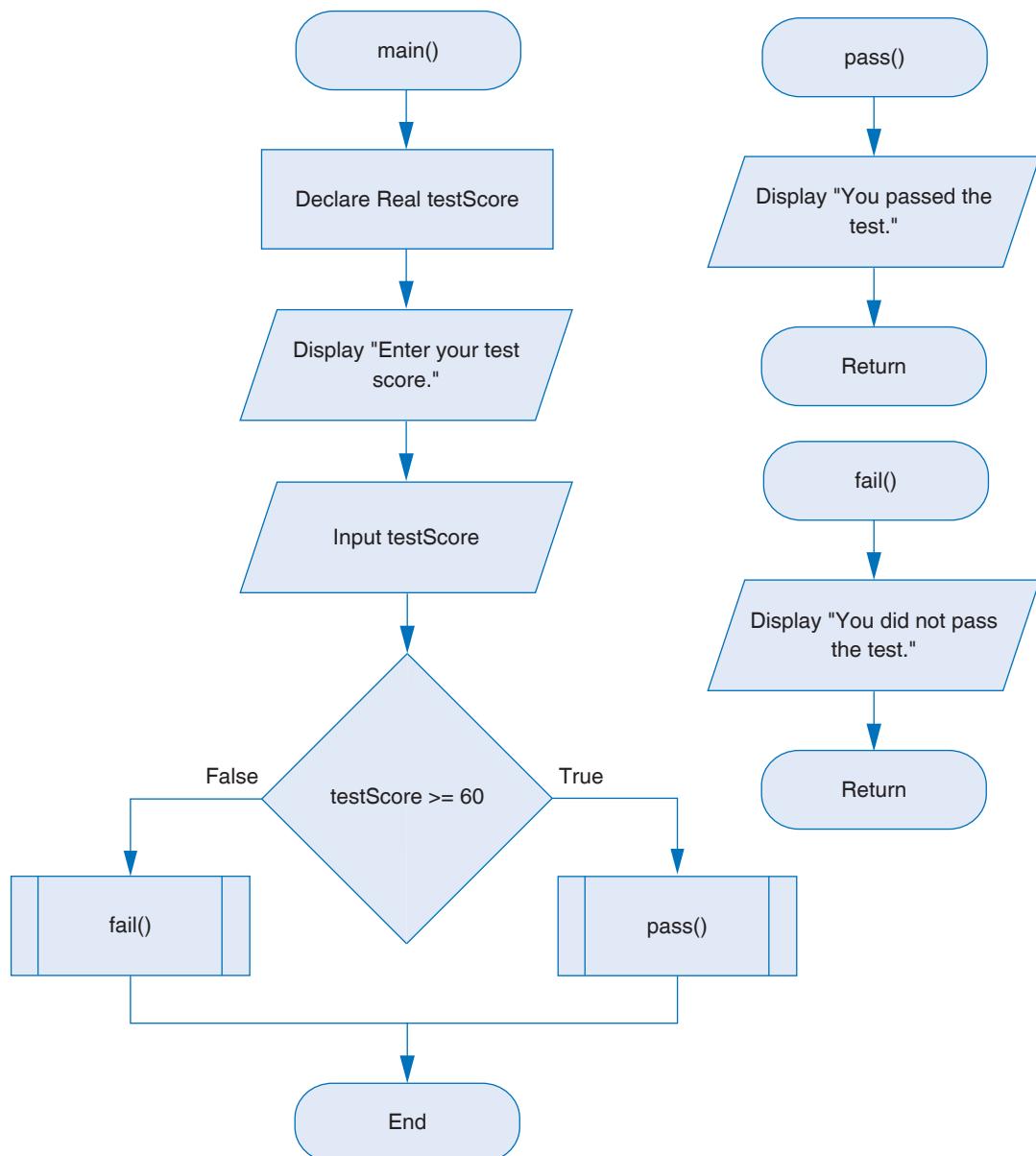
**Figure 5-6** Flowchart for Program 5-1



When drawing a flowchart for a module, the starting terminal symbol usually shows the name of the module. The ending terminal symbol in the `main` module reads End because it marks the end of the program's execution. The ending terminal symbol for all other modules reads Return because it marks the point where the computer returns to the part of the program that called the module. Figure 5-7 shows a flowchart for Program 5-2, and Figure 5-8 shows a flowchart for Program 5-3.

**Figure 5-7** Flowchart for Program 5-2



**Figure 5-8** Flowchart for Program 5-3

## Top-Down Design

In this section, we have discussed and demonstrated how modules work. You've seen how the computer jumps to a module when it is called, and returns to the part of the program that called the module when the module ends. It is important that you understand these mechanical aspects of modules.

Just as important as understanding how modules work is understanding how to design a modularized program. Programmers commonly use a technique known as *top-down*

*design* to break down an algorithm into modules. The process of top-down design is performed in the following manner:

- The overall task that the program is to perform is broken down into a series of subtasks.
- Each of the subtasks is examined to determine whether it can be further broken down into more subtasks. This step is repeated until no more subtasks can be identified.
- Once all of the subtasks have been identified, they are written in code.

This process is called top-down design because the programmer begins by looking at the topmost level of tasks that must be performed, and then breaks down those tasks into lower levels of subtasks.

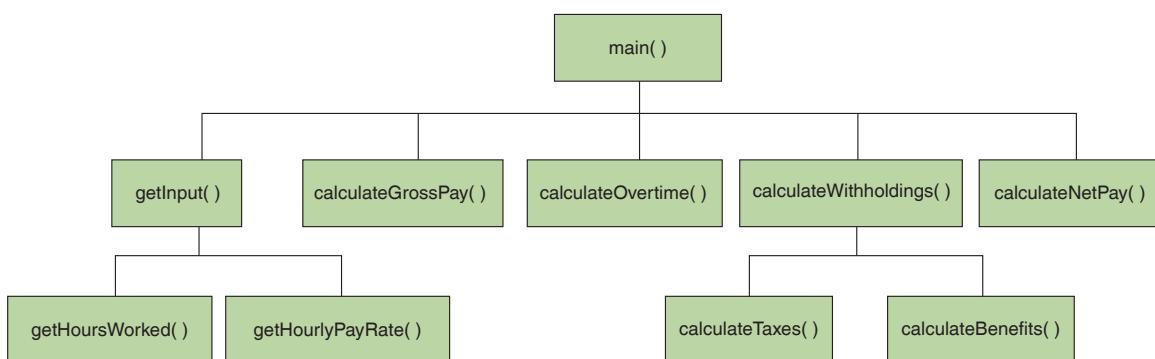


**NOTE:** The top-down design process is sometimes called *stepwise refinement*.

## Hierarchy Charts

Flowcharts are good tools for graphically depicting the flow of logic inside a module, but they do not give a visual representation of the relationships between modules. Programmers commonly use *hierarchy charts* for this purpose. A hierarchy chart, which is also known as a *structure chart*, shows boxes that represent each module in a program. The boxes are connected in a way that illustrates their relationship to one another. Figure 5-9 shows an example of a hierarchy chart for a pay calculating program.

**Figure 5-9** A hierarchy chart



The chart shown in Figure 5-9 shows the `main` module as the topmost module in the hierarchy. The `main` module calls five other modules: `getInput`, `calculateGrossPay`, `calculateOvertime`, `calculateWithholdings`, and `calculateNetPay`. The `getInput` module calls two additional modules: `getHoursWorked` and `getHourlyPayRate`. The `calculateWithholdings` module also calls two modules: `calculateTaxes` and `calculateBenefits`.

Notice that the hierarchy chart does not show the steps that are taken inside a module. Because hierarchy charts do not reveal any details about how modules work, they do not replace flowcharts or pseudocode.

## In the Spotlight: Defining and Calling Modules



Professional Appliance Service, Inc. offers maintenance and repair services for household appliances. The owner wants to give each of the company's service technicians a small handheld computer that displays step-by-step instructions for many of the repairs that they perform. To see how this might work, the owner has asked you to develop a program that displays the following instructions for disassembling an ACME laundry dryer:

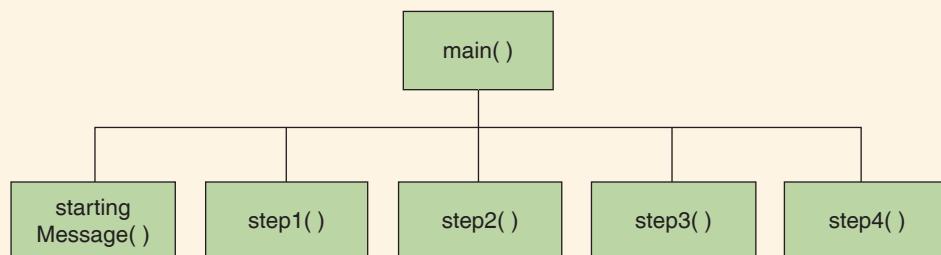
- Step 1. Unplug the dryer and move it away from the wall.
- Step 2. Remove the six screws from the back of the dryer.
- Step 3. Remove the dryer's back panel.
- Step 4. Pull the top of the dryer straight up.

During your interview with the owner, you determine that the program should display the steps one at a time. You decide that after each step is displayed, the user will be asked to press a key to see the next step. Here is the algorithm for the program:

1. Display a starting message, explaining what the program does.
2. Ask the user to press a key to see Step 1.
3. Display the instructions for Step 1.
4. Ask the user to press a key to see the next step.
5. Display the instructions for Step 2.
6. Ask the user to press a key to see the next step.
7. Display the instructions for Step 3.
8. Ask the user to press a key to see the next step.
9. Display the instructions for Step 4.

This algorithm lists the top level of tasks that the program needs to perform, and becomes the basis of the program's `main` module. Figure 5-10 shows the program's structure in a hierarchy chart.

**Figure 5-10** Hierarchy chart for the program



As you can see from the hierarchy chart, the `main` module will call several other modules. Here are summaries of those modules:

- `startingMessage`—This module will display the starting message that tells the technician what the program does.
- `step1`—This module will display the instructions for Step 1.
- `step2`—This module will display the instructions for Step 2.
- `step3`—This module will display the instructions for Step 3.
- `step4`—This module will display the instructions for Step 4.

Between calls to these modules, the `main` module will instruct the user to press a key to see the next step in the instructions. Program 5-4 shows the pseudocode for the program. Figure 5-11 shows the flowchart for the `main` module, and Figure 5-12 shows the flowcharts for the `startingMessage`, `step1`, `step2`, `step3`, and `step4` modules.

### Program 5-4

```
1 Module main()
2 // Display the starting message.
3 Call startingMessage()
4 Display "Press a key to see Step 1."
5 Input
6
7 // Display Step 1.
8 Call step1()
9 Display "Press a key to see Step 2."
10 Input
11
12 // Display Step 2.
13 Call step2()
14 Display "Press a key to see Step 3."
15 Input
16
17 // Display Step 3.
18 Call step3()
19 Display "Press a key to see Step 4."
20 Input
21
22 // Display Step 4.
23 Call step4()
24 End Module
25
26 // The startingMessage module displays
27 // the program's starting message.
28 Module startingMessage()
29 Display "This program tells you how to"
30 Display "disassemble an ACME laundry dryer."
31 Display "There are 4 steps in the process."
32 End Module
33
34 // The step1 module displays the instructions
35 // for Step 1.
```

```
36 Module step1()
37 Display "Step 1: Unplug the dryer and"
38 Display "move it away from the wall."
39 End Module
40
41 // The step2 module displays the instructions
42 // for Step 2.
43 Module step2()
44 Display "Step 2: Remove the six screws"
45 Display "from the back of the dryer."
46 End Module
47
48 // The step3 module displays the instructions
49 // for Step 3.
50 Module step3()
51 Display "Step 3: Remove the dryer's"
52 Display "back panel."
53 End Module
54
55 // The step4 module displays the instructions
56 // for Step 4.
57 Module step4()
58 Display "Step 4: Pull the top of the"
59 Display "dryer straight up."
60 End Module
```

### **Program Output (with Input Shown in Bold)**

This program tells you how to  
disassemble an ACME laundry dryer.

There are 4 steps in the process.

Press a key to see Step 1.

[Enter]

Step 1: Unplug the dryer and  
move it away from the wall.

Press a key to see Step 2.

[Enter]

Step 2: Remove the six screws  
from the back of the dryer.

Press a key to see Step 3.

[Enter]

Step 3: Remove the dryer's  
back panel.

Press a key to see Step 4.

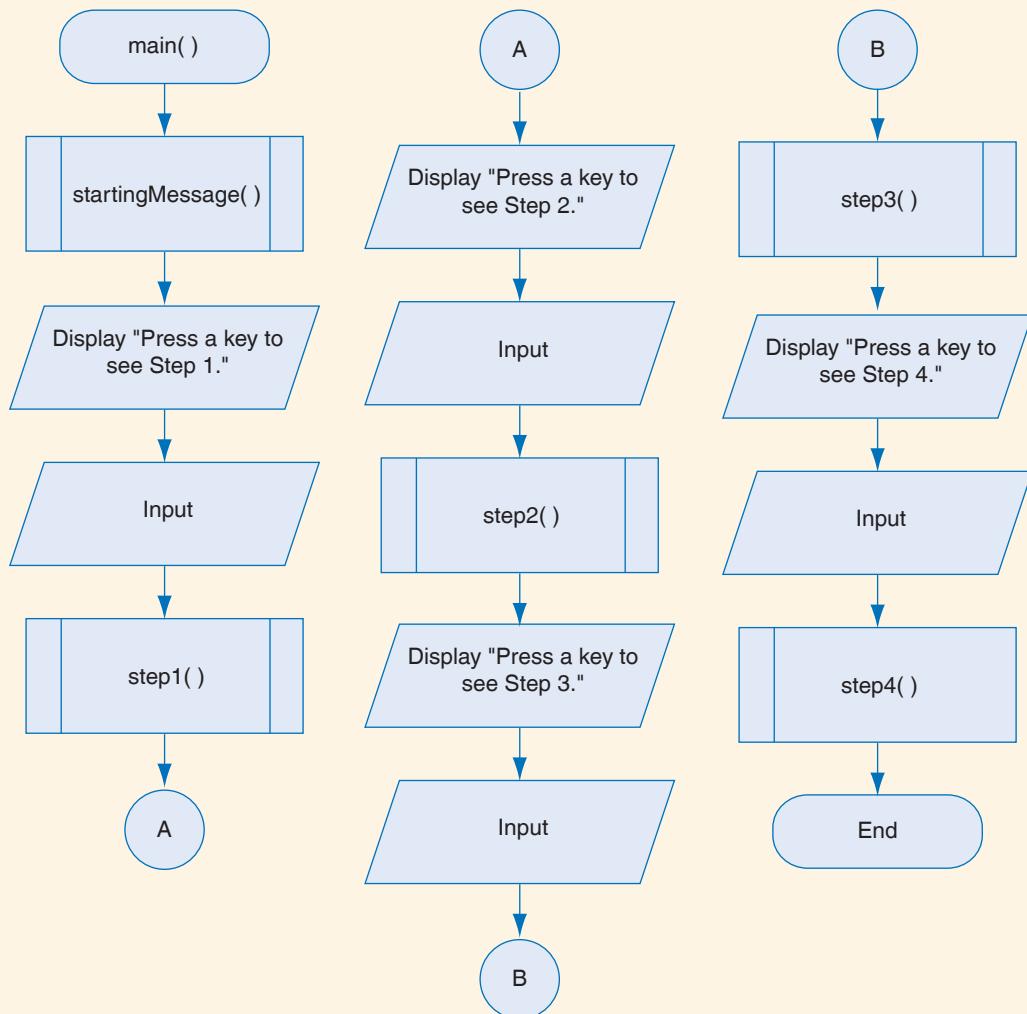
[Enter]

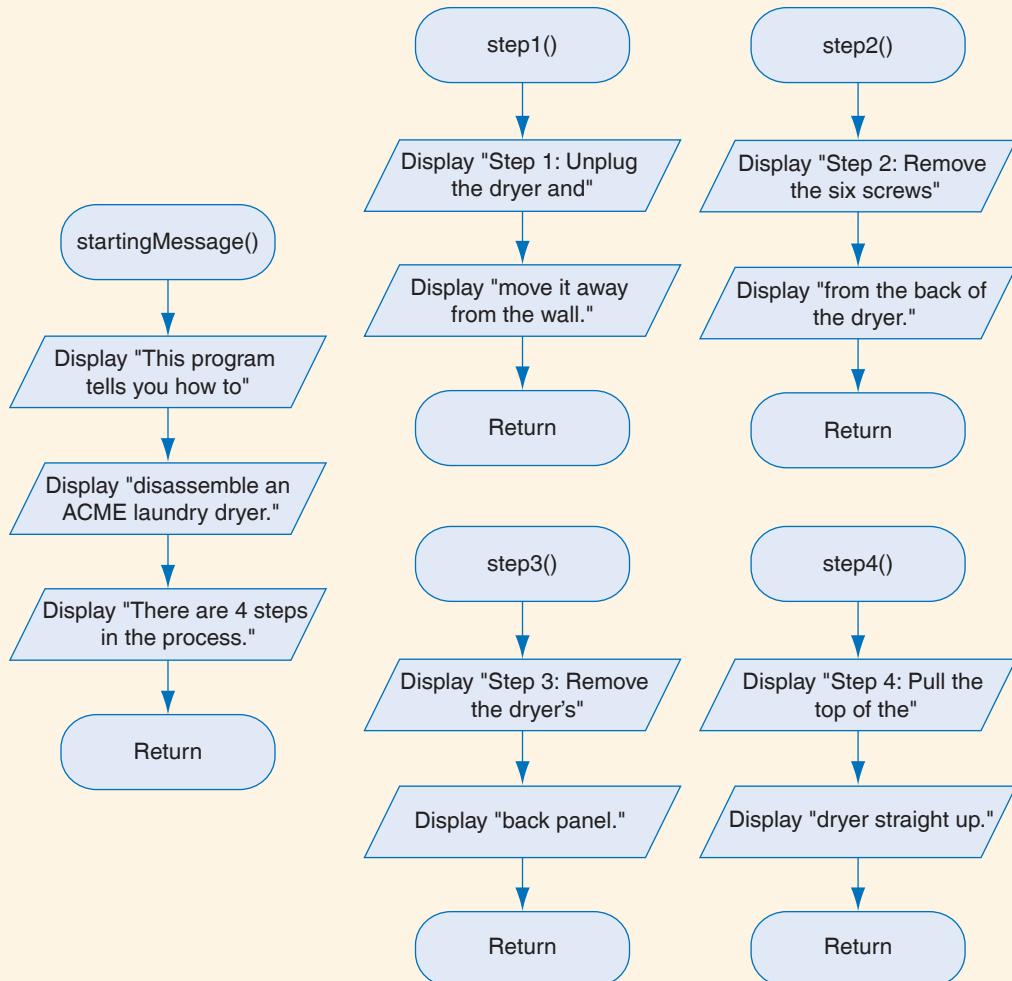
Step 4: Pull the top of the  
dryer straight up.



**NOTE:** Lines 5, 10, 15, and 20 show an **Input** statement with no variable specified. In our pseudocode, this is the way we will read a keystroke from the keyboard without saving the character that was pressed. Most programming languages provide a way to do this.

**Figure 5-11** Flowchart for the main module in Program 5-4



**Figure 5-12** Flowcharts for the other modules in Program 5-4

## Checkpoint

- 5.6 In most languages, a module definition has what two parts?
- 5.7 What does the phrase “calling a module” mean?
- 5.8 When a module is executing, what happens when the end of the module is reached?
- 5.9 Describe the steps involved in the top-down design process.

**5.3**

## Local Variables

**CONCEPT:** A local variable is declared inside a module and cannot be accessed by statements that are outside the module. Different modules can have local variables with the same names because the modules cannot see each other's local variables.

In most programming languages, a variable that is declared inside a module is called a *local variable*. A local variable belongs to the module in which it is declared, and only statements inside that module can access the variable. (The term *local* is meant to indicate that the variable can be used only locally, within the module in which it is declared.)

An error will occur if a statement in one module tries to access a local variable that belongs to another module. For example, look at the pseudocode in Program 5-5.

**Program 5-5**

```

1 Module main()
2 Call getName()
3 Display "Hello ", name ← This will cause an error!
4 End Module
5
6 Module getName()
7 Declare String name ← This is local variable.
8 Display "Enter your name."
9 Input name
10 End Module

```

The `name` variable is declared in line 7, inside the `getName` module. Because it is declared inside the `getName` module, it is a local variable belonging to that module. Line 8 prompts the user to enter their name, and the `Input` statement in line 9 stores the user's input in the `name` variable.

The `main` module calls the `getName` module in line 2. Then, the `Display` statement in line 3 tries to access the `name` variable. This results in an error because the `name` variable is local to the `getName` module, and statements in the `main` module cannot access it.

## Scope and Local Variables

Programmers commonly use the term *scope* to describe the part of a program in which a variable may be accessed. A variable is visible only to statements inside the variable's scope.

A local variable's scope usually begins at the variable's declaration and ends at the end of the module in which the variable is declared. The variable cannot be accessed by statements that are outside this region. This means that a local variable cannot be accessed by code that is outside the module, or inside the module but before the

variable's declaration. For example, look at the following code. It has an error because the `Input` statement tries to store a value in the `name` variable, but the statement is outside the variable's scope. Moving the variable declaration to a line before the `Input` statement will fix this error.

```
Module getName()
 Display "Enter your name."
 Input name ← This statement will cause an error because
 Declare String name the name variable has not been declared yet.
End Module
```

## Duplicate Variable Names

In most programming languages, you cannot have two variables with the same name in the same scope. For example, look at the following module:

```
Module getTwoAges()
 Declare Integer age ← This will cause an error!
 Display "Enter your age."
 Input age
 Declare Integer age ← A variable named age has already
 Display "Enter your pet's age." been declared.
 Input age
End Module
```

This module declares two local variables named `age`. The second variable declaration will cause an error because a variable named `age` has already been declared in the module. Renaming one of the variables will fix this error.



**TIP:** You cannot have two variables with the same name in the same module because the compiler or interpreter would not know which variable to use when a statement tries to access one of them. All variables that exist within the same scope must have unique names.

Although you cannot have two local variables with the same name in the same module, it is usually okay for a local variable in one module to have the same name as a local variable in a different module. For example, look at Program 5-6.

### Program 5-6

```
1 Module main()
2 Call showSquare()
3 Call showHalf()
4 End Module
5
6 Module showSquare()
7 Declare Real number
8 Declare Real square
9
```

```

10 Display "Enter a number."
11 Input number
12 Set square = number^2
13 Display "The square of that number is ", square
14 End Module
15
16 Module showHalf()
17 Declare Real number
18 Declare Real half
19
20 Display "Enter a number."
21 Input number
22 Set half = number / 2
23 Display "Half of that number is ", half
24 End Module

```

### Program Output (with Input Shown in Bold)

```

Enter a number.
5 [Enter]
The square of that number is 25
Enter a number.
20 [Enter]
Half of that number is 10

```

Program 5-6 has three modules: `main`, `showSquare`, and `showHalf`. Notice that the `showSquare` module has a local variable named `number` (declared in line 7) and the `showHalf` module also has a local variable named `number` (declared in line 17). It is legal for the two modules to have a local variable with the same name because the variables are not in the same scope. The scope of the two `number` variables is shown in Figure 5-13.

**Figure 5-13** Scope of the two number variables

```

Module main()
 Call showSquare()
 Call showHalf()
End Module

Module showSquare()
 Declare Real number
 Declare Real square

 Display "Enter a number."
 Input number
 Set square = number^2
 Display "The square of that number is ", square
End Module

Module showHalf()
 Declare Real number
 Declare Real half

 Display "Enter a number."
 Input number
 Set half = number / 2
 Display "Half of that number is ", half
End Module

```

The diagram illustrates the scope of the `number` variable across three modules: `main`, `showSquare`, and `showHalf`. The `showSquare` module's code is highlighted in a light blue box. A red arrow points from the text "Scope of the `number` variable in the `showSquare` module." to the declaration of `number` in line 7 of the `showSquare` module. The `showHalf` module's code is also highlighted in a light blue box. Another red arrow points from the text "Scope of the `number` variable in the `showHalf` module." to the declaration of `number` in line 17 of the `showHalf` module.

 **Checkpoint**

- 5.10 What is a local variable? How is access to a local variable restricted?
- 5.11 What is a variable's scope?
- 5.12 Is it usually permissible to have more than one variable with the same name in the same scope? Why or why not?
- 5.13 Is it usually permissible for a local variable in one module to have the same name as a local variable in a different module?

**5.4**

## Passing Arguments to Modules

**CONCEPT:** An argument is any piece of data that is passed into a module when the module is called. A parameter is a variable that receives an argument that is passed into a module.

VideoNote  
Passing Arguments  
to a Module

Sometimes it is useful not only to call a module, but also to send one or more pieces of data into the module. Pieces of data that are sent into a module are known as *arguments*. The module can use its arguments in calculations or other operations.

If you want a module to receive arguments when it is called, you must equip the module with one or more parameter variables. A *parameter variable*, often simply called a *parameter*, is a special variable that receives an argument when a module is called. Here is an example of a pseudocode module that has a parameter variable:

```
Module doubleNumber(Integer value)
 Declare Integer result
 Set result = value * 2
 Display result
End Module
```

This module's name is `doubleNumber`. Its purpose is to accept an integer number as an argument and display the value of that number doubled. Look at the module header and notice the words `Integer value` that appear inside the parentheses. This is the declaration of a parameter variable. The parameter variable's name is `value` and its data type is `Integer`. The purpose of this variable is to receive an `Integer` argument when the module is called. Program 5-7 demonstrates the module in a complete program.

### Program 5-7

```
1 Module main()
2 Call doubleNumber(4)
3 End Module
4
```

```

5 Module doubleNumber(Integer value)
6 Declare Integer result
7 Set result = value * 2
8 Display result
9 End Module

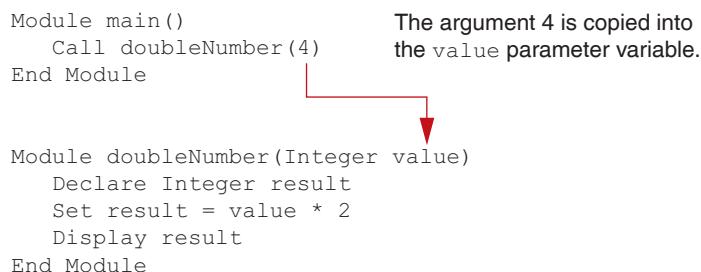
```

**Program Output**

8

When this program runs, the `main` module will begin executing. The statement in line 2 calls the `doubleNumber` module. Notice that the number 4 appears inside the parentheses. This is an argument that is being passed to the `doubleNumber` module. When this statement executes, the `doubleNumber` module will be called with the number 4 copied into the `value` parameter variable. This is shown in Figure 5-14.

**Figure 5-14** The argument 4 is copied into the `value` parameter variable



Let's step through the `doubleNumber` module. As we do, remember that the `value` parameter variable will contain the number that was passed into it as an argument. In this program, that number is 4.

Line 6 declares a local `Integer` variable named `result`. Then, line 7 assigns the value of the expression `value * 2` to `result`. Because the `value` variable contains 4, this line assigns 8 to `result`. Line 8 displays the contents of the `result` variable. The module ends at line 9.

For example, if we had called the module as follows:

```
Call doubleNumber(5)
```

the module would have displayed 10.

We can also pass the contents of a variable as an argument. For example, look at Program 5-8. The `main` module declares an `Integer` variable named `number` in line 2. Lines 3 and 4 prompt the user to enter a number, and line 5 reads the user's input into the `number` variable. Notice that in line 6 `number` is passed as an argument to the

`doubleNumber` module, which causes the `number` variable's contents to be copied into the `value` parameter variable. This is shown in Figure 5-15.

### Program 5-8



```

1 Module main()
2 Declare Integer number
3 Display "Enter a number and I will display"
4 Display "that number doubled."
5 Input number
6 Call doubleNumber(number)
7 End Module
8
9 Module doubleNumber(Integer value)
10 Declare Integer result
11 Set result = value * 2
12 Display result
13 End Module

```

### Program Output (with Input Shown in Bold)

Enter a number and I will display  
that number doubled.

**20** [Enter]

40

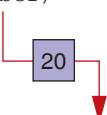
**Figure 5-15** The contents of the `number` variable passed as an argument

```

Module main()
 Declare Integer number
 Display "Enter a number and I will display"
 Display "that number doubled."
 Input number
 Call doubleNumber(number)
End Module

```

The contents of the `number` variable are copied into the `value` parameter variable.

20


```

Module doubleNumber(Integer value)
 Declare Integer result
 Set result = value * 2
 Display result
End Module

```

## Argument and Parameter Compatibility

When you pass an argument to a module, most programming languages require that the argument and the receiving parameter variable be of the same data type. If you try to pass an argument of one type into a parameter variable of another type, an error usually occurs. For example, Figure 5-16 shows that you cannot pass a real number or a `Real` variable into an `Integer` parameter.

**Figure 5-16** Arguments and parameter variables must be of the same type

```

Call doubleNumber(55.9)
 Error! 55.9
Module doubleNumber(Integer value)
 Declare Integer result
 Set result = value * 2
 Display result
End Module

```

```

Declare Real number = 24.7
Call doubleNumber(number)
 Error! 24.7
Module doubleNumber(Integer value)
 Declare Integer result
 Set result = value * 2
 Display result
End Module

```



**NOTE:** Some languages allow you to pass an argument into a parameter variable of a different type as long as no data will be lost. For example, some languages allow you to pass integer arguments into real parameters because real variables can hold whole numbers. If you pass a real argument, such as 24.7, into an integer parameter, the fractional part of the number would be lost.

## Parameter Variable Scope

Earlier in this chapter, you learned that a variable's scope is the part of the program in which the variable may be accessed. A variable is visible only to statements inside the variable's scope. A parameter variable's scope is usually the entire module in which the parameter is declared. No statement outside the module can access the parameter variable.

## Passing Multiple Arguments

Most languages allow you to write modules that accept multiple arguments. Program 5-9 shows a pseudocode module named *showSum* that accepts two *Integer* arguments. The module adds the two arguments and displays their sum.

### Program 5-9



```

1 Module main()
2 Display "The sum of 12 and 45 is:"
3 Call showSum(12, 45)
4 End Module
5
6 Module showSum(Integer num1, Integer num2)
7 Declare Integer result
8 Set result = num1 + num2
9 Display result
10 End Module

```

### Program Output

The sum of 12 and 45 is:

57

Notice that two parameter variables, *num1* and *num2*, are declared inside the parentheses in the module header. This is often referred to as a *parameter list*. Also, notice that a comma separates the declarations.

The statement in line 3 calls the `showSum` module and passes two arguments: 12 and 45. The arguments are passed into the parameter variables in the order that they appear in the module call. In other words, the first argument is passed into the first parameter variable, and the second argument is passed into the second parameter variable. So, this statement causes 12 to be passed into the `num1` parameter and 45 to be passed into the `num2` parameter, as shown in Figure 5-17.

**Figure 5-17** Two arguments passed into two parameters

```
Module main()
 Display "The sum of 12 and 45 is:"
 Call showSum(12, 45)
End Module

Module showSum(Integer num1, Integer num2)
 Declare Integer result
 Set result = num1 + num2
 Display result
End Module
```

Suppose we were to reverse the order in which the arguments are listed in the module call, as shown here:

```
Call showSum(45, 12)
```

This would cause 45 to be passed into the `num1` parameter and 12 to be passed into the `num2` parameter. The following pseudocode code shows one more example. This time we are passing variables as arguments.

```
Declare Integer value1 = 2
Declare Integer value2 = 3
Call showSum(value1, value2)
```

When the `showSum` method executes as a result of this code, the `num1` parameter will contain 2 and the `num2` parameter will contain 3.

## In the Spotlight: Passing an Argument to a Module

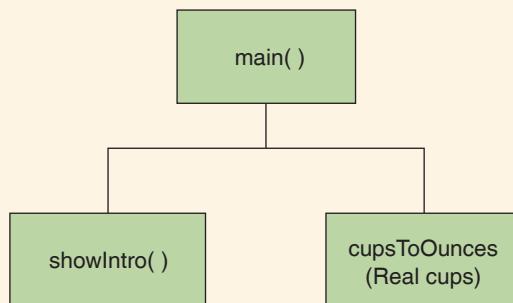


Your friend Michael runs a catering company. Some of the ingredients that his recipes require are measured in cups. When he goes to the grocery store to buy those ingredients, however, they are sold only by the fluid ounce. He has asked you to write a simple program that converts cups to fluid ounces.

You design the following algorithm:

1. Display an introductory screen that explains what the program does.
2. Get the number of cups.
3. Convert the number of cups to fluid ounces and display the result.

This algorithm lists the top level of tasks that the program needs to perform, and becomes the basis of the program's `main` module. Figure 5-18 shows the program's structure in a hierarchy chart.

**Figure 5-18** Hierarchy chart for the program

As shown in the hierarchy chart, the `main` module will call two other modules.

Here are summaries of those modules:

- `showIntro`—This module will display a message on the screen that explains what the program does.
- `cupsToOunces`—This module will accept the number of cups as an argument and calculate and display the equivalent number of fluid ounces.

In addition to calling these modules, the `main` module will ask the user to enter the number of cups. This value will be passed to the `cupsToOunces` module. Program 5-10 shows the pseudocode for the program, and Figure 5-19 shows a flowchart.

### Program 5-10

```

1 Module main()
2 // Declare a variable for the
3 // number of cups needed.
4 Declare Real cupsNeeded
5
6 // Display an intro message.
7 Call showIntro()
8
9 // Get the number of cups.
10 Display "Enter the number of cups."
11 Input cupsNeeded
12
13 // Convert cups to ounces.
14 Call cupsToOunces(cupsNeeded)
15 End Module
16
17 // The showIntro module displays an
18 // introductory screen.
19 Module showIntro()
20 Display "This program converts measurements"
21 Display "in cups to fluid ounces. For your"
22 Display "reference the formula is:"
23 Display " 1 cup = 8 fluid ounces."
24 End Module
25
26 // The cupsToOunces module accepts a number
27 // of cups and displays the equivalent number

```

```

28 // of ounces.
29 Module cupsToOunces(Real cups)
30 // Declare variables.
31 Declare Real ounces
32
33 // Convert cups to ounces.
34 Set ounces = cups * 8
35
36 // Display the result.
37 Display "That converts to ",
38 ounces, " ounces."
39 End Module

```

### Program Output (with Input Shown in Bold)

This program converts measurements in cups to fluid ounces. For your reference the formula is:

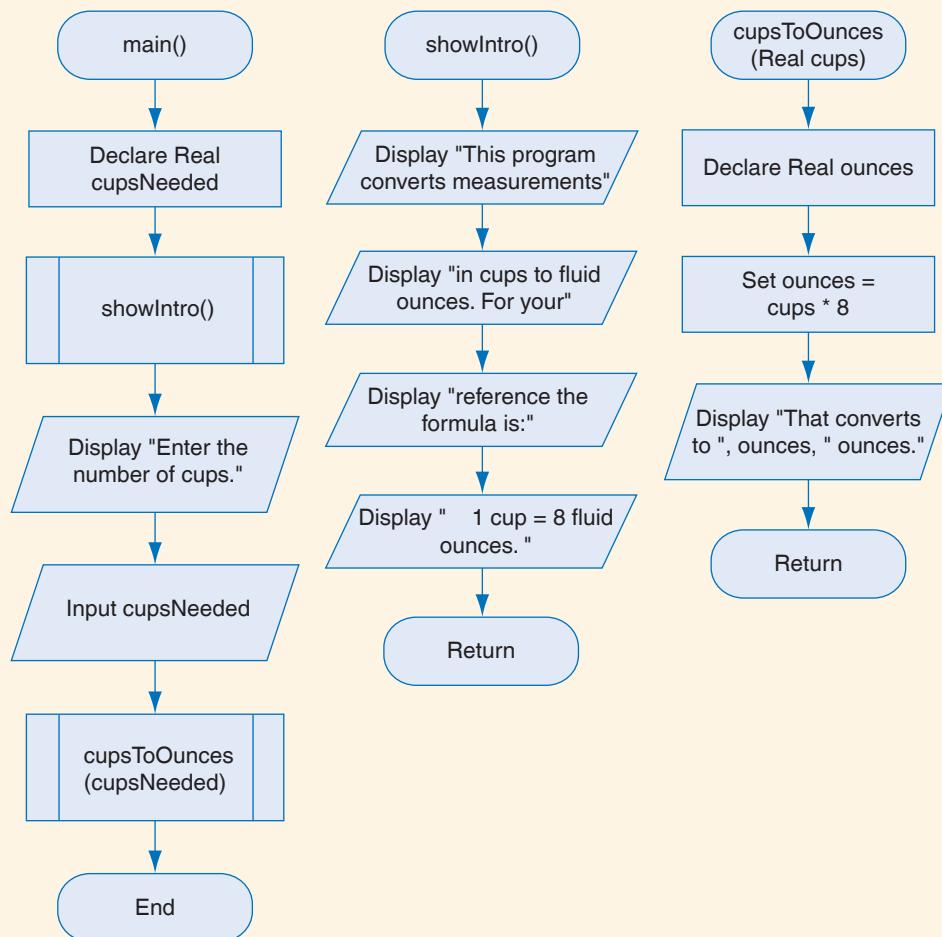
1 cup = 8 fluid ounces.

Enter the number of cups.

**2 [Enter]**

That converts to 16 ounces.

**Figure 5-19** Flowchart for Program 5-10



## Passing Arguments by Value and by Reference

Many programming languages provide two different ways to pass arguments: by value and by reference. Before studying these techniques in detail, we should mention that different languages have their own way of doing each. In this book, we will teach you the fundamental concepts behind these techniques, and show you how to model them in pseudocode. When you begin to use these techniques in an actual language, you will need to learn the details of how they are carried out in that language.

### Passing Arguments by Value

All of the example programs that we have looked at so far pass arguments by value. Arguments and parameter variables are separate items in memory. Passing an argument *by value* means that only a copy of the argument's value is passed into the parameter variable. If the contents of the parameter variable are changed inside the module, it has no effect on the argument in the calling part of the program. For example, look at Program 5-11.

#### Program 5-11

```

1 Module main()
2 Declare Integer number = 99
3
4 // Display the value stored in number.
5 Display "The number is ", number
6
7 // Call the changeMe module, passing
8 // the number variable as an argument.
9 Call changeMe(number)
10
11 // Display the value of number again.
12 Display "The number is ", number
13 End Module
14
15 Module changeMe(Integer myValue)
16 Display "I am changing the value."
17
18 // Set the myValue parameter variable
19 // to 0.
20 Set myValue = 0
21
22 // Display the value in myValue.
23 Display "Now the number is ", myValue
24 End Module

```

#### Program Output

```

The number is 99
I am changing the value.
Now the number is 0
The number is 99

```

The `main` module declares a local variable named `number` in line 2, and initializes it to the value 99. As a result, the `Display` statement in line 5 displays “The number is 99.” The `number` variable’s value is then passed as an argument to the `changeMe` module in

line 9. This means that in the `changeMe` module the value 99 will be copied into the `myValue` parameter variable.

Inside the `changeMe` module, in line 20, the `myValue` parameter variable is set to 0. As a result, the `Display` statement in line 23 displays “Now the number is 0.” The module ends, and control of the program returns to the `main` module.

The next statement to execute is the `Display` statement in line 12. This statement displays “The number is 99.” Even though the `myValue` parameter variable was changed in the `changeMe` method, the argument (the `number` variable in `main`) was not modified.

Passing an argument is a way that one module can communicate with another module. When the argument is passed by value, the communication channel works in only one direction: the calling module can communicate with the called module. The called module, however, cannot use the argument to communicate with the calling module.

### **Passing Arguments by Reference**

Passing an argument *by reference* means that the argument is passed into a special type of parameter known as a *reference variable*. When a reference variable is used as a parameter in a module, it allows the module to modify the argument in the calling part of the program.

A reference variable acts as an alias for the variable that was passed into it as an argument. It is called a reference variable because it references the other variable. Anything that you do to the reference variable is actually done to the variable it references.

Reference variables are useful for establishing two-way communication between modules. When a module calls another module and passes a variable by reference, communication between the modules can take place in the following ways:

- The calling module can communicate with the called module by passing an argument.
- The called module can communicate with the calling module by modifying the value of the argument via the reference variable.

In pseudocode, we will declare that a parameter is a reference variable by writing the word `Ref` before the parameter variable’s name in the module header. For example, look at the following pseudocode module:

```
Module setToZero(Integer Ref value)
 Set value = 0
End Module
```

The word `Ref` indicates that `value` is a reference variable. The module stores 0 in the `value` parameter. Because `value` is a reference variable, this action is actually performed on the variable that was passed to the module as an argument. Program 5-12 demonstrates this module.

#### **Program 5-12**

```
1 Module main()
2 // Declare and initialize some variables.
3 Declare Integer x = 99
```

```

4 Declare Integer y = 100
5 Declare Integer z = 101
6
7 // Display the values in those variables.
8 Display "x is set to ", x
9 Display "y is set to ", y
10 Display "z is set to ", z
11
12 // Pass each variable to setToZero.
13 Call setToZero(x)
14 Call setToZero(y)
15 Call setToZero(z)
16
17 // Display the values now.
18 Display "-----"
19 Display "x is set to ", x
20 Display "y is set to ", y
21 Display "z is set to ", z
22 End Module
23
24 Module setToZero(Integer Ref value)
25 Set value = 0
26 End Module

```

### Program Output

```

x is set to 99
y is set to 100
z is set to 101

x is set to 0
y is set to 0
z is set to 0

```

In the `main` module the variable `x` is initialized with 99, the variable `y` is initialized with 100, and the variable `z` is initialized with 101. Then, in lines 13 through 15 those variables are passed as arguments to the `setToZero` module. Each time `setToZero` is called, the variable that is passed as an argument is set to 0. This is shown when the values of the variables are displayed in lines 19 through 21.



**NOTE:** In an actual program you should never use variable names like `x`, `y`, and `z`. This particular program is meant for demonstration purposes, however, and these simple names are adequate.



**NOTE:** Normally, only variables may be passed by reference. If you attempt to pass a non-variable argument into a reference variable parameter, an error will result. Using the `setToZero` module as an example, the following statement will generate an error:

```
// This is an error!
setToZero(5);
```



**WARNING!** Be careful when using reference variables as parameters. Any time you allow a module to alter a variable that's outside the module, you are creating potential debugging problems. Reference variables should only be used as parameters when the situation requires them.

## In the Spotlight: Passing an Argument by Reference



In the previous *In the Spotlight* case study, we developed a program that your friend Michael can use in his catering business. The program does exactly what Michael wants it to do: it converts cups to fluid ounces. After studying the program that we initially wrote, however, you believe that you can improve the design. As shown in the following pseudocode, the `main` module contains the code that reads the user's input. This code should really be treated as a separate subtask, and put in its own module. If this change is made, the program will be like the new hierarchy chart shown in Figure 5-20.

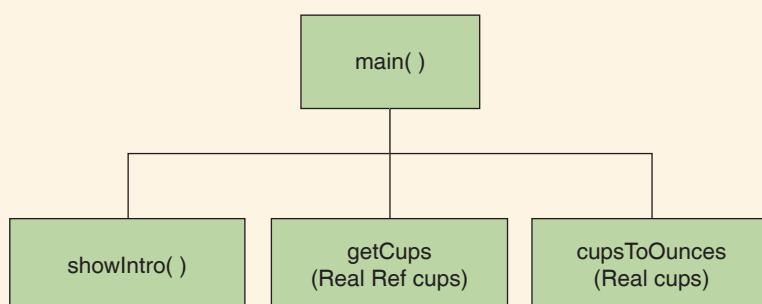
```
Module main()
 // Declare a variable for the
 // number of cups needed.
 Declare Real cupsNeeded

 // Display an intro message.
 Call showIntro()

 // Get the number of cups.
 Display "Enter the number of cups."
 Input cupsNeeded } This code can be put in its
 own module.

 // Convert cups to ounces.
 Call cupsToOunces(cupsNeeded)
End Module
```

**Figure 5-20** Revised hierarchy chart



This version of the hierarchy chart shows a new module: `getCups`. Here is the pseudocode for the `getCups` module:

```
Module getCups(Real Ref cups)
 Display "Enter the number of cups."
 Input cups
End Module
```

The `getCups` module has a parameter, `cups`, which is a reference variable. The module prompts the user to enter the number of cups and then stores the user's input in the `cups` parameter. When the `main` module calls `getCups`, it will pass the local variable `cupsNeeded` as an argument. Because it will be passed by reference, it will contain the user's input when the module returns. Program 5-13 shows the revised pseudocode for the program, and Figure 5-21 shows a flowchart.



**NOTE:** In this case study, we improved the design of an existing program without changing the behavior of the program. In a nutshell, we “cleaned up” the design. Programmers call this *refactoring*.

### Program 5-13

```

1 Module main()
2 // Declare a variable for the
3 // number of cups needed.
4 Declare Real cupsNeeded
5
6 // Display an intro message.
7 Call showIntro()
8
9 // Get the number of cups.
10 Call get Cups(cupsNeeded)
11
12 // Convert cups to ounces.
13 Call cupsToOunces(cupsNeeded)
14 End Module
15
16 // The showIntro module displays an
17 // introductory screen.
18 Module showIntro()
19 Display "This program converts measurements"
20 Display "in cups to fluid ounces. For your"
21 Display "reference the formula is:"
22 Display " 1 cup = 8 fluid ounces."
23 End Module
24
25 // The get Cups module gets the number of cups
26 // and stores it in the reference variable cups.
27 Module get Cups(Real Ref cups)
28 Display "Enter the number of cups."
29 Input cups
30 End Module
31
32 // The cupsToOunces module accepts a number
33 // of cups and displays the equivalent number
34 // of ounces.
35 Module cupsToOunces(Real cups)
36 // Declare variables.
37 Declare Real ounces
38
39 // Convert cups to ounces.

```

```

40 Set ounces = cups * 8
41
42 // Display the result.
43 Display "That converts to ",
44 ounces, " ounces."
45 End Module

```

### Program Output (with Input Shown in Bold)

This program converts measurements  
in cups to fluid ounces. For your  
reference the formula is:

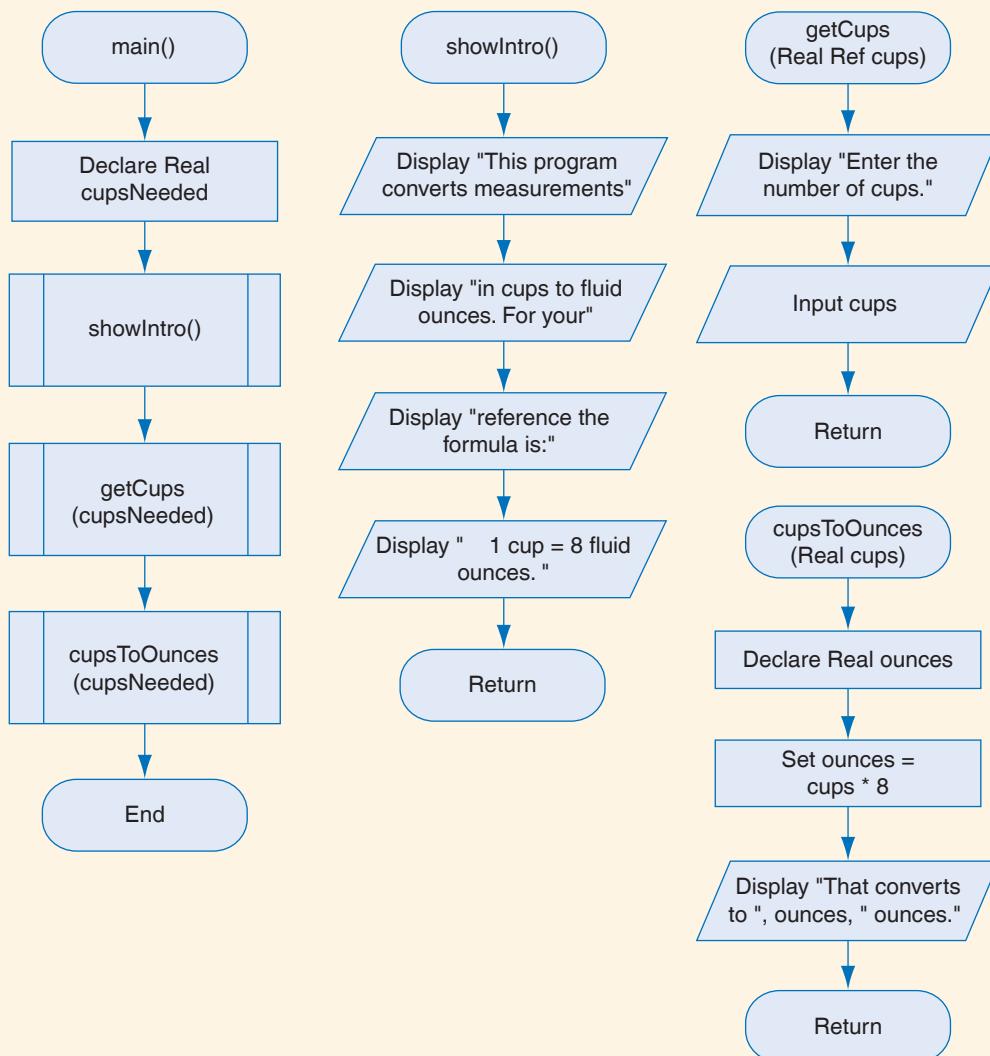
1 cup = 8 fluid ounces.

Enter the number of cups.

**2 [Enter]**

That converts to 16 ounces.

**Figure 5-21** Flowchart for Program 5-13



 **Checkpoint**

- 5.14 What are the pieces of data that are passed into a module called?
- 5.15 What are the variables that receive pieces of data in a module called?
- 5.16 Does it usually matter whether an argument's data type is different from the data type of the parameter that it is being passed to?
- 5.17 Typically, what is a parameter variable's scope?
- 5.18 Explain the difference between passing by value and passing by reference.

**5.5**

## Global Variables and Global Constants

**CONCEPT:** A global variable is accessible to all the modules in a program.

### Global Variables

A *global variable* is a variable that is visible to every module in the program. A global variable's scope is the entire program, so all of the modules in the program can access a global variable. In most programming languages, you create a global variable by writing its declaration statement outside of all the modules, usually at the top of the program. Program 5-14 shows how you can declare a global variable in pseudocode.

#### Program 5-14

```

1 // The following declares a global Integer variable.
2 Declare Integer number
3
4 // The main module
5 Module main()
6 // Get a number from the user and store it
7 // in the global variable number.
8 Display "Enter a number."
9 Input number
10
11 // Call the showNumber module.
12 Call showNumber()
13 End Module
14
15 // The showNumber module displays the contents
16 // of the global variable number.
17 Module showNumber()
18 Display "The number you entered is ", number
19 End Module

```

#### Program Output (with Input Shown in Bold)

```

Enter a number.
22 [Enter]
The number you entered is 22

```

Line 2 declares an `Integer` variable named `number`. Because the declaration does not appear inside a module, the `number` variable is a global variable. All of the modules that are defined in the program have access to the variable. When the `Input` statement in line 9 (inside the `main` module) executes, the value entered by the user is stored in the global variable `number`. When the `Display` statement in line 18 (inside the `showNumber` module) executes, it is the value of the same global variable that is displayed.

Most programmers agree that you should restrict the use of global variables, or not use them at all. The reasons are as follows:

- Global variables make debugging difficult. Any statement in a program can change the value of a global variable. If you find that the wrong value is being stored in a global variable, you have to track down every statement that accesses it to determine where the bad value is coming from. In a program with thousands of lines of code, this can be difficult.
- Modules that use global variables are usually dependent on those variables. If you want to use such a module in a different program, most likely you will have to redesign it so it does not rely on the global variable.
- Global variables make a program hard to understand. A global variable can be modified by any statement in the program. If you are to understand any part of the program that uses a global variable, you have to be aware of all the other parts of the program that access the global variable.

In most cases, you should declare variables locally and pass them as arguments to the modules that need to access them.

## Global Constants

Although you should try to avoid the use of global variables, it is permissible to use global constants in a program. A *global constant* is a named constant that is available to every module in the program. Because a global constant's value cannot be changed during the program's execution, you do not have to worry about many of the potential hazards that are associated with the use of global variables.

Global constants are typically used to represent unchanging values that are needed throughout a program. For example, suppose a banking program uses a named constant to represent an interest rate. If the interest rate is used in several modules, it is easier to create a global constant, rather than a local named constant in each module. This also simplifies maintenance. If the interest rate changes, only the declaration of the global constant has to be changed, instead of several local declarations.

### In the Spotlight: Using Global Constants



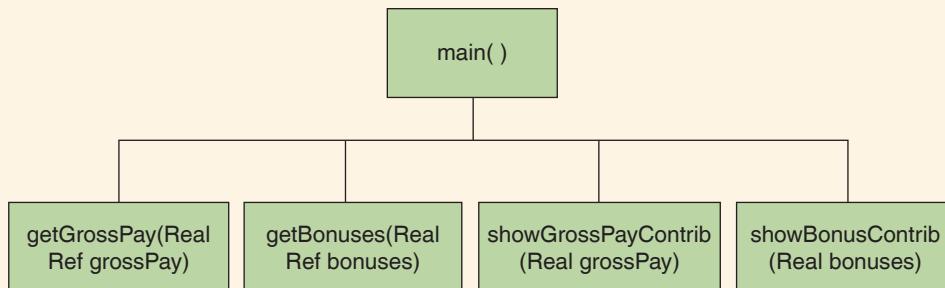
Marilyn works for Integrated Systems, Inc., a software company that has a reputation for providing excellent fringe benefits. One of its benefits is a quarterly bonus that is paid to all employees. Another benefit is a retirement plan for each employee. The company contributes 5 percent of each employee's gross pay and bonuses to their retirement plan. Marilyn wants to design a program that will calculate the company's contribution to an employee's retirement account for a year. She wants the program to show the amount of contribution for the employee's gross pay and for the bonuses separately.

Here is an algorithm for the program:

1. Get the employee's annual gross pay.
2. Get the amount of bonuses paid to the employee.
3. Calculate and display the contribution for the gross pay.
4. Calculate and display the contribution for the bonuses.

Figure 5-22 shows a hierarchy chart for the program. The pseudocode for the program is shown in Program 5-15, and a set of flowcharts is shown in Figure 5-23.

**Figure 5-22** Hierarchy chart



### Program 5-15

```

1 // Global constant for the rate of contribution.
2 Constant Real CONTRIBUTION_RATE = 0.05
3
4 // main module
5 Module main()
6 // Local variables
7 Declare Real annualGrossPay
8 Declare Real totalBonuses
9
10 // Get the annual gross pay.
11 Call getGrossPay(annualGrossPay)
12
13 // Get the total of the bonuses.
14 Call getBonuses(totalBonuses)
15
16 // Display the contribution for
17 // the gross pay.
18 Call showGrossPayContrib(annualGrossPay)
19
20 // Display the contribution for
21 // the bonuses.
22 Call showBonusContrib(totalBonuses)
23 End Module
24
25 // The getGrossPay module gets the
26 // gross pay and stores it in the
27 // grossPay reference variable.
28 Module getGrossPay(Real Ref grossPay)
29 Display "Enter the total gross pay."

```

```
30 Input grossPay
31 End Module
32
33 // The getBonuses module gets the
34 // amount of bonuses and stores it
35 // in the bonuses reference variable.
36 Module getBonuses(Real Ref bonuses)
37 Display "Enter the amount of bonuses."
38 Input bonuses
39 End Module
40
41 // The showGrossPayContrib module
42 // accepts the gross pay as an argument
43 // and displays the retirement contribution
44 // for gross pay.
45 Module showGrossPayContrib(Real grossPay)
46 Declare Real contrib
47 Set contrib = grossPay * CONTRIBUTION_RATE
48 Display "The contribution for the gross pay"
49 Display "is $", contrib
50 End Module
51
52 // The showBonusContrib module accepts
53 // the bonus amount as an argument and
54 // displays the retirement contribution
55 // for bonuses.
56 Module showBonusContrib(Real bonuses)
57 Declare Real contrib
58 Set contrib = bonuses * CONTRIBUTION_RATE
59 Display "The contribution for the bonuses"
60 Display "is $", contrib
61 End Module
```

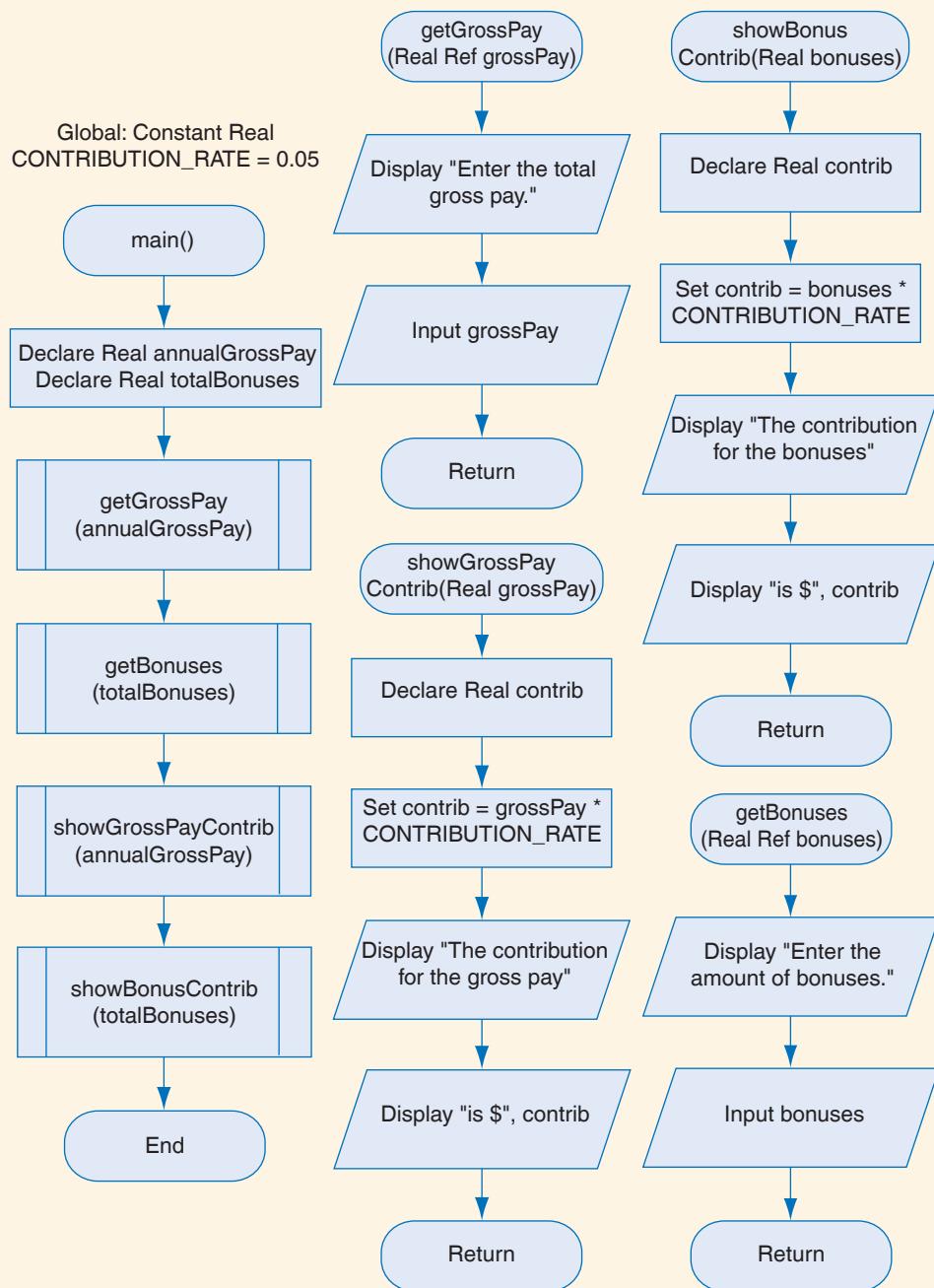
### Program Output (with Input Shown in Bold)

```
Enter the total gross pay.
80000.00 [Enter]
Enter the amount of bonuses.
20000.00 [Enter]
The contribution for the gross pay
is $4000
The contribution for the bonuses
is $1000
```

A global constant named `CONTRIBUTION_RATE` is declared in line 2, and initialized with the value 0.05. The constant is used in the calculation in line 47 (in the `showGrossPayContrib` module) and again in line 58 (in the `showBonusContrib` module). Marilyn decided to use this global constant to represent the 5 percent contribution rate for two reasons:

- It makes the program easier to read. When you look at the calculations in lines 47 and 58, it is apparent what is happening.
- Occasionally the contribution rate changes. When this happens, it will be easy to update the program by changing the declaration statement in line 2.

**Figure 5-23** Flowchart for Program 5-15



## Checkpoint

- 5.19 What is the scope of a global variable?
  - 5.20 Give one good reason that you should not use global variables in a program.
  - 5.21 What is a global constant? Is it permissible to use global constants in a program?

**5.6**

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

#### Modularizing Java Programs with Methods



In Java, modules are called *methods*. To create a method, you must write its *definition*, which consists of two general parts: a header and a body. The *method header* is the line that appears at the beginning of a method definition. It lists several things about the method, including the method's name. The *method body* is a collection of statements that are performed when the method is executed. These statements are enclosed inside a set of curly braces.

As you already know, every complete Java program must have a `main` method. Java programs can have other methods as well. Here is an example of a simple method that displays a message on the screen:

```
public static void showMessage()
{
 System.out.println("Hello world");
}
```

For now, the headers for all of the Java methods that you will write will begin with the key words `public static void`. Following this you write the name of the method, and a set of parentheses. Remember that a method header never ends with a semicolon!

#### Calling a Method in Java

When a method is called, the program branches to that method and executes the statements in its body. Here is an example of a method call statement that calls the `showMessage` method we previously examined:

```
showMessage();
```

The statement is simply the name of the method followed by a set of parentheses. Because it is a complete statement, it is terminated with a semicolon.

#### Local Variables

Variables that are declared inside a method are known as local variables. They are called *local* because they are local to the method in which they are declared. Statements outside a method cannot access that method's local variables.

### Passing Arguments to Methods

If you want to be able to pass an argument into a method, you must declare a parameter variable in that method's header. The parameter variable will receive the argument that is passed when the method is called. Here is the definition of a method that uses a parameter:

```
public static void displayValue(int num)
{
 System.out.println("The value is " + num);
}
```

Notice the integer variable declaration that appears inside the parentheses (`int num`). This is the declaration of a parameter variable, which enables the `displayValue` method to accept an integer value as an argument. Here is an example of a call to the `displayValue` method, passing `5` as an argument:

```
displayValue(5);
```

This statement executes the `displayValue` method. The argument that is listed inside the parentheses is assigned to the method's parameter variable, `num`.

### Passing Multiple Arguments

Often it is useful to pass more than one argument to a method. When you define a method, you must declare a parameter variable for each argument that you want passed into the method. The parameter declarations are separated by commas. Here is an example:

```
public static void showSum(int num1, int num2)
{
 int result;
 result = num1 + num2;
 System.out.println(result);
}
```

Here is an example of how we might call the method:

```
showSum(12, 45);
```

This statement calls the `showSum` method and passes two arguments: `12` and `45`. These arguments are passed *by position* to the corresponding parameter variables in the function. In other words, the first argument is passed to the first parameter variable, and the second argument is passed to the second parameter variable. So, this statement causes `12` to be assigned to the `num1` parameter and `45` to be assigned to the `num2` parameter.

### Arguments Are Passed by Value in Java

In Java, all arguments of the built-in data types are *passed by value*, which means that only a copy of an argument's value is passed into a parameter variable. A method's parameter variables are separate and distinct from the arguments that are listed inside the parentheses of a method call. If a parameter variable is changed inside a method, it has no effect on the original argument.

### Global Constants

In Java, variables and constants cannot be declared outside of a class. If you declare a variable or constant inside a class, but outside of all the class's methods, that variable

or constant is known as a *class field*, and will be available to all the methods within the class. Program 5-16 demonstrates how to declare such a constant. Notice that in line 3, we have declared a constant named VALUE. The declaration is inside the class, but it is not inside any of the methods. As a result, the constant is available to all the methods in the class. Also, notice that the declaration begins with the key words `public static`. At this point, you do not need to be too concerned about why these key words are required, except that this makes the constant available to all `public static` methods.

### Program 5-16 (FieldTest.java)

```

1 public class FieldTest
2 {
3 public static final int VALUE = 10;
4
5 public static void main(String[] args)
6 {
7 // Statements here have access to
8 // the VALUE constant.
9 }
10
11 public static void method2()
12 {
13 // Statements here have access to
14 // the VALUE constant.
15 }
16
17 public static void method3()
18 {
19 // Statements here have access to
20 // the VALUE constant.
21 }
22 }
```

## Python

### Modularizing Python Programs with Functions



This chapter discusses modules as named groups of statements that perform specific tasks in a program. You use modules to break a program down into small, manageable units. In Python, we use *functions* for this purpose. (In Python, the term “module” has a slightly different meaning. A Python module is a file that contains a set of related program elements, such as functions.)

#### Defining and Calling a Function in Python

To create a function you write its *definition*. Here is the general format of a function definition in Python:

```
def function_name():
 statement
 statement
 etc.
```

The first line is known as the *function header*. It marks the beginning of the function definition. The function header begins with the key word `def`, followed by the name of the function, followed by a set of parentheses, followed by a colon.

Beginning at the next line is a set of statements known as a block. A *block* is simply a set of statements that belong together as a group. These statements are performed any time the function is executed. Notice in the general format that all the statements in the block are indented. This indentation is required because the Python interpreter uses it to tell where the block begins and ends. Here is an example of a function definition:

```
def message():
 print('I am Arthur.')
 print('King of the Britons.')
```

This code defines a function named `message`. The `message` function contains a block with two statements. Executing the function will cause these statements to execute.

### Calling a Function in Python

A function definition specifies what a function does, but it does not cause the function to execute. To execute a function, you must *call* it. This is how we would call the `message` function:

```
message()
```

When a function is called, the interpreter jumps to that function and executes the statements in its block. Then, when the end of the block is reached, the interpreter jumps back to the part of the program that called the function, and the program resumes execution at that point. When this happens, we say that the function *returns*. Program 5-17 shows an example.

#### **Program 5-17** (function\_demo.py)

```
1 def message():
2 print('I am Arthur.')
3 print('King of the Britons.')
4
5 message()
```

#### **Program Output**

```
I am Arthur,
King of the Britons.
```

When the Python interpreter reads the `def` statement in line 1, a function named `message` is created in memory, containing the block of statements in lines 2 and 3. (A function definition creates a function, but it does not cause the function to execute.) Next, the interpreter executes the statement in line 5, which is a function call. This causes the `message` function to execute, which prints the two lines of output.

### Indentation in Python

In Python, each line in a block must be indented. As shown in Figure 5-24, the last indented line after a function header is the last line in the function's block.

**Figure 5-24** All of the statements in a Python block are indented

```
def greeting():
 print('Good morning!')
 print('Today we will learn about functions.')
print('I will call the greeting function.')
greeting()
```

When you indent the lines in a block, make sure each line begins with the same number of spaces. Otherwise an error will occur.

### Local Variables in Python

Anytime you assign a value to a variable inside a function, you create a *local variable*. A local variable belongs to the function in which it is created, and only statements inside that function can access the variable. A local variable's scope is the function in which the variable is created.

### Passing Arguments to Functions in Python

If you want a Python function to receive arguments when it is called, you must equip the function with one or more parameter variables. Here is an example of a function that has a parameter variable:

```
def double_number(value):
 result = value * 2
 print(result)
```

Look at the function header and notice the word `value` that appears inside the parentheses. This is the name of a parameter variable. This variable will be assigned the value of an argument when the function is called. Program 5-18 demonstrates the function in a program.

#### Program 5-18 (pass\_integer.py)

```
1 # Define the main function.
2 def main():
3 double_number(4)
4
5 # Define the double_number function.
6 def double_number(value):
7 result = value * 2
8 print(result)
9
10 # Call the main function.
11 main()
```

#### Program Output

When this program runs, the `main` function is called in line 11. Inside the `main` function, line 3 calls the `double_number` function passing the value 4 as an argument.

The `double_number` function is defined in lines 6 through 8. The function has a parameter variable named `value`. In line 7, a local variable named `result` is assigned the value of the math expression `value * 2`. In line 8, the value of the `result` variable is displayed.

### **Passing Multiple Arguments in Python**

Often it is useful to pass more than one argument to a function. When you define a function, you must have a parameter variable for each argument that you want passed into the function. Here is an example:

```
def show_sum(num1, num2):
 result = num1 + num2
 print(result)
```

Notice that two parameter variable names, `num1` and `num2`, appear inside the parentheses in the function header, separated by a comma. Here is an example of how we might call the function:

```
show_sum(12, 45)
```

This statement calls the `show_sum` function and passes two arguments: 12 and 45. These arguments are passed *by position* to the corresponding parameter variables in the function. In other words, the first argument is passed to the first parameter variable, and the second argument is passed to the second parameter variable. So, this statement causes 12 to be assigned to the `num1` parameter and 45 to be assigned to the `num2` parameter.

### **Making Changes to Parameters in Python**

When an argument is passed to a function in Python, the function's parameter variable will be assigned the argument's value. However, any changes that are made to the parameter variable will not affect the argument. To demonstrate this look at Program 5-19.

#### **Program 5-19 (change\_me.py)**

```
1 def main():
2 value = 99
3 print('The value is', value)
4 change_me(value)
5 print('Back in main the value is', value)
6
7 def change_me(arg):
8 print('I am changing the value.')
9 arg = 0
10 print('Now the value is', arg)
11
12 main()
```

#### **Program Output**

```
The value is 99
I am changing the value.
Now the value is 0
Back in main the value is 99
```

The `main` function creates a local variable named `value` in line 2, assigned the value 99. The statement in line 3 displays The *value* is 99. The `value` variable is then passed as an argument to the `change_me` function in line 4. This means that in the `change_me` function the `arg` parameter will also be assigned the value 99. When the statement in line 9 executes, however, the `arg` parameter is assigned a new value, 0. At this point in the program's execution, the `value` variable will still be assigned the value 99, and the `arg` parameter will be assigned the value 0.

### Global Variables in Python

In Python, when a variable is created by an assignment statement that is written outside all the functions in a program file, the variable is *global*. A global variable can be accessed by any statement in the program file, including the statements in any function. For example, look at Program 5-20.

#### Program 5-20 (global1.py)

```
1 # Create a global variable.
2 my_value = 10
3
4 # The show_value function prints
5 # the value of the global variable.
6 def show_value():
7 print(my_value)
8
9 # Call the show_value function.
10 show_value()
```

#### Program Output

```
10
```

The assignment statement in line 2 creates a variable named `my_value`. Because this statement is outside any function, it is global. When the `show_value` function executes, the statement in line 7 prints the value referenced by `my_value`.

An additional step is required if you want a statement in a function to assign a value to a global variable. In the function, you must declare the global variable, as shown in Program 5-21.

#### Program 5-21 (global2.py)

```
1 # Create a global variable.
2 number = 0
3
4 def main():
5 global number
6 number = int(input('Enter a number: '))
7 show_number()
8
9 def show_number():
```

```

10 print('The number you entered is', number)
11
12 # Call the main function.
13 main()

```

### Program Output

Enter a number: 22 [Enter]  
The number you entered is 22

The assignment statement in line 2 creates a global variable named `number`. Notice that inside the `main` function, line 5 uses the `global` key word to declare the `number` variable. This statement tells the interpreter that the `main` function intends to assign a value to the global `number` variable. That's just what happens in line 6. The value entered by the user is assigned to `number`.

### Global Constants in Python

The Python language does not allow you to create true global constants, but you can simulate them with global variables. If you do not declare a global variable with the `global` key word inside a function, then you cannot change the variable's assignment.

## C++

### Modularizing C++ Programs with Functions



This chapter discusses modules as named groups of statements that perform specific tasks in a program. You use modules to break a program down into small, manageable units. In C++, we use *functions* for this purpose.

#### Defining and Calling a Function in C++

To create a function in C++, you write its *definition*. Here is the general format of a function definition:

```

void showMessage()
{
 cout << "Hello world" << endl;
}

```

For now, the headers for all the C++ functions that you will write will begin with the key word `void`. Following this you write the name of the function, and a set of parentheses. Remember that a function header never ends with a semicolon!

#### Calling a Function

A function executes when it is called. The `main` function is automatically called when a program starts, but other functions are executed by function call statements. When a function is called, the program branches to that function and executes the statements in its body. Here is an example of a function call statement that calls the `showMessage` function we previously examined:

```
showMessage();
```

The statement is simply the name of the function followed by a set of parentheses. Because it is a complete statement, it is terminated with a semicolon. Program 5-22 shows a C++ program that demonstrates the `showMessage` function.

### Program 5-22 (FunctionDemo.cpp)

```
1 #include <iostream>
2 using namespace std;
3
4 void showMessage();
5
6 int main()
7 {
8 cout << "I have a message for you." << endl;
9 showMessage();
10 cout << "That's all, folks!" << endl;
11 return 0;
12 }
13
14 void showMessage()
15 {
16 cout << "Hello world" << endl;
17 }
```

### Program Output

```
I have a message for you.
Hello world
That's all, folks!
```

The program has two functions: `main` and `showMessage`. The `main` function appears in lines 6 through 12, and the `showMessage` function appears in lines 14 through 17. When the program runs, the `main` function executes. The statement in line 8 displays “I have a message for you.” Then the statement in line 9 calls the `showMessage` function. This causes the program to branch to the `showMessage` function and execute the statement that appears in line 16. This displays “Hello world”. The program then branches back to the `main` function and resumes execution at line 10. This displays “That’s all, folks!”

Notice the statement that appears in line 4:

```
void showMessage();
```

This line of code is a function prototype. A *function prototype* is a statement that declares the existence of a function, but does not define the function. It is merely a way of telling the compiler that a particular function exists in the program, and its definition appears at a later point. Without this statement, an error would occur when the program is compiled.

### Local Variables in C++

Variables that are declared inside a function are known as local variables. They are called *local* because they are local to the function in which they are declared. Statements

outside a function cannot access that function's local variables. Because a function's local variables are hidden from other functions, the other functions may have their own local variables with the same name.

### **Passing Arguments to Functions in C++**

If you want to be able to pass an argument into a C++ function, you must declare a parameter variable in that function's header. The parameter variable will receive the argument that is passed when the function is called. Here is the definition of a function that uses a parameter:

```
void displayValue(int num)
{
 cout << "The value is " << num << endl;
}
```

Notice the integer variable declaration that appears inside the parentheses (`int num`). This is the declaration of a parameter variable, which enables the `displayValue` function to accept an integer value as an argument. Here is an example of a call to the `displayValue` function, passing 5 as an argument:

```
displayValue(5);
```

This statement executes the `displayValue` function. The argument that is listed inside the parentheses is copied into the function's parameter variable, `num`.

### **Passing Multiple Arguments in C++**

Often it is useful to pass more than one argument to a function. When you define a function, you must declare a parameter variable for each argument that you want passed into the method. The parameter declarations are separated by commas. Here is an example:

```
void showSum(int num1, int num2)
{
 int result;
 result = num1 + num2;
 cout << result << endl;
}
```

Here is an example of how we might call the method:

```
showSum(12, 45);
```

This statement calls the `showSum` method and passes two arguments: 12 and 45. These arguments are passed by *position* to the corresponding parameter variables in the function. In other words, the first argument is passed to the first parameter variable, and the second argument is passed to the second parameter variable. So, this statement causes 12 to be assigned to the `num1` parameter and 45 to be assigned to the `num2` parameter.

### **Passing Arguments by Reference in C++**

When an argument is passed by reference, it means that the function has access to the argument and makes changes to it. C++ provides a special type of variable called a *reference variable* that, when used as a function parameter, allows access to the original argument.

A reference variable is an alias for another variable. Any changes made to the reference variable are actually performed on the variable for which it is an alias. Using a

reference variable as a parameter, a function may change a variable that is defined in another function.

Reference variables are declared like regular variables, except you place an ampersand (&) in front of the name. For example, look at the `setToZero` function shown here:

```
void setToZero(int &num)
{
 num = 0;
}
```

The `setToZero` function sets its parameter variable to 0, which also sets the original variable that was passed as an argument to 0.

### Global Variables and Global Constants in C++

To declare a global variable or constant in a C++ program, you write the declaration outside of all functions, and above the definitions of the functions. As a result, all the functions in the program have access to the variable or constant.

Earlier in this chapter, we warned against the use of global variables because they make programs difficult to debug. Global constants are permissible, however, because statements in the program cannot change their value. Program 5-23 demonstrates how to declare such a constant. Notice that in line 9, we have declared a constant named `INTEREST_RATE`. The declaration is not inside any of the functions, and is written above all function definitions. As a result, the constant is available to all the functions in the program.

#### Program 5-23 (GlobalConstants.cpp)

```
1 #include <iostream>
2 using namespace std;
3
4 // Function prototypes
5 void function2();
6 void function3();
7
8 // Global constant
9 const double INTEREST_RATE = 0.05;
10
11 int main()
12 {
13 // Statements here have access to
14 // the INTEREST_RATE constant.
15 return 0;
16 }
17
18 void function2()
19 {
20 // Statements here have access to
21 // the INTEREST_RATE constant.
22 }
23
24 void function3()
25 {
26 // Statements here have access to
27 // the INTEREST_RATE constant.
28 }
```

## Review Questions

### Multiple Choice

1. A group of statements that exist within a program for the purpose of performing a specific task is a(n) \_\_\_\_\_.
  - a. block
  - b. parameter
  - c. module
  - d. expression
2. A benefit of using modules that helps to reduce the duplication of code within a program is \_\_\_\_\_.
  - a. code reuse
  - b. divide and conquer
  - c. debugging
  - d. facilitation of teamwork
3. The first line of a module definition is known as the \_\_\_\_\_.
  - a. body
  - b. introduction
  - c. initialization
  - d. header
4. You \_\_\_\_\_ the module to execute it.
  - a. define
  - b. call
  - c. import
  - d. export
5. A \_\_\_\_\_ point is the memory address of the location in the program that the computer will return to when a module ends.
  - a. termination
  - b. module definition
  - c. return
  - d. reference
6. A design technique that programmers use to break down an algorithm into modules is known as \_\_\_\_\_.
  - a. top-down design
  - b. code simplification
  - c. code refactoring
  - d. hierarchical subtasking
7. A \_\_\_\_\_ is a diagram that gives a visual representation of the relationships between modules in a program.
  - a. flowchart
  - b. module relationship chart
  - c. symbol chart
  - d. hierarchy chart

8. A \_\_\_\_\_ is a variable that is declared inside a module.
  - a. global variable
  - b. local variable
  - c. hidden variable
  - d. none of the above; you cannot declare a variable inside a module
9. A(n) \_\_\_\_\_ is the part of a program in which a variable may be accessed.
  - a. declaration space
  - b. area of visibility
  - c. scope
  - d. mode
10. A(n) \_\_\_\_\_ is a piece of data that is sent into a module.
  - a. argument
  - b. parameter
  - c. header
  - d. packet
11. A(n) \_\_\_\_\_ is a special variable that receives a piece of data when a module is called.
  - a. argument
  - b. parameter
  - c. header
  - d. packet
12. When \_\_\_\_\_, only a copy of the argument's value is passed into the parameter variable.
  - a. passing an argument by reference
  - b. passing an argument by name
  - c. passing an argument by value
  - d. passing an argument by data type
13. When \_\_\_\_\_, the module can modify the argument in the calling part of the program.
  - a. passing an argument by reference
  - b. passing an argument by name
  - c. passing an argument by value
  - d. passing an argument by data type
14. A variable that is visible to every module in the program is a \_\_\_\_\_.
  - a. local variable
  - b. universal variable
  - c. program-wide variable
  - d. global variable
15. When possible, you should avoid using \_\_\_\_\_ variables in a program.
  - a. local
  - b. global
  - c. reference
  - d. parameter

**True or False**

1. The phrase “divide and conquer” means that all of the programmers on a team should be divided and work in isolation.
2. Modules make it easier for programmers to work in teams.
3. Module names should be as short as possible.
4. Calling a module and defining a module mean the same thing.
5. A flowchart shows the hierarchical relationships between modules in a program.
6. A hierarchy chart does not show the steps that are taken inside a module.
7. A statement in one module can access a local variable in another module.
8. In most programming languages, you cannot have two variables with the same name in the same scope.
9. Programming languages typically require that arguments be of the same data type as the parameters that they are passed to.
10. Most languages do not allow you to write modules that accept multiple arguments.
11. When an argument is passed by reference, the module can modify the argument in the calling part of the program.
12. Passing an argument by value is a means of establishing two-way communication between modules.

**Short Answer**

1. How do modules help you to reuse code in a program?
2. Name and describe the two parts that a module definition has in most languages.
3. When a module is executing, what happens when the end of the module is reached?
4. What is a local variable? What statements are able to access a local variable?
5. In most languages, where does a local variable’s scope begin and end?
6. What is the difference between passing an argument by value and passing it by reference?
7. Why do global variables make a program difficult to debug?

**Algorithm Workbench**

1. Design a module named `timesTen`. The module should accept an `Integer` argument. When the module is called, it should display the product of its argument multiplied times 10.
2. Examine the following pseudocode module header, and then write a statement that calls the module, passing 12 as an argument.

```
Module showValue(Integer quantity)
```

3. Look at the following pseudocode module header:

```
Module myModule(Integer a, Integer b, Integer c)
```

Now look at the following call to `myModule`:

```
Call myModule(3, 2, 1)
```

When this call executes, what value will be stored in `a`? What value will be stored in `b`? What value will be stored in `c`?

4. Assume that a pseudocode program contains the following module:

```
Module display(Integer arg1, Real arg2, String arg3)
 Display "Here are the values:"
 Display arg1, " ", arg2, " ", arg3
End Module
```

Assume that the same program has a `main` module with the following variable declarations:

```
Declare Integer age
Declare Real income
Declare String name
```

Write a statement that calls the `display` module and passes these variables to it.

5. Design a module named `getNumber`, which uses a reference parameter variable to accept an `Integer` argument. The module should prompt the user to enter a number and then store the input in the reference parameter variable.
6. What will the following pseudocode program display?

```
Module main()
 Declare Integer x = 1
 Declare Real y = 3.4
 Display x, " ", y
 Call changeUs(x, y)
 Display x, " ", y
End Module

Module changeUs(Integer a, Real b)
 Set a = 0
 Set b = 0
 Display a, " ", b
End Module
```

7. What will the following pseudocode program display?

```
Module main()
 Declare Integer x = 1
 Declare Real y = 3.4
 Display x, " ", y
 Call changeUs(x, y)
 Display x, " ", y
End Module

Module changeUs(Integer Ref a, Real Ref b)
 Set a = 0
 Set b = 0.0
 Display a, " ", b
End Module
```

## Debugging Exercises

1. Find the error in the following pseudocode.

```
Module main()
 Declare Real mileage
 Call getMileage()
 Display "You've driven a total of ", mileage, " miles."
End Module
```

```
Module getMileage()
 Display "Enter your vehicle's mileage."
 Input mileage
End Module
```

2. Find the error in the following pseudocode.

```
Module main()
 Call getServings()
End Module
```

```
Module getServings()
 Declare Real servings
 Display "How many servings are in the first bag of chips?"
 Input servings
 Declare Real servings
 Display "How many servings are in the second bag of chips?"
 Input servings
End Module
```

3. Find the potential error in the following pseudocode.

```
Module main()
 Call squareNumber(5)
End Module
```

```
Module squareNumber(Integer Ref number)
 Set number = number^2
 Display number
End Module
```

4. Find the error in the following pseudocode.

```
Module main()
 Call raiseToPower(2, 1.5)
End Module
```

```
Module raiseToPower(Real value, Integer power)
 Declare Real result
 Set result = value^power
 Display result
End Module
```

## Programming Exercises



### 1. Kilometer Converter

Design a modular program that asks the user to enter a distance in kilometers, and then converts that distance to miles. The conversion formula is as follows:

$$\text{Miles} = \text{Kilometers} \times 0.6214$$

### 2. Sales Tax Program Refactoring

Programming Exercise 6 in Chapter 2 was the Sales Tax program. For that exercise you were asked to design a program that calculates and displays the county and state sales tax on a purchase. If you have already designed that program, refactor it so the subtasks are in modules. If you have not already designed that program, create a modular design for it.

### 3. How Much Insurance?

Many financial experts advise that property owners should insure their homes or buildings for at least 80 percent of the amount it would cost to replace the structure. Design a modular program that asks the user to enter the replacement cost of a building and then displays the minimum amount of insurance the user should buy for the property.

### 4. Automobile Costs

Design a modular program that asks the user to enter the monthly costs for the following expenses incurred from operating their automobile: loan payment, insurance, gas, oil, tires, and maintenance. The program should then display the total monthly cost of these expenses, and the total annual cost of these expenses.

### 5. Property Tax

A county collects property taxes on the assessment value of property, which is 60 percent of the property's actual value. For example, if an acre of land is valued at \$10,000, its assessment value is \$6,000. The property tax is then 64¢ for each \$100 of the assessment value. The tax for the acre assessed at \$6,000 will be \$38.40. Design a modular program that asks for the actual value of a piece of property and displays the assessment value and property tax.

### 6. Cost of Goods Sold

In business, the cost of goods sold is the amount it costs a business to produce a product or service over a period of time. The formula to calculate the cost of goods sold is:

$$\text{COGS} = B + P - E$$

where:

- COGS is the cost of goods sold
- $B$  is the beginning inventory cost, which is the cost of the inventory at the beginning of the time period
- $P$  is the amount of purchases made during the time period
- $E$  is the ending inventory cost, which is the cost of the inventory at the end of the time period

Design a modular program that calculates a business's cost of goods sold. The program should use modules to get the amounts of beginning inventory, purchases, and ending inventory from the user, and then display the cost of goods sold.

### 7. Inventory Shrinkage

In business, inventory shrinkage is the percentage of inventory that is lost to damage, theft, and miscalculations. The formula to calculate inventory shrinkage is:

$$IS = \left( \frac{RI - AI}{RI} \right) 100$$

where:

- $IS$  is inventory shrinkage, which is the percentage of inventory that has been lost
- $RI$  is the recorded inventory, which is the amount of inventory that should be on-hand
- $AI$  is the actual inventory, which is the amount of inventory that is actually on-hand

Design a modular program that calculates a business's inventory shrinkage. The program should use modules to get the amounts of recorded inventory and actual inventory from the user, and then display the inventory shrinkage percentage.

### 8. Stadium Seating

There are three seating categories at a stadium. For a softball game, Class A seats cost \$15, Class B seats cost \$12, and Class C seats cost \$9. Design a modular program that asks how many tickets for each class of seats were sold, and then displays the amount of income generated from ticket sales.

### 9. Paint Job Estimator

A painting company has determined that for every 115 square feet of wall space, one gallon of paint and eight hours of labor will be required. The company charges \$20.00 per hour for labor. Design a modular program that asks the user to enter the square feet of wall space to be painted and the price of the paint per gallon. The program should display the following data:

- The number of gallons of paint required
- The hours of labor required
- The cost of the paint
- The labor charges
- The total cost of the paint job

### 10. Monthly Sales Tax

A retail company must file a monthly sales tax report listing the total sales for the month, and the amount of state and county sales tax collected. The state sales tax rate is 4 percent and the county sales tax rate is 2 percent. Design a modular program that asks the user to enter the total sales for the month. Using this amount, the application should calculate and display the following:

- The amount of county sales tax
- The amount of state sales tax
- The total sales tax (county plus state)

In the pseudocode, represent the county tax rate (0.02) and the state tax rate (0.04) as named constants.

**11. Hot Dog Cookout Calculator**

Assume that hot dogs come in packages of 10, and hot dog buns come in packages of 8. Design a modular program that calculates the number of packages of hot dogs and the number of packages of hot dog buns needed for a cookout, with the minimum amount of leftovers. The program should ask the user for the number of people attending the cookout, and the number of hot dogs each person will be given. The program should display the following:

- The minimum number of packages of hot dogs required
- The minimum number of packages of buns required
- The number of hot dogs that will be left over
- The number of buns that will be left over

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## TOPICS

- |                                                            |                                                 |
|------------------------------------------------------------|-------------------------------------------------|
| 6.1   Introduction to Functions: Generating Random Numbers | 6.3   More Library Functions                    |
| 6.2   Writing Your Own Functions                           | 6.4   Focus on Languages: Java, Python, and C++ |

## 6.1

## Introduction to Functions: Generating Random Numbers

**CONCEPT:** A *function* is a module that returns a value back to the part of the program that called it. Most programming languages provide a library of prewritten functions that perform commonly needed tasks. In these libraries you typically find a function that generates random numbers.

In Chapter 5 you learned that a module is a group of statements that exist within a program for the purpose of performing a specific task. When you need the module to perform its task, you call the module. This causes the program to execute the statement inside the module.

A *function* is a special type of module. It is like a regular module in the following ways:

- A function is a group of statements that perform a specific task.
- When you want to execute a function, you call it.

When a function finishes, however, it returns a value back to the statement that called it. The value that is returned from a function can be used like any other value: it can be assigned to a variable, displayed on the screen, used in a mathematical expression (if it is a number), and so on.



**NOTE:** It should be mentioned that functions are called differently than modules. In our pseudocode, you use the `Call` statement to call a module. You do not use the `Call` statement to call a function, however. Function calls are usually inserted into statements that perform some operation with the value that is returned from the function. For example, a function call might be inserted into a `Set` statement that assigns the value that is returned from the function to a variable. A function call might also be inserted into a `Display` statement that displays the value that is returned from the function. You will see many such examples in this chapter.

## Library Functions

Most programming languages come with a library of functions that have already been written. These functions, known as *library functions*, are built into the programming language, and you can call them any time you need them. Library functions make a programmer's job easier because they perform many of the tasks that programmers commonly need to perform. As you will see in this chapter, there are library functions to manipulate numbers and perform various math operations, to convert data from one type to another, to manipulate strings, and more.

The code for a language's library functions is usually stored in special files. These files are normally placed on your computer when you install a compiler or interpreter. When you call a library function in one of your programs, the compiler or interpreter automatically causes the function to execute, without requiring the function's code to appear in your program. This way, you never have to see the code for a library function—you only need to know the purpose of the library function, the arguments that you must pass to it, and what type of data it returns.

Because you do not see the internal workings of library functions, many programmers think of them as *black boxes*. The term *black box* is used to describe any mechanism that accepts input, performs some operation that cannot be seen on the input, and produces output. Figure 6-1 illustrates this idea.

**Figure 6-1** A library function viewed as a black box



This section demonstrates how functions work by looking at a library function that generates random numbers. Most programming languages provide such a function, and we will look at some interesting programs that can be written with it. In the following section you will learn to write your own functions. The last section in this chapter comes back to the topic of library functions and looks at several other useful functions that programming languages commonly provide.

## Using the random Function

Most programming languages provide a library function that generates random numbers. This chapter uses the `random` function for this purpose in the pseudocode. Random numbers are useful for lots of different programming tasks. The following are just a few examples:

- Random numbers are commonly used in games. For example, computer games that let the player roll dice use random numbers to represent the values of the dice. Programs that show cards being drawn from a shuffled deck use random numbers to represent the face values of the cards.
- Random numbers are useful in simulation programs. In some simulations, the computer must randomly decide how a person, animal, insect, or other living being will behave. Formulas can be constructed in which a random number is used to determine various actions and events that take place in the program.
- Random numbers are useful in statistical programs that must randomly select data for analysis.
- Random numbers are commonly used in computer security to encrypt sensitive data.

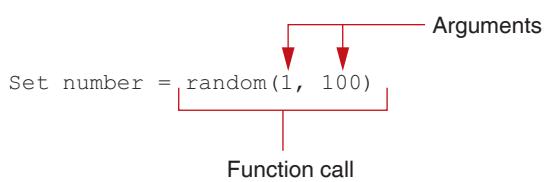
The following pseudocode statement shows an example of how you might call the `random` function. Assume that `number` is an `Integer` variable.

```
Set number = random(1, 100)
```

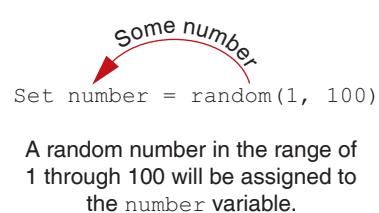
The part of the statement that reads `random(1, 100)` is a call to the `random` function. Notice that two arguments appear inside the parentheses: 1 and 100. These arguments tell the function to give a random number in the range of 1 through 100. Figure 6-2 illustrates this part of the statement.

Notice that the call to the `random` function appears on the right side of an `=` operator. When the function is called, it will generate a random number in the range of 1 through 100 and then *return* that number. The number that is returned will be assigned to the `number` variable, as shown in Figure 6-3.

**Figure 6-2** A statement that calls the `random` function



**Figure 6-3** The `random` function returns a value



Program 6-1 shows the pseudocode for a complete program that uses the `random` function. The statement in line 2 generates a random number in the range of 1 through 10 and assigns it to the `number` variable. (The program output shows that the number 7 was generated, but this value is arbitrary. If this were an actual program, it could display any number between 1 and 10.)

**Program 6-1**

```

1 Declare Integer number
2 Set number = random(1, 10)
3 Display number

```

**Program Output**

7



**NOTE:** The way that you set up a program to work with library functions differs among programming languages. In some languages you don't have to do anything special to call library functions. That's the approach we take in our pseudocode. In other languages, however, you may have to write a statement near the top of a program indicating that it will access a particular library function.

The pseudocode in Program 6-2 shows another example. This program uses a For loop that iterates five times. Inside the loop, the statement in line 9 calls the `random` function to generate a random number in the range of 1 through 100.

**Program 6-2**

```

1 // Declare variables
2 Declare Integer number, counter
3
4 // The following loop displays
5 // five random numbers.
6 For counter = 1 To 5
7 // Get a random number in the range of
8 // 1 through 100 and assign it to number.
9 Set number = random(1, 100)
10
11 // Display the number.
12 Display number
13 End For

```

**Program Output**

```

89
7
16
41
12

```

The pseudocode in both Programs 6-1 and 6-2 calls the `random` function and assigns its return value to the `number` variable. If you just want to display a random number, it is not necessary to assign the `random` number to a variable. You can send the `random` function's return value directly to the `Display` statement, as shown here:

```
Display random(1, 10)
```

When this statement executes, the `random` function is called. The function generates a random number in the range of 1 through 10. That value is returned and then sent to the `Display` statement. As a result, a random number in the range of 1 through 10 will be displayed. Figure 6-4 illustrates this.

The pseudocode in Program 6-3 shows how you could simplify Program 6-2. This program also displays five random numbers, but this program does not use a variable to hold those numbers. The `random` function's return value is sent directly to the `Display` statement in line 4.

**Figure 6-4** Displaying a random number

Some number  
Display `random(1, 10)`

A random number in the range of 1 through 10 will be displayed.

### Program 6-3

```
1 // Counter variable
2 Declare Integer counter
3
4 // This loop displays five random numbers.
5 For counter = 1 To 5
6 Display random(1, 100)
7 End For
```

### Program Output

```
32
79
6
12
98
```

## In the Spotlight: Using Random Numbers



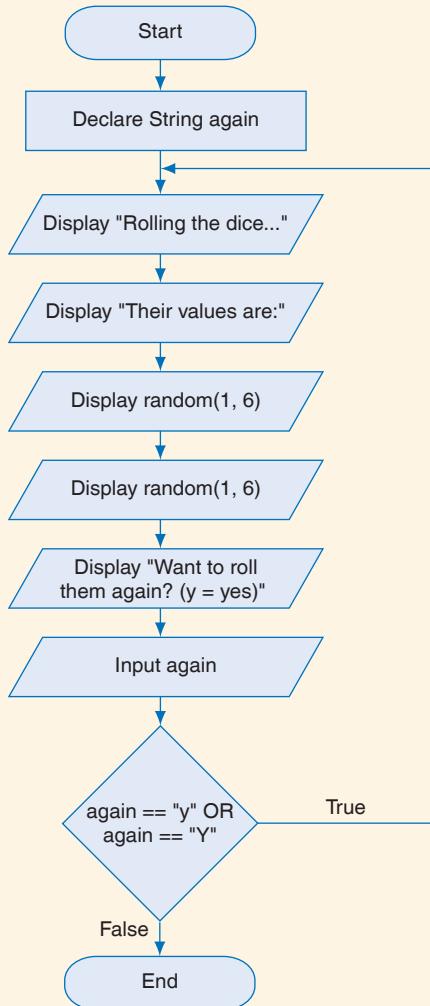
Dr. Kimura teaches an introductory statistics class, and has asked you to write a program that he can use in class to simulate the rolling of dice. The program should randomly generate two numbers in the range of 1 through 6 and display them. In your interview with Dr. Kimura, you learn that he would like to use the program to simulate several rolls of the dice, one after the other. You decide to write a loop that simulates one roll of the dice, and then asks the user whether another roll should be performed. As long as the user answers “y” for yes, the loop will repeat. Program 6-4 shows the pseudocode for the program, and Figure 6-5 shows the flowchart.

**Program 6-4**

```
1 // Declare a variable to control the
2 // loop iterations.
3 Declare String again
4
5 Do
6 // Roll the dice.
7 Display "Rolling the dice..."
8 Display "Their values are:"
9 Display random(1, 6)
10 Display random(1, 6)
11
12 // Do this again?
13 Display "Want to roll them again? (y = yes)"
14 Input again
15 While again == "y" OR again == "Y"
```

**Program Output (with Input Shown in Bold)**

```
Rolling the dice...
Their values are:
2
6
Want to roll them again? (y = yes)
y [Enter]
Rolling the dice...
Their values are:
4
1
Want to roll them again? (y = yes)
y [Enter]
Rolling the dice...
Their values are:
3
3
Want to roll them again? (y = yes)
n [Enter]
```

**Figure 6-5** Flowchart for Program 6-4

The `random` function returns an integer value, so you can write a call to the function anywhere that you can write an integer value. You have already seen examples where the function's return value is assigned to a variable and where the function's return value is sent to the `Display` statement. To further illustrate the point, here is a statement that uses the `random` function in a math expression:

```
Set x = random(1, 10) * 2
```

In this statement, a random number in the range of 1 through 10 is generated and then multiplied by 2. The result is assigned to the `x` variable. You can also test the return value of the function with an `If-Then` statement, as demonstrated in the following *In the Spotlight* section.

## In the Spotlight: Using Random Numbers to Represent Other Values



Dr. Kimura was so happy with the dice rolling simulator that you wrote for him, he has asked you to write one more program. He would like a program that he can use to simulate ten coin flips, one after the other. Each time the program simulates a coin flip, it should randomly display either “Heads” or “Tails.”

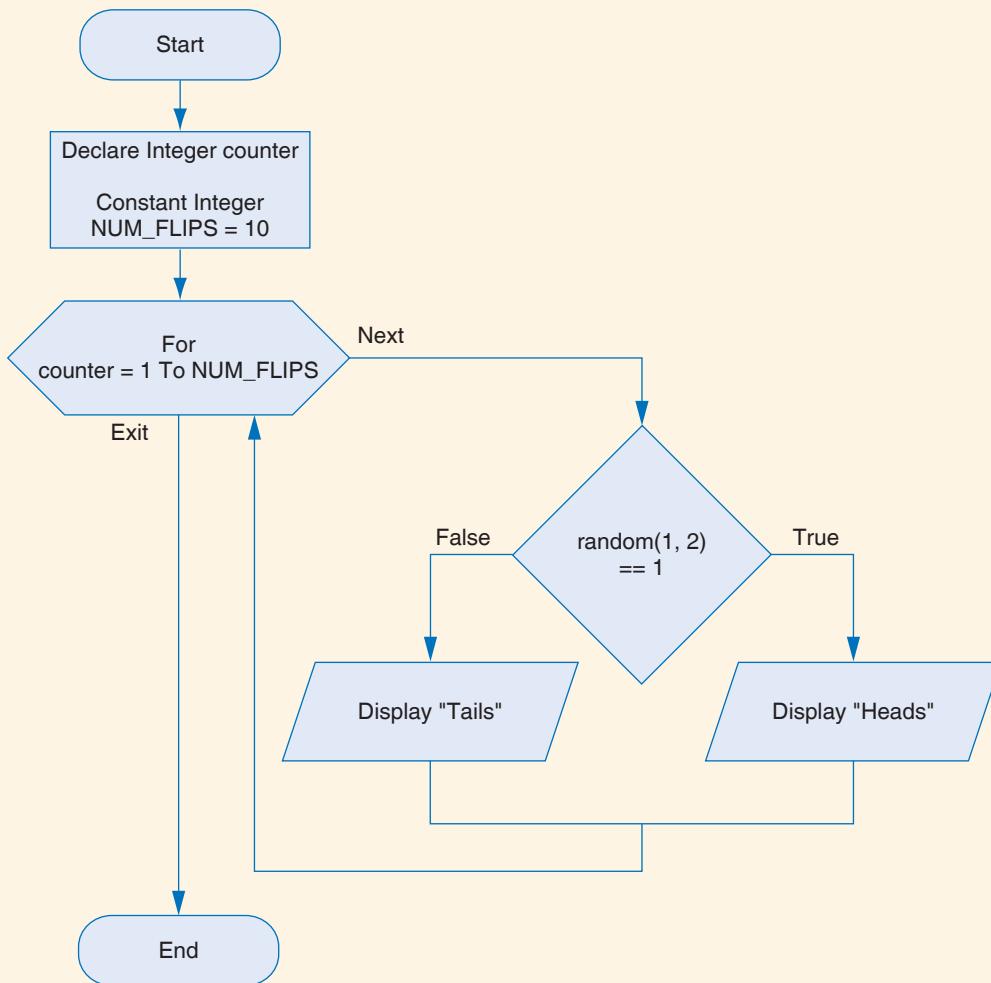
You decide that you can simulate the flipping of a coin by randomly generating a number in the range of 1 through 2. You will design a decision structure that displays “Heads” if the random number is 1, or “Tails” otherwise. Program 6-5 shows the pseudocode for the program, and Figure 6-6 shows the flowchart.

### Program 6-5

```
1 // Declare a counter variable.
2 Declare Integer counter
3
4 // Constant for the number of flips.
5 Constant Integer NUM_FLIPS = 10
6
7 For counter = 1 To NUM_FLIPS
8 // Simulate the coin flip.
9 If random(1, 2) == 1 Then
10 Display "Heads"
11 Else
12 Display "Tails"
13 End If
14 End For
```

### Program Output

```
Tails
Tails
Heads
Tails
Heads
Heads
Heads
Tails
Heads
Tails
```

**Figure 6-6** Flowchart for Program 6-5

### Checkpoint

- 6.1 How does a function differ from a module?
- 6.2 What is a library function?
- 6.3 Why are library functions like “black boxes”?
- 6.4 In pseudocode, what does the following statement do?  
`Set x = random(1, 100)`
- 6.5 In pseudocode, what does the following statement do?  
`Display random(1, 20)`

## 6.2

## Writing Your Own Functions

**CONCEPT:** Most programming languages allow you to write your own functions. When you write a function, you are essentially writing a module that can send a value back to the part of the program that called it.

Recall from Chapter 5 that when you create a module you write its definition. Functions are defined in a manner similar to modules. The following are the important characteristics of a function definition:



VideoNote

Writing a Function

- The first line of a function definition, the *function header*, specifies the data type of the value that is returned from the function, the name of the function, and any parameter variables used by the function to accept arguments.
- Following the function header is the *function body*, which is comprised of one or more statements that are executed when the function is called.
- One of the statements in the function body must be a Return statement. A Return statement specifies the value that is returned from the function when the function ends.

Here is the general format that we will use for writing functions in pseudocode:

```
Function DataType FunctionName(ParameterList)
 statement
 statement
 etc.
 Return value ← A function must have a Return statement. This causes a
 End Function value to be sent back to the part of the program that called
 the function.
```

The first line in this pseudocode, the function header, begins with the word *Function* and is followed by these items:

- *DataType* is the data type of the value that the function returns. For example, if the function returns an integer, the word *Integer* will appear here. If the function returns a real number, the word *Real* will appear here. Likewise, if the function returns a string, the word *String* will appear here.
- *FunctionName* is the name of the function. As with modules, you should give a function a name that describes what the function does. In most languages you follow the same rules for naming functions that you follow for naming modules and variables.
- An optional parameter list appears inside a set of parentheses. If the function does not accept arguments, then an empty set of parentheses will appear.

On the line after the function header, one or more statements will appear. These statements, the function's body, are performed any time the function is executed. One of the statements in the body must be a *Return* statement, which takes the following form:

Return *value*

The *value* that follows the word *Return* is the value that the function will send back to the part of the program that called the function. This can be any value, variable, or expression that has a value (such as a math expression). The value that is returned must be of the same data type as that specified in the function header. Otherwise, an error will occur.

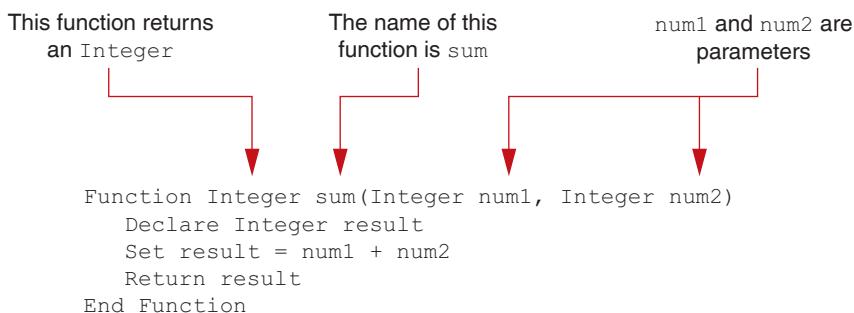
The last line of the definition, after the body, reads `End Function`. This line marks the end of the function definition.

Here is an example of a function written in pseudocode:

```
Function Integer sum(Integer num1, Integer num2)
 Declare Integer result
 Set result = num1 + num2
 Return result
End Function
```

Figure 6-7 illustrates the various parts of the function header. Notice that the function returns an `Integer`, the function's name is `sum`, and the function has two `Integer` parameters, named `num1` and `num2`.

**Figure 6-7** Parts of the function header



The purpose of this function is to accept two integer values as arguments and return their sum. Let's look at the body of the function to see how it works. The first statement, a variable declaration, declares a local `Integer` variable named `result`. The next statement assigns the value of `num1 + num2` to the `result` variable. Next, the `Return` statement executes, which causes the function to end execution and sends the value in the `result` variable back to the part of the program that called the function.

Program 6-6 shows a complete pseudocode program that uses the function.

### Program 6-6



```
1 Module main()
2 // Local variables
3 Declare Integer firstAge, secondAge, total
4
5 // Get the user's age and the user's
6 // best friend's age.
7 Display "Enter your age."
8 Input firstAge
9 Display "Enter your best friend's age."
```

```

10 Input secondAge
11
12 // Get the sum of both ages.
13 Set total = sum(firstAge, secondAge)
14
15 // Display the sum.
16 Display "Together you are ", total, " years old."
17 End Module
18
19 // The sum function accepts two Integer arguments and
20 // returns the sum of those arguments as an Integer.
21 Function Integer sum(Integer num1, Integer num2)
22 Declare Integer result
23 Set result = num1 + num2
24 Return result
25 End Function

```

### Program Output (with Input Shown in Bold)

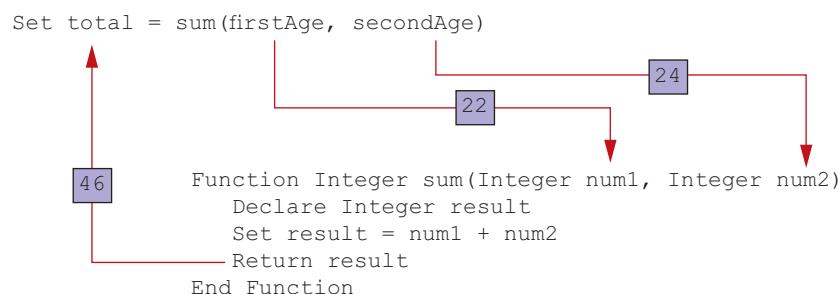
```

Enter your age.
22 [Enter]
Enter your best friend's age.
24 [Enter]
Together you are 46 years old.

```

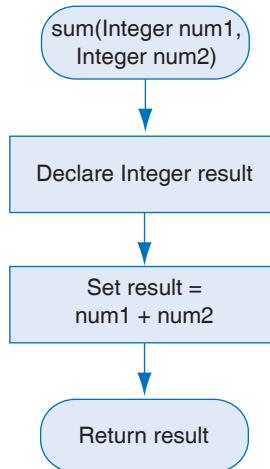
In the main module, the program gets two integer values from the user and stores them in the `firstAge` and `secondAge` variables. The statement in line 13 calls the `sum` function, passing `firstAge` and `secondAge` as arguments. The value that is returned from the `sum` function is assigned to the `total` variable. In this case, the function will return 46. Figure 6-8 shows how the arguments are passed into the function, and how a value is returned back from the function.

**Figure 6-8** Arguments are passed to the `sum` function and a value is returned



## Flowcharting a Function

When creating a flowchart for a program that has functions, you draw a separate flowchart for each function. In a flowchart for a function, the starting terminal symbol usually shows the name of the function, along with any parameters that the function has. The ending terminal symbol reads *Return*, followed by the value or expression that is being returned. Figure 6-9 shows the flowchart for the `sum` function in Program 6-6.

**Figure 6-9** Flowchart for the `sum` function

## Making the Most of the Return Statement

Look again at the `sum` function presented in Program 6-6:

```

Function Integer sum(Integer num1, Integer num2)
 Declare Integer result
 Set result = num1 + num2
 Return result
End Function

```

Notice that three things happen inside this function: (1) a local variable, `result`, is declared, (2) the value of the expression `num1 + num2` is assigned to the `result` variable, and (3) the value of the `result` variable is returned.

Although this function does what it sets out to do, it can be simplified. Because the `Return` statement can return the value of an expression, you can eliminate the `result` variable and rewrite the function as:

```

Function Integer sum(Integer num1, Integer num2)
 Return num1 + num2
End Function

```

This version of the function does not store the value of `num1 + num2` in a variable. Instead, it takes advantage of the fact that the `Return` statement can return the value of an expression. This version of the function does the same thing as the previous version, but in only one step.



**NOTE:** In most programming languages you can pass as many arguments into a function as you need, but you can return only one value from a function.

## How to Use Functions

Most programming languages allow you to create both modules and functions. Functions provide many of the same benefits as modules: they simplify code, reduce duplication, enhance your ability to test code, increase the speed of development, and ease the facilitation of teamwork.

Because functions return a value, they can be useful in specific situations. For example, you can use a function to prompt the user for input, and then it can return the value entered by the user. Suppose you've been asked to design a program that calculates the sale price of an item in a retail business. To do that, the program would need to get the item's regular price from the user. Here is a function you could define for that purpose:

```
Function Real getRegularPrice()
 // Local variable to hold the price.
 Declare Real price

 // Get the regular price.
 Display "Enter the item's regular price."
 Input price

 // Return the regular price.
 Return price
End Function
```

Then, elsewhere in the program, you could call that function, as shown here:

```
// Get the item's regular price.
Set regularPrice = getRegularPrice()
```

When this statement executes, the `getRegularPrice` function is called, which gets a value from the user and returns it. That value is then assigned to the `regularPrice` variable.

You can also use functions to simplify complex mathematical expressions. For example, calculating the sale price of an item seems like it would be a simple task: you calculate the discount and subtract it from the regular price. In a program, however, a statement that performs this calculation is not that straightforward, as shown in the following example. (Assume `DISCOUNT_PERCENTAGE` is a global constant that is defined in the program, and it specifies the percentage of the discount.)

```
Set salePrice = regularPrice - (regularPrice * DISCOUNT_PERCENTAGE)
```

This statement isn't easy to understand because it performs so many steps: it calculates the discount amount, subtracts that value from `regularPrice`, and assigns the result to `salePrice`. You could simplify the statement by breaking out part of the math expression and placing it in a function. Here is a function named `discount` that accepts an item's price as an argument and returns the amount of the discount:

```
Function Real discount(Real price)
 Return price * DISCOUNT_PERCENTAGE
End Function
```

You could then call the function in your calculation:

```
Set salePrice = regularPrice - discount(regularPrice)
```

This statement is easier to read than the one previously shown, and it is clearer that the discount is being subtracted from the regular price. The pseudocode in Program 6-7 shows the complete sale price calculating program using the functions just described.

**Program 6-7**

```
1 // Global constant for the discount percentage.
2 Constant Real DISCOUNT_PERCENTAGE = 0.20
3
4 // The main module is the program's starting point.
5 Module main()
6 // Local variables to hold regular and sale prices.
7 Declare Real regularPrice, salePrice
8
9 // Get the item's regular price.
10 Set regularPrice = getRegularPrice()
11
12 // Calculate the sale price.
13 Set salePrice = regularPrice - discount(regularPrice)
14
15 // Display the sale price.
16 Display "The sale price is $", salePrice
17 End Module
18
19 // The getRegularPrice function prompts the
20 // user to enter an item's regular price and
21 // returns that value as a Real.
22 Function Real getRegularPrice()
23 // Local variable to hold the price.
24 Declare Real price
25
26 // Get the regular price.
27 Display "Enter the item's regular price."
28 Input price
29
30 // Return the regular price.
31 Return price
32 End Function
33
34 // The discount function accepts an item's price
35 // as an argument and returns the amount of the
36 // discount specified by DISCOUNT_PERCENTAGE.
37 Function Real discount(Real price)
38 Return price * DISCOUNT_PERCENTAGE
39 End Function
```

**Program Output (with Input Shown in Bold)**

```
Enter the item's regular price.
100.00 [Enter]
The sale price is $80
```

## Using IPO Charts with Functions

You learned in Chapter 2 that an IPO chart is a simple but effective tool for designing a program. Recall that IPO stands for *input*, *processing*, and *output*, and an *IPO chart* describes the input, processing, and output of a program. You can also create IPO charts

for the individual functions in a program. The input column shows a description of the data that is passed to the function as arguments, the processing column shows a description of the process that the function performs, and the output column describes the data that is returned from the function. For example, Figure 6-10 shows IPO charts for the `getRegularPrice` and `discount` functions that you saw in Program 6-7.

**Figure 6-10** IPO charts for the `getRegularPrice` and `discount` functions

| IPO Chart for the <code>getRegularPrice</code> Function |                                                   |                                                  |
|---------------------------------------------------------|---------------------------------------------------|--------------------------------------------------|
| Input                                                   | Processing                                        | Output                                           |
| None                                                    | Prompts the user to enter an item's regular price | The item's regular price, as a <code>Real</code> |

| IPO Chart for the <code>discount</code> Function |                                                                                                                        |                                             |
|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|
| Input                                            | Processing                                                                                                             | Output                                      |
| An item's regular price                          | Calculates an item's discount by multiplying the regular price by the global constant <code>DISCOUNT_PERCENTAGE</code> | The item's discount, as a <code>Real</code> |

Notice that the IPO charts provide only brief descriptions of a function's input, processing, and output, but do not show the specific steps taken in a function. In many cases, however, IPO charts include sufficient information so that they can be used instead of a flowchart. The decision of whether to use an IPO chart, a flowchart, or both is often left to the programmer's personal preference.

## In the Spotlight: Modularizing with Functions

Hal owns a business named Make Your Own Music, which sells guitars, drums, banjos, synthesizers, and many other musical instruments. Hal's sales staff works strictly on commission. At the end of the month, each salesperson's commission is calculated according to Table 6-1.



**Table 6-1** Sales commission rates

| Sales This Month      | Commission Rate |
|-----------------------|-----------------|
| Less than \$10,000.00 | 10%             |
| \$10,000.00–14,999.99 | 12%             |
| \$15,000.00–17,999.99 | 14%             |
| \$18,000.00–21,999.99 | 16%             |
| \$22,000 or more      | 18%             |

For example, a salesperson with \$16,000 in monthly sales will earn a 14 percent commission (\$2,240). Another salesperson with \$20,000 in monthly sales will earn a 16 percent commission (\$3,200). A person with \$30,000 in monthly sales will earn an 18 percent commission (\$5,400).

Because the staff gets paid once per month, Hal allows each employee to take up to \$2,000 per month in advance. When sales commissions are calculated, the amount of each employee's advanced pay is subtracted from the commission. If any salesperson's commission is less than the amount of their advance, the salesperson must reimburse Hal for the difference. To calculate a salesperson's monthly pay, Hal uses the following formula:

$$\text{Pay} = \text{Sales} \times \text{Commission rate} - \text{Advanced pay}$$

Hal has asked you to write a program that makes this calculation for him. The following general algorithm outlines the steps the program must take:

1. Get the salesperson's monthly sales.
2. Get the amount of advanced pay.
3. Use the amount of monthly sales to determine the commission rate.
4. Calculate the salesperson's pay using the formula previously shown. If the amount is negative, indicate that the salesperson must reimburse the company.

Program 6-8 shows the pseudocode for the program, which is modularized with numerous functions. Rather than presenting the entire program at once, let's first examine the `main` module and then each function separately. Here is the `main` module:

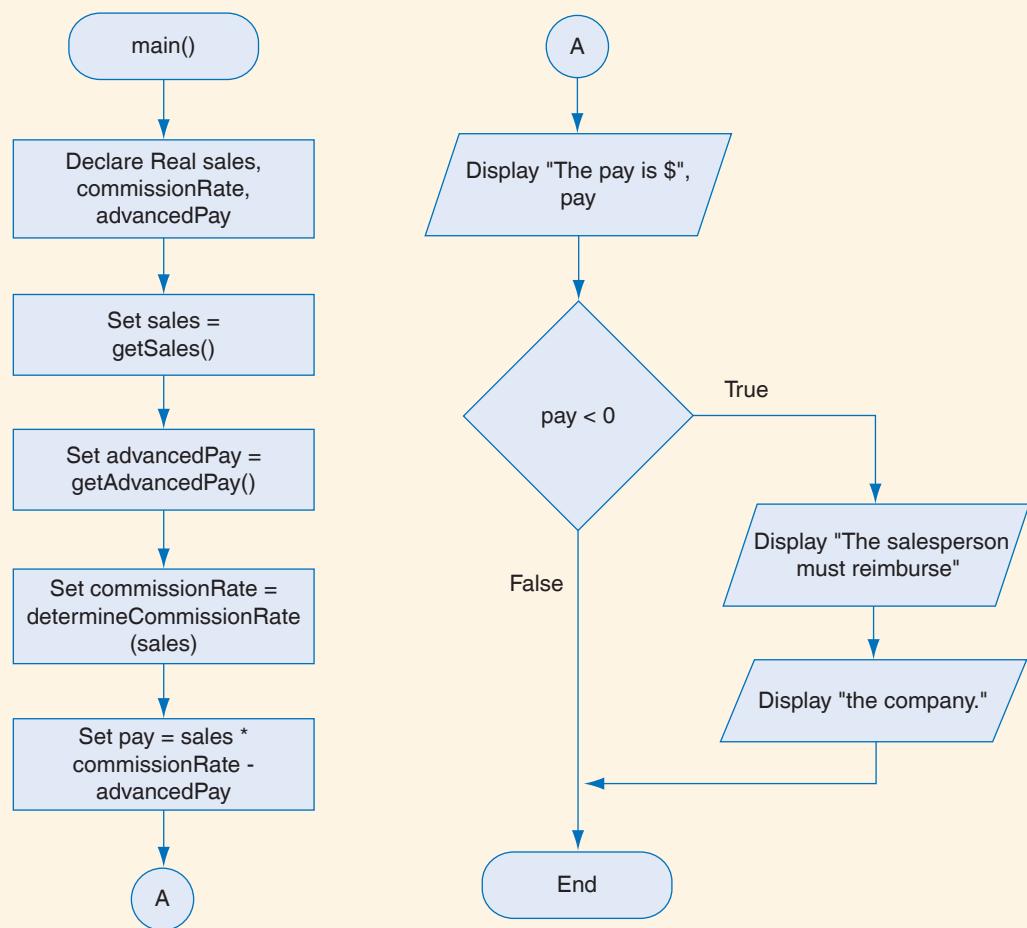
**Program 6-8****Commission rate program: main module**

```
1 Module main()
2 // Local variables
3 Declare Real sales, commissionRate, advancedPay
4
5 // Get the amount of sales.
6 Set sales = getSales()
7
8 // Get the amount of advanced pay.
9 Set advancedPay = getAdvancedPay()
10
11 // Determine the commission rate.
12 Set commissionRate = determineCommissionRate(sales)
13
14 // Calculate the pay.
15 Set pay = sales * commissionRate - advancedPay
16
17 // Display the amount of pay.
18 Display "The pay is $", pay
19
20 // Determine whether the pay is negative.
21 If pay < 0 Then
22 Display "The salesperson must reimburse"
23 Display "the company."
24 End If
25 End Module
26
```

Line 3 declares the variables to hold the sales, the commission rate, and the amount of advanced pay. Line 6 calls the `getSales` function, which gets the amount of sales from the user and returns that value. The value that is returned from the function is assigned to the `sales` variable. Line 9 calls the `getAdvancedPay` function, which gets the amount of advanced pay from the user and returns that value. The value that is returned from the function is assigned to the `advancedPay` variable.

Line 12 calls the `determineCommissionRate` function, passing `sales` as an argument. This function returns the rate of commission for the amount of sales. That value is assigned to the `commissionRate` variable. Line 15 calculates the amount of pay, and then line 18 displays that amount. The If-Then statement in lines 21 through 24 determines whether the pay is negative, and if so, displays a message indicating that the salesperson must reimburse the company. Figure 6-11 shows a flowchart for the `main` module.

**Figure 6-11** Flowchart for the `main` module



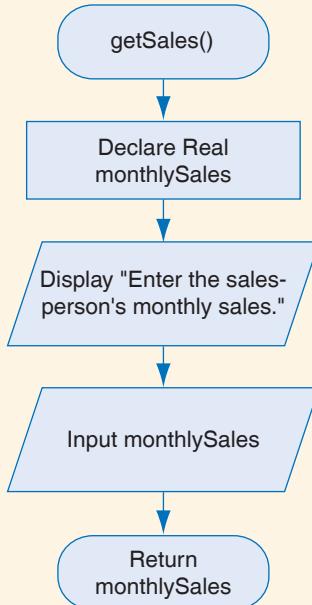
The `getSales` function definition is next.

**Program 6-8****Commission rate program (continued):  
getSales function**

```
27 // The getSales function gets a salesperson's
28 // monthly sales from the user and returns
29 // that value as a Real.
30 Function Real getSales()
31 // Local variable to hold the monthly sales.
32 Declare Real monthlySales
33
34 // Get the amount of monthly sales.
35 Display "Enter the salesperson's monthly sales."
36 Input monthlySales
37
38 // Return the amount of monthly sales.
39 Return monthlySales
40 End Function
41
```

The purpose of the `getSales` function is to prompt the user to enter the amount of sales for a salesperson and return that amount. A local variable named `monthlySales` is declared in line 32. Line 35 tells the user to enter the sales, and line 36 gets the user's input and stores it in the local `monthlySales` variable. Line 39 returns the amount in the `monthlySales` variable. Figure 6-12 shows a flowchart for this function.

**Figure 6-12** Flowchart for the `getSales` function



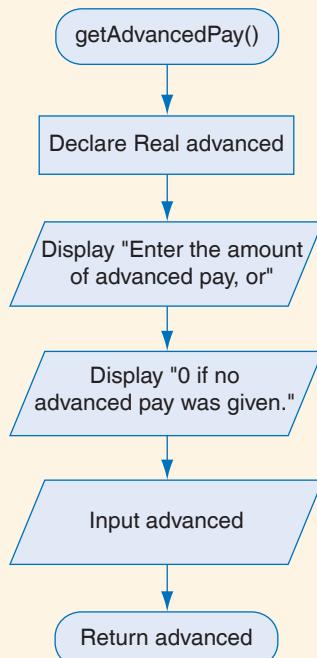
Next is the definition of the `getAdvancedPay` function.

**Program 6-8****Commission rate program (continued):  
getAdvancedPay function**

```
42 // The getAdvancedPay function gets the amount of
43 // advanced pay given to the salesperson and
44 // returns that amount as a Real.
45 Function Real getAdvancedPay()
46 // Local variable to hold the advanced pay.
47 Declare Real advanced
48
49 // Get the amount of advanced pay.
50 Display "Enter the amount of advanced pay, or"
51 Display "0 if no advanced pay was given."
52 Input advanced
53
54 // Return the advanced pay.
55 Return advanced
56 End Function
57
```

The purpose of the `getAdvancedPay` function is to prompt the user to enter the amount of advanced pay for a salesperson and return that amount. A local variable named `advanced` is declared in line 47. Lines 50 and 51 tell the user to enter the amount of advanced pay (or 0 if none was given), and line 52 gets the user's input and stores it in the local `advanced` variable. Line 55 returns the amount in the `advanced` variable. Figure 6-13 shows a flowchart for this function.

**Figure 6-13** Flowchart for the `getAdvancedPay` function

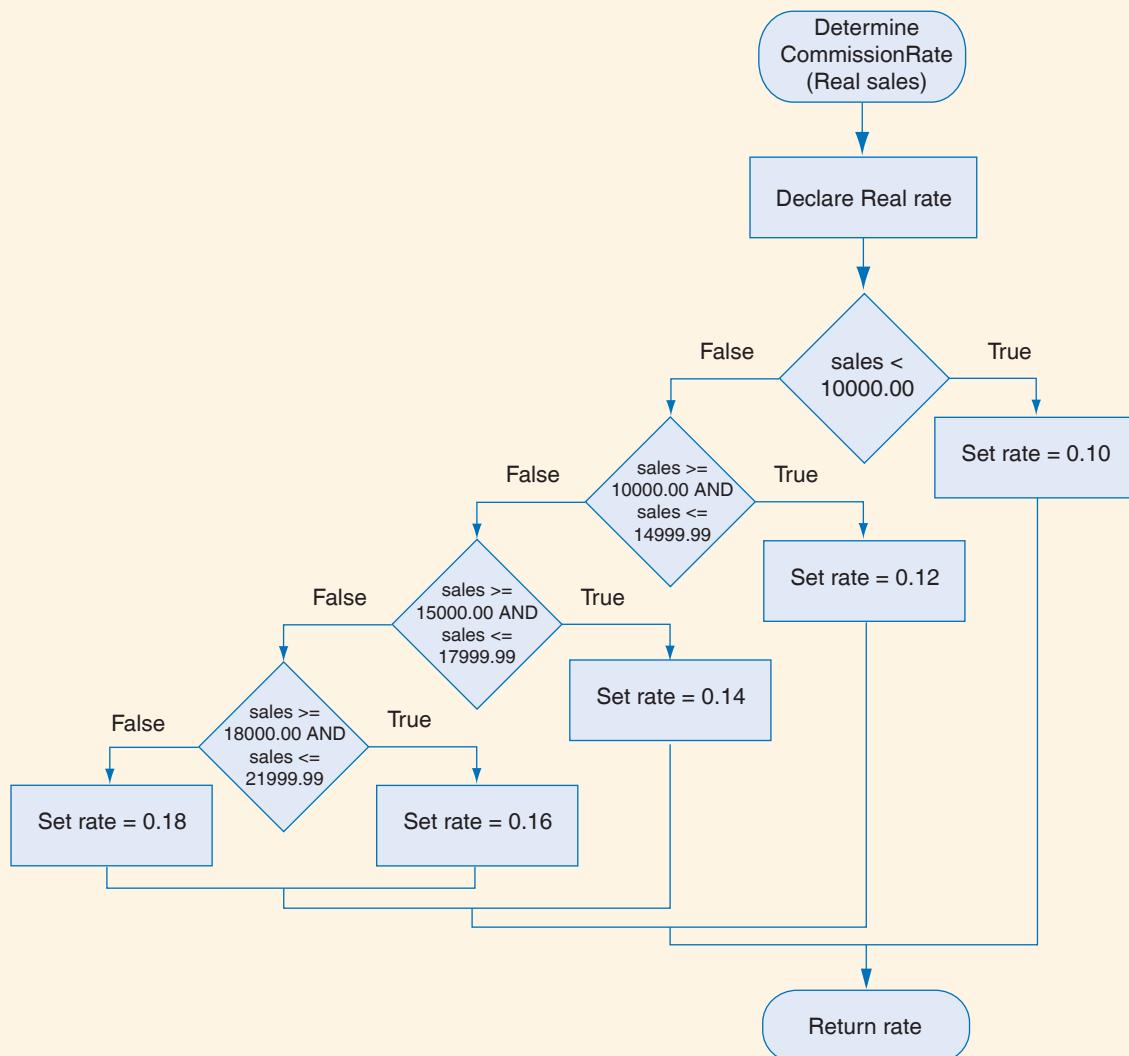


Defining the `determineCommissionRate` function comes next.

**Program 6-8****Commission rate program (continued):  
`determineCommissionRate` function**

```
58 // The determineCommissionRate function accepts the
59 // amount of sales as an argument and returns the
60 // commission rate as a Real.
61 Function Real determineCommissionRate(Real sales)
62 // Local variable to hold commission rate.
63 Declare Real rate
64
65 // Determine the commission rate.
66 If sales < 10000.00 Then
67 Set rate = 0.10
68 Else If sales >= 10000.00 AND sales <= 14999.99 Then
69 Set rate = 0.12
70 Else If sales >= 15000.00 AND sales <= 17999.99 Then
71 Set rate = 0.14
72 Else If sales >= 18000.00 AND sales <= 21999.99 Then
73 Set rate = 0.16
74 Else
75 Set rate = 0.18
76 End If
77
78 // Return the commission rate.
79 Return rate
80 End Function
```

The `determineCommissionRate` function accepts the amount of sales as an argument, and it returns the applicable commission rate for that amount of sales. Line 63 declares a local variable named `rate` that will hold the commission rate. The `If-Then-Else If` statement in lines 66 through 76 tests the `sales` parameter and assigns the correct value to the local `rate` variable. Line 79 returns the value in the local `rate` variable. Figure 6-14 shows a flowchart for this function.

**Figure 6-14** Flowchart for the `determineCommissionRate` function**Program Output (with Input Shown in Bold)**

Enter the salesperson's monthly sales.  
**14650.00 [Enter]**  
 Enter the amount of advanced pay, or  
 0 if no advanced pay was given.  
**1000.00 [Enter]**  
 The pay is \$758.00

**Program Output (with Input Shown in Bold)**

Enter the salesperson's monthly sales.  
**9000.00 [Enter]**  
 Enter the amount of advanced pay, or  
 0 if no advanced pay was given.  
**0 [Enter]**  
 The pay is \$900.00

### Program Output (with Input Shown in Bold)

```
Enter the salesperson's monthly sales.
12000.00 [Enter]
Enter the amount of advanced pay, or
0 if no advanced pay was given.
2000.00 [Enter]
The pay is $-560
The salesperson must reimburse
the company.
```

## Returning Strings

So far you've seen examples of functions that return numbers. Most programming languages also allow you to write functions that return strings. For example, the following pseudocode function prompts the user to enter their name, and then returns the string that the user entered.

```
Function String getName()
 // Local variable to hold the user's name.
 Declare String name

 // Get the user's name.
 Display "Enter your name."
 Input name

 // Return the name.
 Return name
End Function
```

## Returning Boolean Values

Most languages also allow you to write *Boolean functions*, which return either `True` or `False`. You can use a Boolean function to test a condition, and then return either `True` or `False` to indicate whether the condition exists. Boolean functions are useful for simplifying complex conditions that are tested in decision and repetition structures.

For example, suppose you are designing a program that will ask the user to enter a number, and then determine whether that number is even or odd. The following pseudocode shows how you can make that determination. Assume `number` is an `Integer` variable containing the number entered by the user.

```
If number MOD 2 == 0 Then
 Display "The number is even."
Else
 Display "The number is odd."
End If
```

The meaning of the Boolean expression being tested by this `If-Then` statement isn't clear, so let's take a closer look at it:

```
number MOD 2 == 0
```

This expression uses the `MOD` operator, which was introduced in Chapter 2. Recall that the `MOD` operator divides two integers and returns the remainder of the division. So,

this pseudocode is saying, “If the remainder of `number` divided by 2 is equal to 0, then display a message indicating the number is even, or else display a message indicating the number is odd.”

Because dividing an even number by 2 will always give a remainder of 0, this logic will work. The pseudocode would be easier to understand, however, if you could somehow rewrite it to say, “If the number is even, then display a message indicating it is even, or else display a message indicating it is odd.” As it turns out, this can be done with a Boolean function. In this example, you could design a Boolean function named `isEven` that accepts a number as an argument and returns `True` if the number is even, or `False` otherwise. The following is the pseudocode for such a function.

```
Function Boolean isEven(Integer number)
 // Local variable to hold True or False.
 Declare Boolean status

 // Determine whether number is even. If it is, set
 // status to True. Otherwise, set status to False.
 If number MOD 2 == 0 Then
 Set status = True
 Else
 Set status = False
 End If

 // Return the value in the status variable.
 Return status
End Function
```

Then you can rewrite the `If-Then` statement so it calls the `isEven` function to determine whether `number` is even.

```
If isEven(number) Then
 Display "The number is even."
Else
 Display "The number is odd."
End If
```

Not only is this logic easier to understand, but now you have a function that you can call in the program any time you need to test a number to determine whether it is even.



## Checkpoint

6.6 What is the purpose of the `Return` statement in a function?

6.7 Look at the following pseudocode function definition:

```
Function Integer doSomething(Integer number)
 Return number * 2
End Function
```

a. What is the name of the function?

b. What type of data does the function return?

c. Given the function definition, what will the following statement display?

```
Display doSomething (10)
```

6.8 What is a Boolean function?

**6.3**

## More Library Functions



**NOTE:** The library functions that we present in this chapter are generic versions of the ones that you will find in most programming languages. In this book, the names of the functions, the arguments that they accept, and their behavior might differ slightly from the way they work in actual programming languages.

### Mathematical Functions

Most programming languages provide several mathematical library functions. These functions typically accept one or more values as arguments, perform a mathematical operation using the arguments, and return the result. For example, two common mathematical functions are `sqrt` and `pow`. Let's take a closer look at each.

#### The `sqrt` Function

The `sqrt` function accepts an argument and returns the square root of the argument. Here is an example of how it is used:

```
Set result = sqrt(16)
```

This statement calls the `sqrt` function, passing 16 as an argument. The function returns the square root of 16, which is then assigned to the `result` variable. The pseudocode in Program 6-9 demonstrates the `sqrt` function.

#### Program 6-9

```
1 // Variable declarations
2 Declare Integer number
3 Declare Real squareRoot
4
5 // Get a number.
6 Display "Enter a number."
7 Input number
8
9 // Calculate and display its square root.
10 Set squareRoot = sqrt(number)
11 Display "The square root of that number is ", squareRoot
```

#### Program Output (with Input Shown in Bold)

```
Enter a number.
25 [Enter]
The square root of that number is 5
```

The pseudocode in Program 6-10 finds the hypotenuse of a right triangle. The program uses the following formula, which you might recall from geometry class:

$$c = \sqrt{a^2 + b^2}$$

In the formula,  $c$  is the length of the hypotenuse, and  $a$  and  $b$  are the lengths of the other sides of the triangle.

**Program 6-10**

```

1 // Variable declarations
2 Declare Real a, b, c
3
4 // Get the length of side A.
5 Display "Enter the length of side A."
6 Input a
7
8 // Get the length of side B.
9 Display "Enter the length of side B."
10 Input b
11
12 // Calculate the length of the hypotenuse.
13 Set c = sqrt(a^2 + b^2)
14
15 // Display the length of the hypotenuse.
16 Display "The length of the hypotenuse is ", c

```

**Program Output (with Input Shown in Bold)**

```

Enter the length of side A.
5.0 [Enter]
Enter the length of side B.
12.0 [Enter]
The length of the hypotenuse is 13

```

Take a closer look at line 13:

```
Set c = sqrt(a^2 + b^2)
```

The statement works like this: The value of the expression  $a^2 + b^2$  is calculated, and that value is passed as an argument to the `sqrt` function. The `sqrt` function returns the square root of the argument, which is then assigned to the variable `c`.

**The `pow` Function**

Another common mathematical function is the `pow` function. The purpose of the `pow` function is to raise a number to a power. In a nutshell, it does the same thing that we have been using the `^` operator for. Some programming languages, however, do not have an operator that raises a number to a power. Instead, they use a function such as `pow`. Here is an example of how the `pow` function is used:

```
Set area = pow(4, 2)
```

This statement calls the `pow` function, passing 4 and 2 as arguments. The function returns the value of 4 raised to the power of 2, which is assigned to the `area` variable.

**Other Common Mathematical Functions**

In addition to `sqrt` and `pow`, Table 6-2 describes several other mathematical functions that most programming languages provide.

**Table 6-2** Other common mathematical functions

| Function Name | Description and Example Usage                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| abs           | Returns the absolute value of the argument.<br><br><i>Example:</i> After the following statement executes, the variable <code>y</code> will contain the absolute value of the value in <code>x</code> . The variable <code>x</code> will remain unchanged.<br><br><code>y = abs(x)</code>                                                                                                                                                                                      |
| cos           | Returns the cosine of the argument. The argument should be an angle expressed in radians.<br><br><i>Example:</i> After the following statement executes, the variable <code>y</code> will contain the cosine of the angle stored in the variable <code>x</code> . The variable <code>x</code> will remain unchanged.<br><br><code>y = cos(x)</code>                                                                                                                            |
| round         | Accepts a real number as an argument and returns the value of the argument rounded to the nearest integer. For example, <code>round(3.5)</code> will return 4, and <code>round(3.2)</code> will return 3.<br><br><i>Example:</i> After the following statement executes, the variable <code>y</code> will contain the value of the variable <code>x</code> rounded to the nearest integer. The variable <code>x</code> will remain unchanged.<br><br><code>y = round(x)</code> |
| sin           | Returns the sine of the argument. The argument should be an angle expressed in radians.<br><br><i>Example:</i> After the following statement executes, the variable <code>y</code> will contain the sine of the angle stored in the variable <code>x</code> . The variable <code>x</code> will remain unchanged.<br><br><code>y = sin(x)</code>                                                                                                                                |
| tan           | Returns the tangent of the argument. The argument should be an angle expressed in radians.<br><br><i>Example:</i> After the following statement executes, the variable <code>y</code> will contain the tangent of the angle stored in the variable <code>x</code> . The variable <code>x</code> will remain unchanged.<br><br><code>y = tan(x)</code>                                                                                                                          |

## Data Type Conversion Functions

Most programming languages provide library functions that convert values from one data type to another. For example, most languages provide a function that converts a real number to an integer, as well as a function that converts an integer to a real number. In this book's pseudocode, we will use the `toInteger` function to convert a real number to an integer, and the `toReal` function to convert an integer to a real number. These functions are described in Table 6-3.

**Table 6-3** Data type conversion functions

| Function  | Description and Example Usage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| toInteger | <p>The <code>toInteger</code> function accepts a real number as its argument and returns that number converted to an integer. If the real number has a fractional part, the fractional part will be thrown away. For example, the function call <code>toInteger(2.5)</code> will return 2.</p> <p><i>Example:</i> If the following were actual code, the variable <code>i</code> would contain the value 2 after these statements execute.</p> <pre>Declare Integer i Declare Real r = 2.5 Set i = toInteger(r)</pre> |
| toReal    | <p>The <code>toReal</code> function accepts an integer number as its argument and returns that number converted to a real number.</p> <p><i>Example:</i> If the following were actual code, the variable <code>r</code> would contain the value 7.0 after these statements execute.</p> <pre>Declare Integer i = 7 Declare Real r Set r = toReal(i)</pre>                                                                                                                                                             |

In many languages, an error will occur if you try to assign a value of one data type to a variable of another data type. For example, look at the following pseudocode:

```
Declare Integer number
Set number = 6.17 ← This will cause an error in many languages!
```

The first statement declares an `Integer` variable named `number`. The second statement attempts to assign a real number, 6.17, to the variable. In most programming languages this will cause an error because an integer variable cannot hold fractional values. The error that will result is sometimes referred to as a *type mismatch error*.



**NOTE:** Most languages let you assign an integer value to a real variable without causing an error because doing so does not cause a loss of data. Functions for converting integers to real numbers still exist in case you need to explicitly perform this type of conversion.

Sometimes you might write code that causes a type mismatch error without realizing it. For example, look at the pseudocode in Program 6-11. This program calculates the number of people who can be served with a given amount of lemonade.

### Program 6-11

```

1 // Declare a variable to hold the number
2 // of ounces of lemonade available.
3 Declare Real ounces
4
5 // Declare a variable to hold the number
6 // of people whom we can serve.

```

```
7 Declare Integer numberOfPeople
8
9 // Constant for the number of ounces per person.
10 Constant Integer OUNCES_PER_PERSON = 8
11
12 // Get the number of ounces of lemonade available.
13 Display "How many ounces of lemonade do you have?"
14 Input ounces
15
16 // Calculate the number of people who can be served.
17 Set numberOfPeople = ounces / OUNCES_PER_PERSON ← Error!
18
19 // Display the number of people who can be served.
20 Display "You can serve ", numberOfPeople, " people."
```

The `ounces` variable, declared in line 3, will hold the number of ounces of lemonade that are available, and the `numberOfPeople` variable, declared in line 7, will hold the number of people who can be served. In line 10, the `OUNCES_PER_PERSON` constant is initialized with the value 8. This indicates that each person consumes 8 ounces of lemonade.

After the number of ounces of lemonade is entered and stored in the `ounces` variable (in line 14), the statement in line 17 attempts to calculate the number of people who can be served. But there is a problem with this statement: `numberOfPeople` is an `Integer` variable, and the math expression `ounces / OUNCES_PER_PERSON` will most likely result in a real number. (For example, if `ounces` is set to 12, the result will be 1.5.) When the statement attempts to assign the result of the math expression to `numberOfPeople`, an error will result.

At first, you might decide to simply change the data type of the `numberOfPeople` variable to `Real`. That would fix the error, but it wouldn't make sense to use a `Real` variable to hold the number of people. After all, you can't serve fractional people at your lemonade stand! A better solution is to convert the result of the math expression `ounces / OUNCES_PER_PERSON` to an integer, and then assign that integer to the `numberOfPeople` variable. This is the approach taken in Program 6-12.

### Program 6-12

```
1 // Declare a variable to hold the number
2 // of ounces of lemonade available.
3 Declare Real ounces
4
5 // Declare a variable to hold the number
6 // of people whom we can serve.
7 Declare Integer numberOfPeople
8
9 // Constant for the number of ounces per person.
10 Constant Integer OUNCES_PER_PERSON = 8
11
12 // Get the number of ounces of lemonade available.
13 Display "How many ounces of lemonade do you have?"
14 Input ounces
15
16 // Calculate the number of people who can be served.
```

```

17 Set numberOfPeople = toInteger(ounces / OUNCES_PER_PERSON)
18
19 // Display the number of people who can be served.
20 Display "You can serve ", numberOfPeople, " people."

```

### Program Output (with Input Shown in Bold)

How many ounces of lemonade do you have?  
**165 [Enter]**  
 You can serve 20 people.

In this version of the program, line 17 has been rewritten as follows:

```
Set numberOfPeople = toInteger(ounces / OUNCES_PER_PERSON)
```

Let's see how this statement worked in the sample running of the program. When this statement executes, the math expression `ounces / OUNCES_PER_PERSON` is evaluated. The user entered 165 into the `ounces` variable, so this expression gives us the value 20.625. This value is then passed as an argument to the `toInteger` function. The `toInteger` function throws away the .625 part of the number and returns the integer 20. The integer 20 is then assigned to the `numberOfPeople` variable.

The `toInteger` function always throws away the fractional part of its argument. In this particular program it is acceptable to do this because you are calculating the number of people you can serve with the amount of available lemonade. Any fractional part that remains represents an amount of leftover lemonade that is not a full serving.

## Formatting Functions

Most programming languages provide one or more functions that format numbers in some way. A common use of formatting functions is to format numbers as currency amounts. In this book we will use a function named `currencyFormat` that accepts a `Real` number as an argument and returns a string containing the number formatted as a currency amount. The following pseudocode shows an example of how the `currencyFormat` function can be used.

```

Declare Real amount = 6450.879
Display currencyFormat(amount)

```

If this pseudocode were an actual program it would display:

\$6,450.88

Notice that the function displays a currency symbol (in this case a dollar sign), inserts commas where necessary, and rounds the number to two decimal places.



**NOTE:** Many programming languages today support *localization*, which means they can be configured for a specific country. In these languages a function such as `currencyFormat` would display the correct currency symbol for the country that the program is localized for.

## String Functions

Many types of programs work extensively with strings. For example, text editors like Notepad and word processors like Microsoft Word work almost entirely with strings. Web browsers also work heavily with strings. When a Web browser loads a Web page, it reads formatting instructions that are written into the text of the Web page.

Most programming languages provide several library functions for working with strings. This section discusses the most commonly supported string functions.

### The length Function

The `length` function returns the length of a string. It accepts a string as its argument and returns the number of characters in the string (the string's length). The value that is returned is an integer. The following pseudocode shows how the `length` function might be used. In this program segment, the length of a password is checked to make sure it is at least six characters long.

```
Display "Enter your new password."
Input password
If length(password) < 6 Then
 Display "The password must be at least six characters long."
End If
```

### The append Function

The `append` function accepts two strings as arguments, which we will refer to as `string1` and `string2`. It returns a third string that is created by appending `string2` to the end of `string1`. After the function executes, `string1` and `string2` will remain unchanged. The following pseudocode shows an example of its usage:

```
Declare String lastName = "Conway"
Declare String salutation = "Mr. "
Declare String properName
Set properName = append(salutation, lastName)
Display properName
```

If this pseudocode were an actual program, it would display:

Mr. Conway



**NOTE:** The process of appending one string to the end of another string is called *concatenation*.

### The `toUpperCase` and `toLowerCase` Functions

The `toUpperCase` and `toLowerCase` functions convert the case of the alphabetic characters in a string. The `toUpperCase` function accepts a string as an argument and returns a string that is a copy of the argument, but with all characters converted to uppercase. Any character that is already uppercase or is not an alphabetic letter is left unchanged. The following pseudocode shows an example of its usage:

```
Declare String str = "Hello World!"
Display toUpper(str)
```

If this pseudocode were an actual program, it would display:

```
HELLO WORLD!
```

The `toLower` function accepts a string as an argument and returns a string that is a copy of the argument, but with all characters converted to lowercase. Any character that is already lowercase or is not an alphabetic letter is left unchanged. The following pseudocode shows an example of its usage:

```
Declare String str = "WARNING!"
Display toLower(str)
```

If this pseudocode were an actual program, it would display:

```
warning!
```

The `toUpperCase` and `toLower` functions are useful for making case-insensitive string comparisons. Normally, string comparisons are *case-sensitive*, which means that the uppercase characters are distinguished from the lowercase characters. For example, in a case-sensitive comparison the string "hello" is not the same as the strings "HELLO" and "Hello" because the case of the characters is different. Sometimes it is more convenient to perform a *case-insensitive* comparison, in which the case of the characters is ignored. In a case-insensitive comparison, the string "hello" is considered the same as "HELLO" and "Hello".

For example, look at the following pseudocode:

```
Declare String again
Do
 Display "Hello!"
 Display "Do you want to see that again? (Y = Yes)"
 Input again
 While toUpper(again) == "Y"
```

The loop displays "Hello!" and then prompts the user to enter "Y" to see it again. The expression `toUpper(again) == "Y"` will be true if the user enters either "y" or "Y." Similar results can be achieved by using the `toLower` function, as shown here:

```
Declare String again
Do
 Display "Hello!"
 Display "Do you want to see that again? (Y = Yes)"
 Input again
 While toLower(again) == "y"
```

### The `substring` Function

This function returns a *substring*, which is a string within a string. The `substring` function typically accepts three arguments: (1) a string that you want to extract a substring from, (2) the beginning position of the substring, and (3) the ending position of the substring.

Each character in a string is identified by its position number. The first character in a string is at position 0, the second character is at position 1, and so forth. In the sample pseudocode below, the `substring` function returns the substring in positions 5 through 7 of the string "New York City".

```
Declare String str = "New York City"
Declare String search
Set search = substring(str, 5, 7)
Display search
```

If this pseudocode were an actual program, it would display:

ork

The `substring` function can also be used to extract individual characters from a string. For example, look at the following pseudocode:

```
Declare String name = "Kevin"
Display substring(name, 2, 2)
```

This code will display:

v

The function call `substring(name, 2, 2)` will return the substring that begins and ends at position 2. In this case, that's the substring "v". The pseudocode in Program 6-13 shows another example. This program prompts the user to enter a string, and then it counts the number of times the letter "T" appears in the string.

### Program 6-13

```
1 // Declare a variable to hold a string.
2 Declare String str
3
4 // Declare a variable to hold the number
5 // of Ts in a string.
6 Declare Integer numTs = 0
7
8 // Declare a counter variable.
9 Declare Integer counter
10
11 // Get a sentence from the user.
12 Display "Enter a string."
13 Input str
14
15 // Count the number of Ts in the string.
16 For counter = 0 To length(str)
17 If substring(str, counter, counter) == "T" Then
18 numTs = numTs + 1
19 End If
20 End For
21
22 // Display the number of Ts.
23 Display "That string contains ", numTs
24 Display "instances of the letter T."
```

### Program Output (with Input Shown in Bold)

```
Enter a string.
Ten Times I Told You To STOP! [Enter]
That string contains 5
instances of the letter T.
```

### The contains Function

The `contains` function accepts two strings as arguments. It returns `True` if the first string contains the second string; otherwise, the function returns `False`. For example, the following pseudocode determines whether the string "four score and seven years ago" contains the string "seven":

```
Declare string1 = "four score and seven years ago"
Declare string2 = "seven"
If contains(string1, string2) Then
 Display string2, " appears in the string."
Else
 Display string2, " does not appear in the string."
End If
```

If this were actual code in a program, it would display "seven appears in the string."

### The `stringToInteger` and `stringToReal` Functions

Strings are sequences of characters, and are meant to hold text items such as names, addresses, descriptions, and so on. You can also store numbers as strings. In a program, any time you put quotation marks around a number, it becomes a string instead of a number. For example, the following pseudocode declares a `String` variable named `interestRate` and initializes it with the string "4.3":

```
Declare String interestRate = "4.3"
```

Problems can arise when you store numbers as strings, however. Most of the things that you do with numbers, such as arithmetic and numeric comparisons, cannot be done with strings. Those types of operations can be done only with numeric data such as `Integers` and `Reals`.

Some programs must read data from a source that can provide input only as strings. This commonly happens with programs that read data from files. In addition, some programming languages allow you to read keyboard input only as strings. In these situations, numbers that are read as input initially come into the program as strings and then have to be converted to a numeric data type.

Most programming languages provide library functions that convert strings to numbers. The following pseudocode examples use the `stringToInteger` and `stringToReal` functions for this purpose. The `stringToInteger` function accepts a string as an argument, converts it to an `Integer`, and returns the `Integer` value. For example, suppose a program has a `String` variable named `str`, and an integer value has been stored as a string in this variable. The following statement converts the contents of the `str` variable to an `Integer` and stores it in the `intNumber` variable.

```
Set intNumber = stringToInteger(str)
```

The `stringToReal` function works the same way, but it converts a string to a `Real`. For example, suppose a real number has been stored as a string in the `String` variable named `str`. The following statement converts the contents of the `str` variable to a `Real` and stores it in the `realNumber` variable.

```
Set realNumber = stringToReal(str)
```

When you use a function such as these, there is always the possibility of an error. For example, look at the following pseudocode:

```
Set intNumber = stringToInteger("123abc")
```

Obviously, the string "123abc" cannot be converted to an `Integer` because it contains alphabetic characters. Here is another example that will cause an error:

```
Set realNumber = stringToReal("3.14.159")
```

The string "3.14.159" cannot be converted to a `Real` because it has two decimal points. Exactly what happens when these errors occur depends on the programming language.

### The `isInteger` and `isReal` Functions

To help prevent errors when converting strings to numbers, many programming languages provide library functions that test a string and then return either `True` or `False` indicating whether the string can successfully be converted to a number. The following pseudocode examples use the `isInteger` function to determine whether a string can be converted to an `Integer`, and the `isReal` function to determine whether a string can be converted to a `Real`. The following example uses the `isInteger` function. Assume `str` is a `String` and `intNumber` is an `Integer`.

```
If isInteger(str) Then
 Set intNumber = stringToInteger(str)
Else
 Display "Invalid data"
End If
```

The `isReal` function works the same way, as shown in the following example (assume `str` is a `String` and `realNumber` is an `Integer`).

```
If isReal(str) Then
 Set realNumber = stringToReal(str)
Else
 Display "Invalid data"
End If
```

6.4

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

#### Value-Returning Methods

##### Generating Random Integers in Java

To generate random numbers in Java you create a type of object in memory known as a `Random` object. You can then use the `Random` object to generate random numbers. First, you write the following statement at the top of your program:

```
import java.util.Random;
```

Then, at the point where you wish to create the `Random` object you write a statement like this:

```
Random randomNumbers = new Random();
```

This statement creates a `Random` object in memory and gives it the name `randomNumbers`. (You can give the object any name that you wish. We simply chose `randomNumbers` for this one.) Once you've created a `Random` object, you can use it to call a value-returning method named `nextInt`, which returns a random integer number. A `Random` object's `nextInt` method is similar to the `random` library function that is discussed in your textbook. The following code snippet shows an example of how to use it:

```
int number;
number = randomNumbers.nextInt(10);
```

In this example, we are passing the argument 10 to the `randomNumbers.nextInt` method. This causes the method to return a random integer in the range of 0 through 9. The argument that we pass to the method is the upper limit of the range, but is not included in the range. In the code snippet, we are assigning the random number to the `number` variable. Here is an example of how we would generate a random number in the range of 1 through 100:

```
int number;
number = randomNumbers.nextInt(100) + 1;
```

In this example, we are passing the argument 100 to the `randomNumbers.nextInt` method. This generates a random integer in the range of 0 through 99. Then we add 1 to that number, thus causing it to be in the range of 1 through 100, and assigning the result to the `number` variable.

### **Writing Your Own Value-Returning Methods in Java**

When you are writing a value-returning method, you must decide what type of value the method will return. This is because, instead of specifying `void` in the method header, you must specify the data type of the return value. A value-returning method will use `int`, `double`, `String`, `boolean`, or any other valid data type in its header. Here is an example of a method that returns an `int` value:

```
public static int sum(int num1, int num2)
{
 int result;
 result = num1 + num2;
 return result;
}
```

The name of this method is `sum`. Notice in the method header that instead of the word `void` we have specified `int` as the return type. This code defines a method named `sum` that accepts two `int` arguments. The arguments are passed into the parameter variables `num1` and `num2`. Inside the method, a local variable, `result`, is declared. The parameter variables `num1` and `num2` are added, and their sum is assigned to the `result` variable. The last statement in the method is:

```
return result;
```

You must have a `return` statement in a value-returning method. It causes the method to end execution and it returns a value to the statement that called the method. In a value-returning method, the general format of the `return` statement is as follows:

```
return Expression;
```

*Expression* is the value to be returned. It can be any expression that has a value, such as a variable, literal, or mathematical expression. In this case, the `sum` method returns the value of the `result` variable. The following code snippet shows how we might call the `sum` method:

```
int total;
total = sum(2, 3);
```

After this code executes, the value of the `total` variable will be 5.

### Returning a String from a Java Method

The following code shows an example of how a method can return string. Notice that the method header specifies `String` as the return type. This method accepts two string arguments (a person's first name and last name). It combines those two strings into a string that contains the person's full name. The full name is then returned.

```
public static String fullName(String firstName, String lastName)
{
 String name;

 name = firstName + " " + lastName;
 return name;
}
```

The following code snippet shows how we might call the method:

```
String customerName;
customerName = fullName("John", "Martin");
```

After this code executes, the value of the `customerName` variable will be “John Martin”.

### Returning a boolean Value from a Java Method

Methods can also return `boolean` values. The following method accepts an argument and returns `true` if the argument is within the range of 1 through 100, or `false` otherwise:

```
public static boolean isValid(int number)
{
 boolean status;

 if (number >= 1 && number <= 100)
 status = true;
 else
 status = false;
 return status;
}
```

The following code shows an `if-else` statement that uses a call to the method:

```
int value = 20;

if (isValid(value))
 System.out.println("The value is within range.");
else
 System.out.println("The value is out of range.");
```

When this code executes, the message “The value is within range.” will be displayed.

## Python

### Value-Returning Functions

#### Generating Random Integers in Python

Python provides several library functions for working with random numbers. To use any of these functions, you first need to write this `import` statement at the top of your program:

```
import random
```

The first random-number generating function that we will discuss is `random.randint`. The following statement shows an example of how you might call the `random.randint` function.

```
number = random.randint(1, 100)
```

The part of the statement that reads `random.randint(1, 100)` is a call to the function. Notice that two arguments appear inside the parentheses: 1 and 100. These arguments tell the function to give an integer random number in the range of 1 through 100. (The values 1 and 100 are included in the range.) When the function is called, it will generate a random number in the range of 1 through 100 and then *return* that number. The number that is returned will be assigned to the `number` variable.

#### Writing Your Own Value-Returning Functions in Python

In Python, you write a value-returning function in the same way that you write a simple function, with one exception: a value-returning function must have a `return` statement. Here is the general format of a value-returning function definition in Python:

```
def function_name():
 statement
 statement
 etc.
 return expression
```

One of the statements in the function must be a `return` statement, which takes the following form:

```
return expression
```

The value of the `expression` that follows the key word `return` will be sent back to the part of the program that called the function. This can be any value, variable, or expression that has a value (such as a math expression). Here is a simple example of a value-returning function:

```
def sum(num1, num2):
 result = num1 + num2
 return result
```

The purpose of this function is to accept two integer values as arguments and return their sum. The first statement in the function's block assigns the value of `num1 + num2` to the `result` variable. Next, the `return` statement executes, which causes the function to end execution and sends the value of the `result` variable back to the part of the program that called the function. The following statement shows how we might call the `sum` function:

```
total = sum(2, 3)
```

After this code executes, the value assigned to the `total` variable will be 5.

### Returning a String from a Python Function

So far you've seen examples of functions that return numbers. You can also write functions that return strings. For example, the following function prompts the user to enter their name, and then returns the string that the user entered.

```
def get_name():
 # Get the user's name.
 name = input('Enter your name: ')

 # Return the name.
 return name
```

### Returning a Boolean Value from a Python Function

Python allows you to write *Boolean functions*, which return either `True` or `False`. For example, the following function accepts a number as an argument, and returns `True` if the argument is an even number. Otherwise, it returns `False`.

```
def is_even(number):
 # Determine whether number is even. If it is,
 # set status to true. Otherwise, set status
 # to false.
 if (number % 2) == 0:
 status = True
 else:
 status = False

 # Return the value of the status variable.
 return status
```

The following code gets a number from the user, and then calls the function to determine whether the number is even or odd:

```
value = int(input('Enter a number: '))
if is_even(value):
 print('The number is even.')
else:
 print('The number is odd.')
```

## C++

### Value-Returning Functions

#### Generating Random Integers in C++

The C++ library provides a value-returning function named `rand()` that returns a random number. (The `rand()` function requires the directive `#include <cstdlib>`). The random number that is returned from the `rand()` function is an `int`. Here is an example of its usage:

```
y = rand();
```

After this statement executes, the variable `y` will contain a random number. In actuality, the numbers produced by `rand()` are pseudorandom. The function uses an algorithm that produces the same sequence of numbers each time the program is repeated on the same system. For example, suppose the following statements are executed:

```
cout << rand() << endl;
cout << rand() << endl;
cout << rand() << endl;
```

The three numbers displayed will appear to be random, but each time the program runs, the same three values will be generated. In order to randomize the results of `rand()`, the `srand()` function must be used. The `srand()` function accepts an `unsigned int` argument, which acts as a seed value for the algorithm. By specifying different seed values, `rand()` will generate different sequences of random numbers.

A common practice for getting unique seed values is to call the `time()` function, which is part of the C++ standard library. The `time()` function returns the number of seconds that have elapsed since midnight, January 1, 1970. The `time()` function requires the directive `#include <ctime>`. When you call the `time()` function, you pass 0 as an argument. The following code snippet shows an example:

```
// Get the system time.
unsigned seed = time(0);

// Seed the random number generator.
srand(seed);

// Display a random number.
cout << rand() << endl;
```

If you wish to limit the range of the random number, use the following formula:

```
y = 1 + rand() % maxRange;
```

The `maxRange` value is the upper limit of the range. For example, if you wish to generate a random number in the range of 1 through 100, use the following statement:

```
y = 1 + rand() % 100;
```

This is how the statement works: Look at the following expression:

```
rand() % 100
```

Assuming `rand()` returns 37894, the value of the expression above is 94. That is because 37894 divided by 100 is 378 with a remainder of 94. (The modulus operator returns the remainder.) But, what if `rand()` returns a number that is evenly divisible by 100, such as 500? The expression above will return a 0. If we want a number in the range 1–100, we must add 1 to the result. That is why we use the expression `1 + rand() % 100`.

### **Writing Your Own Value-Returning Functions in C++**

When you are writing a value-returning function in C++, you must decide what type of value the function will return. This is because, instead of specifying `void` in the function header, you must specify the data type of the value that will be returned.

A value-returning function will use `int`, `double`, `string`, `bool`, or any other valid data type in its header. Here is an example of a function that returns an `int` value:

```
int sum(int num1, int num2)
{
 int result;
 result = num1 + num2;
 return result;
}
```

The name of this function is `sum`. Notice in the function header that instead of the word `void` we have specified `int` as the return type. This code defines a function named `sum` that accepts two `int` arguments. The arguments are passed into the parameter variables `num1` and `num2`. Inside the function, a local variable, `result`, is declared. The parameter variables `num1` and `num2` are added, and their sum is assigned to the `result` variable. The last statement in the function is as follows:

```
return result;
```

You must have a `return` statement in a value-returning function. It causes the function to end execution and it returns a value to the statement that called the function. In a value-returning function, the general format of the `return` statement is as follows:

```
return Expression;
```

*Expression* is the value to be returned. It can be any expression that has a value, such as a variable, literal, or mathematical expression. In this case, the `sum` function returns the value of the `result` variable. The following code snippet shows how we might call the `sum` function:

```
int total;
total = sum(2, 3);
```

After this code executes, the value of the `total` variable will be 5.

### Returning a String from a C++ Function

The following code shows an example of how a function can return `string`. Notice that the function header specifies `string` as the return type. This function accepts two `string` arguments (a person's first name and last name). It combines those two strings into a `string` that contains the person's full name. The full name is then returned.

```
string fullName(string firstName, string lastName)
{
 string name;

 name = firstName + " " + lastName;
 return name;
}
```

The following code snippet shows how we might call the function:

```
string customerName;
customerName = fullName("John", "Martin");
```

After this code executes, the value of the `customerName` variable will be "John Martin".

### Returning a bool Value from a C++ Function

Functions can also return `bool` values. The following function accepts an argument and returns `true` if the argument is within the range of 1 through 100, or `false` otherwise:

```
bool isValid(int number)
{
 bool status;

 if (number >= 1 && number <= 100)
 status = true;
 else
 status = false;

 return status;
}
```

The following code shows an `if-else` statement that uses a call to the function:

```
int value = 20;

if (isValid(value))
 cout << "The value is within range." << endl;
else
 cout << "The value is out of range." << endl;
```

When this code executes, the message “The value is within range.” will be displayed.

## Review Questions

### Multiple Choice

1. This is a prewritten function that is built into a programming language.
  - a. standard function
  - b. library function
  - c. custom function
  - d. cafeteria function
2. This term describes any mechanism that accepts input, performs some operation that cannot be seen on the input, and produces output.
  - a. glass box
  - b. white box
  - c. opaque box
  - d. black box

3. This part of a function definition specifies the data type of the value that the function returns.
  - a. header
  - b. footer
  - c. body
  - d. `Return` statement
4. This part of a function definition is comprised of one or more statements that are executed when the function is called.
  - a. header
  - b. footer
  - c. body
  - d. `Return` statement
5. In pseudocode, this statement causes a function to end and sends a value back to the part of the program that called the function.
  - a. `End`
  - b. `Send`
  - c. `Exit`
  - d. `Return`
6. This is a design tool that describes the input, processing, and output of a function.
  - a. hierarchy chart
  - b. IPO chart
  - c. datagram chart
  - d. data processing chart
7. This type of function returns either `True` or `False`.
  - a. Binary
  - b. `TrueFalse`
  - c. Boolean
  - d. logical
8. This is an example of a data type conversion function in pseudocode.
  - a. `sqrt`
  - b. `toReal`
  - c. `substring`
  - d. `isNumeric`
9. This type of error occurs when you try to assign a value of one data type to a variable of another data type.
  - a. type mismatch error
  - b. Boolean logic error
  - c. relational error
  - d. bit conversion error
10. This is a string inside of another string.
  - a. substring
  - b. inner string
  - c. mini string
  - d. component string

**True or False**

1. The code for a library function must appear in a program in order for the program to call the library function.
2. Complex mathematical expressions can sometimes be simplified by breaking out part of the expression and putting it in a function.
3. In many languages it is an error to assign a real number to an integer variable.
4. In some languages you must use a library function to raise a number to a power.
5. In a case-sensitive comparison, the strings "yoda" and "YODA" are equivalent.

**Short Answer**

1. What is the difference between a module and a function?
2. What three characteristics of a function are described in an IPO chart?
3. When a conversion function is used to convert a real number to an integer, what usually happens to the real number's fractional part?
4. What is a substring?
5. What is the purpose of the `stringToInteger` and `stringToReal` functions described in this chapter?
6. What is the purpose of the `isInteger` and `isReal` functions described in this chapter?

**Algorithm Workbench**

1. As shown in this chapter, write a pseudocode statement that generates a random number in the range of 1 through 100 and assigns it to a variable named `rand`.
2. The following pseudocode statement calls a function named `half`, which returns a value that is half that of the argument. (Assume both the `result` and `number` variables are `Real`.) Write pseudocode for the function.

```
Set result = half(number)
```

3. A pseudocode program contains the following function definition:

```
Function Integer cube(Integer num)
 Return num * num * num
End Function
```

Write a statement that passes the value 4 to this function and assigns its return value to the variable `result`.

4. Design a pseudocode function named `timesTen` that accepts an `Integer` argument. When the function is called, it should return the value of its argument multiplied times 10.
5. Design a pseudocode function named `getFirstName` that asks the user to enter their first name, and returns it.
6. Assume that a program has two `String` variables named `str1` and `str2`. Write a pseudocode statement that assigns an all uppercase version of `str1` to the `str2` variable.

## Debugging Exercises

1. The programmer intends for this pseudocode to display three random numbers in the range of 1 through 7. According to the way we've been generating random numbers in this book, however, there appears to be an error. Can you find it?

```
// This program displays three random numbers
// in the range of 1 through 7.
Declare Integer count

// Display three random numbers.
For count = 1 To 3
 Display random(7, 1)
End For
```

2. Can you find the reason that the following pseudocode function does not return the value indicated in the comments?

```
// The calcDiscountPrice function accepts an item's price and
// the discount percentage as arguments. It uses those
// values to calculate and return the discounted price.
Function Real calcDiscountPrice(Real price, Real percentage)
 // Calculate the discount.
 Declare Real discount = price * percentage

 // Subtract the discount from the price.
 Declare Real discountPrice = price - discount

 // Return the discount price.
 Return discount
End Function
```

3. Can you find the reason that the following pseudocode does not perform as indicated in the comments?

```
// Find the error in the following pseudocode.
Module main()
 Declare Real value, result

 // Get a value from the user.
 Display "Enter a value."
 Input value

 // Get 10 percent of the value.
 Call tenPercent(value)

 // Display 10 percent of the value.
 Display "10 percent of ", value, " is ", result
End Module

// The tenPercent function returns 10 percent
// of the argument passed to the function.
Function Real tenPercent(Real num)
 Return num * 0.1
End Function
```



VideoNote

The Rectangle Area Problem

## Programming Exercises

### 1. Rectangle Area

The area of a rectangle is calculated according to the following formula:

$$\text{Area} = \text{Width} \times \text{Length}$$

Design a function that accepts a rectangle's width and length as arguments and returns the rectangle's area. Use the function in a program that prompts the user to enter the rectangle's width and length, and then displays the rectangle's area.

### 2. Feet to Inches

One foot equals 12 inches. Design a function named `feetToInches` that accepts a number of feet as an argument, and returns the number of inches in that many feet. Use the function in a program that prompts the user to enter a number of feet and then displays the number of inches in that many feet.

### 3. Math Quiz

Design a program that gives simple math quizzes. The program should display two random numbers that are to be added, such as:

$$\begin{array}{r} 247 \\ + 129 \\ \hline \end{array}$$

The program should allow the student to enter the answer. If the answer is correct, a message of congratulations should be displayed. If the answer is incorrect, a message showing the correct answer should be displayed.

### 4. Maximum of Two Values

Design a function named `max` that accepts two integer values as arguments and returns the value that is the greater of the two. For example, if 7 and 12 are passed as arguments to the function, the function should return 12. Use the function in a program that prompts the user to enter two integer values. The program should display the value that is the greater of the two.

### 5. Falling Distance

When an object is falling because of gravity, the following formula can be used to determine the distance the object falls in a specific time period:

$$d = \frac{1}{2} gt^2$$

The variables in the formula are as follows:  $d$  is the distance in meters,  $g$  is 9.8, and  $t$  is the amount of time, in seconds, that the object has been falling.

Design a function named `fallingDistance` that accepts an object's falling time (in seconds) as an argument. The function should return the distance, in meters, that the object has fallen during that time interval. Design a program that calls the function in a loop that passes the values 1 through 10 as arguments and displays the return value.

### 6. Kinetic Energy

In physics, an object that is in motion is said to have kinetic energy. The following formula can be used to determine a moving object's kinetic energy:

$$KE = \frac{1}{2} mv^2$$

The variables in the formula are as follows:  $KE$  is the kinetic energy,  $m$  is the object's mass in kilograms, and  $v$  is the object's velocity, in meters per second.

Design a function named `kineticEnergy` that accepts an object's mass (in kilograms) and velocity (in meters per second) as arguments. The function should return the amount of kinetic energy that the object has. Design a program that asks the user to enter values for mass and velocity, and then calls the `kineticEnergy` function to get the object's kinetic energy.

## 7. Test Average and Grade

Write a program that asks the user to enter five test scores. The program should display a letter grade for each score and the average test score. Design the following functions in the program:

- `calcAverage`—This function should accept five test scores as arguments and return the average of the scores.
- `determineGrade`—This function should accept a test score as an argument and return a letter grade for the score (as a `String`), based on the following grading scale:

| Score    | Letter Grade |
|----------|--------------|
| 90–100   | A            |
| 80–89    | B            |
| 70–79    | C            |
| 60–69    | D            |
| Below 60 | F            |

## 8. Odd/Even Counter

In this chapter you saw an example of how to design an algorithm that determines whether a number is even or odd (see *Returning Boolean Values* in Section 6.2). Design a program that generates 100 random numbers, and keeps a count of how many of those random numbers are even and how many are odd.

## 9. Guess the Number

Design a number guessing game program. The program should generate a random number and then ask the user to guess the number. Each time the user enters their guess, the program should indicate whether it was too high or too low. The game is over when the user correctly guesses the number. When the game ends, the program should display the number of guesses that the user made.

## 10. Prime Numbers

A prime number is a number that is only evenly divisible by itself and 1. For example, the number 5 is prime because it can only be evenly divided by 1 and 5. The number 6, however, is not prime because it can be divided evenly by 1, 2, 3, and 6.

Design a Boolean function named `isPrime`, which takes an integer as an argument and returns `True` if the argument is a prime number, or `False` otherwise. Use the function in a program that prompts the user to enter a number and then displays a message indicating whether the number is prime.



**TIP:** Recall that the MOD operator divides one number by another and returns the remainder of the division. In an expression such as `num1 MOD num2`, the MOD operator will return 0 if `num1` is evenly divisible by `num2`.

### 11. Prime Number List

This exercise assumes you have already designed the `isPrime` function in Programming Exercise 10. Design another program that displays all of the prime numbers from 1 through 100. The program should have a loop that calls the `isPrime` function.

### 12. Rock, Paper, Scissors Game

Design a program that lets the user play the game of Rock, Paper, Scissors against the computer. The program should work as follows:

- (1) When the program begins, a random number in the range of 1 through 3 is generated. If the number is 1, then the computer has chosen rock. If the number is 2, then the computer has chosen paper. If the number is 3, then the computer has chosen scissors. (Don't display the computer's choice yet.)
- (2) The user enters their choice of "rock," "paper," or "scissors" at the keyboard.
- (3) The computer's choice is displayed.
- (4) The program should display a message indicating whether the user or the computer was the winner. A winner is selected according to the following rules:
  - If one player chooses rock and the other player chooses scissors, then rock wins. (The rock smashes the scissors.)
  - If one player chooses scissors and the other player chooses paper, then scissors wins. (Scissors cut paper.)
  - If one player chooses paper and the other player chooses rock, then paper wins. (Paper wraps rock.)
  - If both players make the same choice, the game must be played again to determine the winner.

### 13. Slot Machine Simulation

A slot machine is a gambling device that the user inserts money into and then pulls a lever (or presses a button). The slot machine then displays a set of random images. If two or more of the images match, the user wins an amount of money, which the slot machine dispenses back to the user.

Design a program that simulates a slot machine. When the program runs, it should do the following:

- Ask the user to enter the amount of money they want to insert into the slot machine.
- Instead of displaying images, the program will randomly select a word from the following list:

*Cherries, Oranges, Plums, Bells, Melons, Bars*

- The program will select and display a word from this list three times.

- If none of the randomly selected words match, the program will inform the user that they have won \$0. If two of the words match, the program will inform the user that they have won two times the amount entered. If three of the words match, the program will inform the user that they have won three times the amount entered.
- The program will ask whether the user wants to play again. If so, these steps are repeated. If not, the program displays the total amount of money entered into the slot machine and the total amount won.

#### 14. ESP Game

Design a program that tests your ESP, or extrasensory perception. The program will randomly pick a color, and you will be asked to predict the program's selection before it is revealed. Design the program to randomly select one of the following words:

*Red, Green, Blue, Orange, Yellow*

To select a word, the program can generate a random number. For example, if the number is 0, the selected word is Red, if the number is 1, the selected word is Green, and so forth.

Next, the program should ask the user to enter the color that the computer has selected. After the user has entered their guess, the program should display the name of the randomly selected color. The program should repeat this 10 times and then display the number of times the user correctly guessed the selected color.

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## TOPICS

- 7.1 Garbage In, Garbage Out
- 7.2 The Input Validation Loop

- 7.3 Defensive Programming
- 7.4 Focus on Languages: Java, Python, and C++

## 7.1

## Garbage In, Garbage Out

**CONCEPT:** If a program reads bad data as input, it will produce bad data as output. Programs should be designed to reject bad data that is given as input.

One of the most famous sayings among computer programmers is “garbage in, garbage out.” This saying, sometimes abbreviated as *GIGO*, refers to the fact that computers cannot tell the difference between good data and bad data. If a user provides bad data as input to a program, the program will process that bad data and, as a result, will produce bad data as output. For example, look at the pseudocode for the payroll program in Program 7-1 and notice what happens in the sample run when the user gives bad data as input.

## Program 7-1

```
1 // Variables to hold the hours worked, the
2 // hourly pay rate, and the gross pay.
3 Declare Real hours, payRate, grossPay
4
5 // Get the number of hours worked.
6 Display "Enter the number of hours worked."
7 Input hours
8
9 // Get the hourly pay rate.
10 Display "Enter the hourly pay rate."
11 Input payRate
```

```
12
13 // Calculate the gross pay.
14 Set grossPay = hours * payRate
15
16 // Display the gross pay.
17 Display "The gross pay is", currencyFormat(grossPay)
```

### Program Output (with Input Shown in Bold)

Enter the number of hours worked.

400 [Enter]

Enter the hourly pay rate.

20 [Enter]

The gross pay is \$8,000.00

Did you spot the bad data that was provided as input? The person receiving the paycheck will be pleasantly surprised, because in the sample run the payroll clerk entered 400 as the number of hours worked. The clerk probably meant to enter 40, because there are not 400 hours in a week. The computer, however, is unaware of this fact, and the program processed the bad data just as if it were good data. Can you think of other types of input that can be given to this program that will result in bad output? One example is a negative number entered for the hours worked; another is an invalid hourly pay rate.

Sometimes stories are reported in the news about computer errors that mistakenly cause people to be charged thousands of dollars for small purchases or to receive large tax refunds that they were not entitled to. These “computer errors” are rarely caused by the computer, however; they are more commonly caused by software bugs or bad data that was read into a program as input.

The integrity of a program’s output is only as good as the integrity of its input. For this reason, you should design your programs in such a way that bad input is never accepted. When input is given to a program, it should be inspected before it is processed. If the input is invalid, the program should discard it and prompt the user to enter the correct data. This process is known as *input validation*. This chapter discusses techniques that you can use to validate data before it is processed.



### Checkpoint

7.1 What does the phrase “garbage in, garbage out” mean?

7.2 Give a general description of the input validation process.

7.2

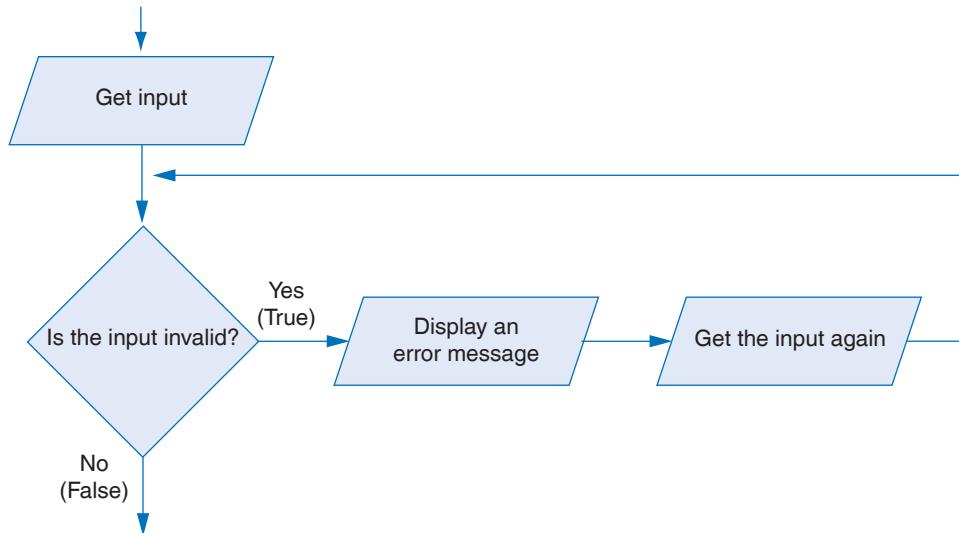
## The Input Validation Loop

**CONCEPT:** Input validation is commonly done with a loop that iterates as long as an input variable contains bad data.

Figure 7-1 shows a common technique for validating an item of input. In this technique, the input is read, and then a pretest loop is executed. If the input data is invalid, the

body of the loop executes. The loop displays an error message so the user will know that the input was invalid, and then the loop reads the new input. The loop repeats as long as the input is invalid.

**Figure 7-1** Logic containing an input validation loop



Notice that the flowchart in Figure 7-1 reads input in two places: first just before the loop and then inside the loop. The first input operation—just before the loop—is called a *priming read*, and its purpose is to get the first input value that will be tested by the validation loop. If that value is invalid, the loop will perform subsequent input operations.



Let's consider an example. Suppose you are designing a program that reads a test score and you want to make sure the user does not enter a value less than 0. The following pseudocode shows how you can use an input validation loop to reject any input value that is less than 0.

```

// Get a test score.
Display "Enter a test score."
Input score

// Make sure it is not less than 0.
While score < 0
 Display "ERROR: The score cannot be less than 0."
 Display "Enter the correct score."
 Input score
End While

```

This pseudocode first prompts the user to enter a test score (this is the priming read), and then the `While` loop executes. Recall from Chapter 4 that the `While` loop is a pretest loop, which means it tests the expression `score < 0` before performing an iteration. If the user entered a valid test score, this expression will be false and the loop will not iterate. If the test score is invalid, however, the expression will be true and the statements in the body of the loop will execute. The loop displays an error message and prompts the user to enter the correct test score. The loop will continue to iterate until the user enters a valid test score.



**NOTE:** An input validation loop, such as the one in Figure 7-1, is sometimes called an *error trap* or an *error handler*.

This pseudocode only rejects negative test scores. What if you also want to reject any test scores that are greater than 100? You can modify the input validation loop so it uses a compound Boolean expression, as shown next.

```
// Get a test score.
Display "Enter a test score."
Input score
// Validate the test score.
While score < 0 OR score > 100
 Display "ERROR: The score cannot be less than 0"
 Display "or greater than 100."
 Display "Enter the correct score."
 Input score
End While
```

The loop in this pseudocode determines whether `score` is less than 0 or greater than 100. If either is true, an error message is displayed and the user is prompted to enter a correct score.



**NOTE:** This pseudocode used the OR operator to determine whether `score` was outside the range. Think about what would happen if this Boolean expression used the AND operator instead:

```
score < 0 AND score > 100
```

This expression would never be true because it is impossible for a number to be less than 0 AND greater than 100!

## In the Spotlight: Designing an Input Validation Loop



In Chapter 4 you saw a program that your friend Samantha can use to calculate the retail price of an item in her import business (see Program 4-5 in Chapter 4). Samantha has encountered a problem when using the program, however. Some of the items that she sells have a wholesale cost of 50 cents, which she enters into the program as 0.50. Because the 0 key is next to the key for the negative sign, she sometimes accidentally enters a negative number. She has asked you to revise the program so it will not allow a negative number to be entered for the wholesale cost.

You decide to add an input validation loop to the `showRetail` module that rejects any negative numbers that are entered into the `wholesale` variable. Program 7-2 shows the new pseudocode, with the new input validation code shown in lines 28 through 33.

Figure 7-2 shows a new flowchart for the `showRetail` module.

### Program 7-2

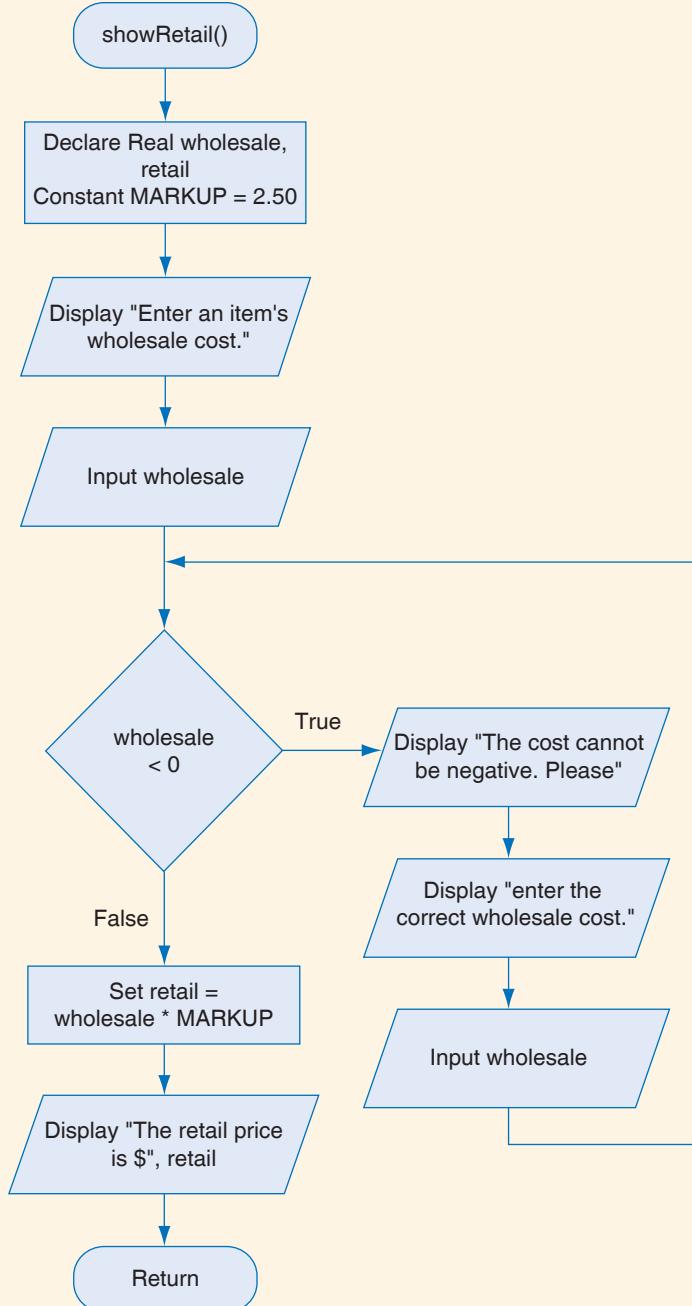


```
1 Module main()
2 // Local variable
```

```
3 Declare String doAnother
4
5 Do
6 // Calculate and display a retail price.
7 Call showRetail()
8
9 // Do this again?
10 Display "Do you have another item? (Enter y for yes.)"
11 Input doAnother
12 While doAnother == "y" OR doAnother == "Y"
13 End Module
14
15 // The showRetail module gets an item's wholesale cost
16 // from the user and displays its retail price.
17 Module showRetail()
18 // Local variables
19 Declare Real wholesale, retail
20
21 // Constant for the markup percentage
22 Constant Real MARKUP = 2.50
23
24 // Get the wholesale cost.
25 Display "Enter an item's wholesale cost."
26 Input wholesale
27
28 // Validate the wholesale cost.
29 While wholesale < 0
30 Display "The cost cannot be negative. Please"
31 Display "enter the correct wholesale cost."
32 Input wholesale
33 End While
34
35 // Calculate the retail price.
36 Set retail = wholesale * MARKUP
37
38 // Display the retail price.
39 Display "The retail price is $", retail
40 End Module
```

### Program Output (with Input Shown in Bold)

```
Enter an item's wholesale cost.
-0.50 [Enter]
The cost cannot be negative. Please
enter the correct wholesale cost.
0.50 [Enter]
The retail price is $1.25
Do you have another item? (Enter y for yes.)
n [Enter]
```

**Figure 7-2** Flowchart for the showRetail module

## Using a Posttest Loop to Validate Input

You might be wondering whether you could use a posttest loop to validate input instead of using the priming read. For example, the pseudocode to get a test score and validate it could be written as follows with a Do-While loop.

```
Do
 Display "Enter a test score."
 Input score
 While score < 0 OR score > 100
```

Although this logic will work, it does not display an error message when the user enters an invalid value—it simply repeats the original prompt each time the loop iterates. This might be confusing to the user, so it is usually better to have a priming read followed by a pretest validation loop.

## Writing Validation Functions

The input validation examples shown so far have been simple and straightforward. You have seen how to write validation loops that reject both negative numbers and numbers that are outside of a range. However, input validation can sometimes be more complex than these examples.

For instance, suppose you are designing a program that prompts the user to enter a product model number and should only accept the values 100, 200, and 300. You could design the input algorithm as follows:

```
// Get the model number.
Display "Enter the model number."
Input model

While model != 100 AND model != 200 AND model != 300
 Display "The valid model numbers are 100, 200, and 300."
 Display "Enter a valid model number."
 Input model
End While
```

The validation loop uses a long compound Boolean expression that will iterate as long as `model` does not equal 100 AND `model` does not equal 200 AND `model` does not equal 300. Although this logic will work, you can simplify the validation loop by writing a Boolean function to test the `model` variable and then calling that function in the loop. For example, suppose you pass the `model` variable to a function you write named `isValid`. The function returns `True` if `model` is invalid, or `False` otherwise. You could rewrite the validation loop as follows:

```
// Get the model number.
Display "Enter the model number."
Input model

While isValid(model)
 Display "The valid model numbers are 100, 200, and 300."
 Display "Enter a valid model number."
 Input model
End While
```

This makes the loop easier to read. It is evident now that the loop iterates as long as `model` is invalid. The following pseudocode shows how you might design the `isValid` function. It accepts a model number as an argument, and if the argument is not 100 AND the argument is not 200 AND the argument is not 300, the function returns `True` to indicate that it is invalid. Otherwise, the function returns `False`.

```

Function Boolean isValid(Integer model)
 // A local variable to hold True or False.
 Declare Boolean status

 // If the model number is invalid, set status to True.
 // Otherwise, set status to False.
 If model != 100 AND model != 200 AND model != 300 Then
 Set status = True
 Else
 Set status = False
 End If

 // Return the test status.
 Return status
End Function

```

## Validating String Input

In some programs you must validate string input. For example, suppose you are designing a program that asks a yes/no question, and you want to make sure that only the strings "yes" and "no" are accepted as valid input. The following pseudocode shows how this might be done.

```

// Get the answer to the question.
Display "Is your supervisor an effective leader?"
Input answer
// Validate the input.
While answer != "yes" AND answer != "no"
 Display "Please answer yes or no. Is your supervisor an"
 Display "effective leader?"
 Input answer
End While

```

This input validation loop rejects any input except the strings "yes" and "no". This particular design might be too rigid, however; as it is written, the loop performs a case-sensitive comparison. This means that strings such as "YES", "NO", "Yes", and "NO" will be rejected. To make the program more convenient for users, the program should accept "yes" and "no" written in any combination of upper- or lowercase letters. Recall from Chapter 6 that library functions such as `toUpperCase` and `toLowerCase` can help make case-insensitive string comparisons. The following pseudocode shows an example using the `toLowerCase` function.

```

// Get the answer to the question.
Display "Is your supervisor an effective leader?"
Input answer
// Validate the input.
While toLowerCase(answer) != "yes" AND toLowerCase(answer) != "no"
 Display "Please answer yes or no. Is your supervisor an"
 Display "effective leader?"
 Input answer
End While

```

Sometimes the length of a string plays a role in the string's validity. For example, you have probably used a Web site or other system that required you to set up a password. Some systems require that passwords have a minimum number of characters. The length

of a string, you use the `length` function discussed in Chapter 6. In the following pseudo-code, the `length` function is used to make sure a password is at least six characters long.

```
// Get the new password.
Display "Enter your new password."
Input password
// Validate the length of the password.
While length(password) < 6
 Display "The password must be at least six"
 Display "characters long. Enter your new password."
 Input password
End While
```



## Checkpoint

- 7.3 Describe the steps that are generally taken when an input validation loop is used to validate data.
- 7.4 What is a priming read? What is its purpose?
- 7.5 If the input that is read by the priming read is valid, how many times will the input validation loop iterate?

7.3

## Defensive Programming

**CONCEPT:** Input validation is part of the practice of defensive programming. Thorough input validation anticipates both obvious and unobvious errors.

*Defensive programming* is the practice of anticipating errors that can happen while a program is running, and designing the program to avoid those errors. All of the input validation algorithms examined in this chapter are examples of defensive programming.

Some types of input errors are obvious and easily handled. For example, you should make sure that negative numbers are not entered for items such as prices and test scores. Some types of input errors are not so obvious, however. One example of such an error is reading *empty input*, which happens when an input operation attempts to read data, but there is no data to read. This occurs when an `Input` statement executes and the user simply presses the `[Enter]` key without typing a value. Although different programming languages handle the problem of empty input in different ways, there is often a way to determine whether an input operation failed to read data.

Another often overlooked type of error is the entry of the wrong type of data. This happens, for example, when a program attempts to read an integer but the user enters a real number or a string. Most programming languages provide library functions that you can use to avoid this type of error. Quite often you will find functions similar to the `isInteger` and `isReal` functions discussed in Chapter 6. To use these functions in an input validation algorithm, you typically follow these steps:

1. Read the input as a string.
2. Determine whether the string can be converted to the desired data type.

3. If the string can be converted, convert it and continue processing; otherwise, display an error message and attempt to read the data again.

Thorough input validation also requires that you check for accurate data. Even when the user provides the right type of data, it might not be accurate. Consider the following examples:

- When the user enters a U.S. address, the state abbreviation should be checked to make sure it is a two-character string and also a valid U.S. Postal Service abbreviation. For example, there is no U.S. state with the abbreviation NW. Similar validations can be performed on international addresses. For example, Canadian province abbreviations are two-character strings.
- When the user enters a U.S. address, the value entered as the ZIP code should be checked to verify that it is both in the correct format (a 5- or 9-digit number) and a valid U.S. Postal Service ZIP code. For example, 99999 is not currently a valid U.S. ZIP code. In addition, ZIP codes should be valid for the state that is entered. (Databases of valid ZIP codes are readily available for a small fee. Programmers usually purchase one of these and use it in the validation process.)
- Hourly wages and salary amounts should be checked to make sure they are numeric values and within the range of allowable wages established by the company.
- Dates should be checked for validity. For example, the date February 29 should be accepted only in leap years, and invalid dates such as February 30 should never be accepted.
- Time measurements should also be checked for validity. For example, there are 168 hours in a week, so a payroll program should verify that no value greater than 168 is entered for the number of hours worked in a week.
- Reasonableness should also be considered when validating data. Even though there are 168 hours in a week, it is improbable that any employee ever works 24 hours a day, 7 days a week. Dates should also be checked for reasonableness. For example, a birth date can't be in the future and a person, based on birth year, probably isn't 150 years old. When unreasonable data is entered, the program should at least ask the user to confirm that they intended to enter it.

## 7.4

### Focus on Languages: Java, Python, and C++

This section demonstrates how input validation can be performed in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

There are no new language features introduced in this chapter, so here we will simply show you a Java version of the pseudocode Program 7-2. The program shown in Program 7-3 uses an input validation loop in lines 42 through 47 to validate that the value entered by the user is not negative.

**Program 7-3      (InputValidation.java)**

```
1 import java.util.Scanner;
2
3 public class InputValidation
4 {
5 public static void main(String[] args)
6 {
7 // Create a Scanner object for keyboard input.
8 Scanner keyboard = new Scanner(System.in);
9
10 // Local variable
11 String doAnother;
12
13 do
14 {
15 // Calculate and display a retail price.
16 showRetail();
17
18 // Do this again?
19 System.out.print("Do you have another item? (Enter y for yes): ");
20 doAnother = keyboard.next();
21 } while (doAnother.equals("y") || doAnother.equals("Y"));
22 }
23
24 // The showRetail module gets an item's wholesale cost
25 // from the user and displays its retail price.
26 public static void showRetail()
27 {
28 // Create a Scanner object for keyboard input.
29 Scanner keyboard = new Scanner(System.in);
30
31 // Local variables
32 double wholesale, retail;
33
34 // Constant for the markup percentage
35 final double MARKUP = 2.5;
36
37 // Get the wholesale cost.
38 System.out.print("Enter an item's wholesale cost: ");
39 wholesale = keyboard.nextDouble();
40
41 // Validate the wholesale cost.
42 while (wholesale < 0)
43 {
44 System.out.println("The cost cannot be negative. Please");
45 System.out.print("enter the correct wholesale cost: ");
46 wholesale = keyboard.nextDouble();
47 }
48
49 // Calculate the retail price.
50 retail = wholesale * MARKUP;
51
52 // Display the retail price.
53 System.out.println("The retail price is $" + retail);
```

```
54 }
55 }
```

### Program Output

```
Enter an item's wholesale cost: -1 [Enter]
The cost cannot be negative. Please
enter the correct wholesale cost: 1.50 [Enter]
The retail price is $3.75
Do you have another item? (Enter y for yes): n [Enter]
```

## Python

There are no new language features introduced in this chapter, so here we will simply show you a Python version of the pseudocode Program 7-2. The program shown in Program 7-4 uses an input validation loop in lines 28 through 30 to validate that the value entered by the user is not negative.

### Program 7-4 (*retail.py*)

```
1 # This program calculates retail prices.
2
3 # MARK_UP is used as a global constant for
4 # the markup up percentage.
5 MARK_UP = 2.5
6
7 # The main function
8 def main():
9 # Variable to control the loop.
10 another = 'y'
11
12 # Process one or more items.
13 while another == 'y' or another == 'Y':
14 # Display an item's retail price.
15 show_retail()
16
17 # Do this again?
18 another = input('Do you have another item? ' +
19 '(Enter y for yes): ')
20
21 # The show_retail function gets an item's wholesale
22 # cost and displays the item's retail price.
23 def show_retail():
24 # Get the item's wholesale cost.
25 wholesale = float(input("Enter the item's wholesale cost: "))
26
27 # Validate the wholesale cost.
28 while wholesale < 0:
29 print('ERROR: the cost cannot be negative.')
30 wholesale = float(input('Enter the correct wholesale cost: '))
31
32 # Calculate the retail price.
33 retail = wholesale * MARK_UP
34
```

```
35 # Display the retail price.
36 print('The retail price is $', format(retail, '.2f'))
37
38 # Call the main function.
39 main()
```

### Program Output

```
Enter the item's wholesale cost: -.50 [Enter]
ERROR: The cost cannot be negative.
Enter the correct wholesale cost: 0.50 [Enter]
The retail price is $ 1.25.
Do you have another item? (Enter y for yes): n [Enter]
```

## C++

There are no new language features introduced in this chapter, so here we will simply show you a C++ version of the pseudocode Program 7-2. The program shown in Program 7-5 uses an input validation loop in lines 41 through 46 to validate that the value entered by the user is not negative.

### Program 7-5 (validation.cpp)

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 // Function prototype
6 void showRetail();
7
8 int main()
9 {
10 // Local variable
11 string doAnother;
12
13 do
14 {
15 // Calculate and display a retail price.
16 showRetail();
17
18 // Do this again?
19 cout << "Do you have another item? (Enter y for yes.)" << endl;
20 cin >> doAnother;
21 } while (doAnother == "y" || doAnother == "Y");
22
23 return 0;
24 }
25
26 // The showRetail function gets an item's wholesale cost
27 // from the user and displays its retail price.
28 void showRetail()
29 {
30 // Local variables
31 double wholesale, retail;
```

```
32
33 // Constant for the markup percentage
34 const double MARKUP = 2.5;
35
36 // Get the wholesale cost.
37 cout << "Enter an item's wholesale cost." << endl;
38 cin >> wholesale;
39
40 // Validate the wholesale cost.
41 while (wholesale < 0)
42 {
43 cout << "The cost cannot be negative. Please" << endl;
44 cout << "enter the correct wholesale cost." << endl;
45 cin >> wholesale;
46 }
47
48 // Calculate the retail price.
49 retail = wholesale * MARKUP;
50
51 // Display the retail price.
52 cout << "The retail price is $" << retail << endl;
53 }
```

### Program Output

```
Enter an item's wholesale cost.
-1 [Enter]
The cost cannot be negative. Please
enter the correct wholesale cost.
1.50 [Enter]
The retail price is $3.75
Do you have another item? (Enter y for yes.)
n [Enter]
```

## Review Questions

### Multiple Choice

1. GIGO stands for
  - a. great input, great output
  - b. garbage in, garbage out
  - c. GIgahertz Output
  - d. GIgabyte Operation
2. The integrity of a program's output is only as good as the integrity of the program's
  - a. compiler
  - b. programming language
  - c. input
  - d. debugger

3. The input operation that appears just before a validation loop is known as the
  - a. prevalidation read
  - b. primordial read
  - c. initialization read
  - d. priming read
4. Validation loops are also known as
  - a. error traps
  - b. doomsday loops
  - c. error avoidance loops
  - d. defensive programming loops
5. The term *empty input* describes what happens when
  - a. the user presses the [Spacebar] and then the [Enter] key
  - b. an input operation attempts to read data, but there is no data to read
  - c. the user enters 0 when 0 is an invalid value
  - d. the user enters any invalid data as input

### True or False

1. The process of input validation works like this: When the user of a program enters invalid data, the program should ask the user, “Are you sure you meant to enter that?” If the user answers “yes,” the program should accept the data.
2. The priming read appears inside the validation loop.
3. The approach of using a posttest validation loop shown in this chapter requires a priming read.

### Short Answer

1. What does the phrase “garbage in, garbage out” mean?
2. Give a general description of the input validation process.
3. What is the purpose of the priming read?
4. In this chapter you saw how a posttest loop can be used in input validation, as an alternative to the priming read followed by a pretest loop. Why is it typically not best to use a posttest loop approach?

### Algorithm Workbench

1. Design an algorithm that prompts the user to enter a positive nonzero number and validates the input.
2. Design an algorithm that prompts the user to enter a number in the range of 1 through 100 and validates the input.
3. Design an algorithm that prompts the user to enter “yes” or “no” and validates the input. (Use a case-insensitive comparison.)
4. Design an algorithm that prompts the user to enter a number that is greater than 99 and validates the input.
5. Design an algorithm that prompts the user to enter a secret word. The secret word should be at least 8 characters long. Validate the input.

## Debugging Exercises

1. Why does the following pseudocode not perform as indicated in the comments?

```
// This program asks the user to enter a value
// between 1 and 10 and validates the input.
Declare Integer value

// Get a value from the user.
Display "Enter a value between 1 and 10."
Input value

// Make sure the value is between 1 and 10.
While value < 1 AND value > 10
 Display "ERROR: The value must be between 1 and 10."
 Display "Enter a value between 1 and 10."
 Input value
End While
```

2. Why does the following pseudocode not perform as indicated in the comments?

```
// This program gets a dollar amount from the user
// and validates the input.
Declare Real amount

// Get the amount from the user.
Display "Enter a dollar amount"
Input amount

// Make sure the amount is not less than zero. If it is,
// get a new amount from the user.
While amount < 0
 Display "ERROR: The dollar amount cannot be less than 0."
 Display "Enter a dollar amount."
End While
```

3. The following pseudocode works, but it performs a case-sensitive validation of the user's input. How could the algorithm be improved so the user does not have to pay attention to capitalization when entering a name?

```
// This program asks the user to enter a string
// and validates the input.
Declare String choice

// Get the user's response.
Display "Cast your vote for Chess Team Captain."
Display "Would you like to nominate Lisa or Tim?"
Input choice

// Validate the input.
While choice != "Lisa" AND choice != "Tim"
 Display "Please enter Lisa or Tim."
 Display "Cast your vote for Chess Team Captain."
 Display "Would you like to nominate Lisa or Tim?"
 Input response
End While
```

## Programming Exercises



VideoNote

The Payroll Program  
with Input Validation  
Problem

### 1. Payroll Program with Input Validation

Design a payroll program that prompts the user to enter an employee's hourly pay rate and the number of hours worked. Validate the user's input so that only pay rates in the range of \$7.50 through \$18.25 and hours in the range of 0 through 40 are accepted. The program should display the employee's gross pay.

### 2. Theater Seating Revenue with Input Validation

A dramatic theater has three seating sections, and it charges the following prices for tickets in each section: section A seats cost \$20 each, section B seats cost \$15 each, and section C seats cost \$10 each. The theater has 300 seats in section A, 500 seats in section B, and 200 seats in section C. Design a program that asks for the number of tickets sold in each section and then displays the amount of income generated from ticket sales. The program should validate the numbers that are entered for each section.

### 3. Speeding Violation Calculator

Design a program that calculates and displays the number of miles per hour over the speed limit that a speeding driver was doing. The program should ask for the speed limit and the driver's speed. Validate the input as follows:

- The speed limit should be at least 20, but not greater than 70.
- The driver's speed should be at least the value entered for the speed limit (otherwise the driver was not speeding).

Once correct data has been entered, the program should calculate and display the number of miles per hour over the speed limit that the driver was doing.

### 4. Rock, Paper, Scissors Modification

Programming Exercise 11 in Chapter 6 asked you to design a program that plays the Rock, Paper, Scissors game. In the program, the user enters one of the three strings—"rock", "paper", or "scissors"—at the keyboard. Add input validation (with a case-insensitive comparison) to make sure the user enters one of those strings only.

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## TOPICS

- |                                         |                                               |
|-----------------------------------------|-----------------------------------------------|
| 8.1 Array Basics                        | 8.5 Two-Dimensional Arrays                    |
| 8.2 Sequentially Searching an Array     | 8.6 Arrays of Three or More Dimensions        |
| 8.3 Processing the Contents of an Array | 8.7 Focus on Languages: Java, Python, and C++ |
| 8.4 Parallel Arrays                     |                                               |

## 8.1

## Array Basics

**CONCEPT:** An array allows you to store a group of items of the same data type together in memory. Processing a large number of items in an array is usually easier than processing a large number of items stored in separate variables.

In the programs you have designed so far, you have used variables to store data in memory. In most programming languages, the simplest way to store a value in memory is to store it in a variable. Variables work well in many situations, but they have limitations. For example, they can hold only one value at a time. Consider the following pseudocode variable declaration:

```
Declare Integer number = 99
```

This pseudocode statement declares an `Integer` variable named `number`, initialized with the value 99. Consider what happens if the following statement appears later in the program:

```
Set number = 5
```

This statement assigns the value 5 to `number`, replacing the value 99 that was previously stored there. Because `number` is an ordinary variable, it can hold only one value at a time.

Because variables hold only a single value, they can be cumbersome in programs that process lists of data. For example, suppose you are asked to design a program that holds the names of 50 employees. Imagine declaring 50 variables to hold all of those names:

```
Declare String employee1
Declare String employee2
Declare String employee3
and so on...
Declare String employee50
```

Then, imagine designing the code to input all 50 names:

```
// Get the first employee name.
Display "Enter the name of employee 1."
Input employee1

// Get the second employee name.
Display "Enter the name of employee 2."
Input employee2

// Get the third employee name.
Display "Enter the name of employee 3."
Input employee3

and so on...

// Get the fiftieth employee name.
Display "Enter the name of employee 50."
Input employee50
```

As you can see, variables are not well-suited for storing and processing lists of data. Each variable is a separate item that must be declared and individually processed. Fortunately, most programming languages allow you to create *arrays*, which are specifically designed for storing and processing lists of data. Like a variable, an array is a named storage location in memory. Unlike a variable, an array can hold a group of values. All of the values in an array must be the same data type. You can have an array of **Integers**, an array of **Reals**, or an array of **Strings**, but you cannot store a mixture of data types in an array. The following example shows how we will declare an array in pseudocode:

```
Declare Integer units[10]
```

Notice that this statement looks like a regular **Integer** variable declaration except for the number inside the brackets. The number inside the brackets, called a *size declarator*, specifies the number of values that the array can hold. This pseudocode statement declares an array named **units** that can hold 10 integer values. In most programming languages, an array size declarator must be a nonnegative integer. Here is another example:

```
Declare Real salesAmounts[7]
```

This statement declares an array named **salesAmounts** that can hold 7 real numbers. The following pseudocode shows one more example. This statement declares an array that can hold 50 strings. The name of the array is **names**.

```
Declare String names[50]
```

In most languages, an array's size cannot be changed while the program is running. If you have written a program that uses an array and then find that you must change the array's size, you have to change the array's size declarator in the source code. Then you must recompile the program (or rerun the program if you are using an interpreted language) with the new size declarator. To make array sizes easier to maintain, many programmers prefer to use named constants as array size declarators. Here is an example:

```
Constant Integer SIZE = 10
Declare Integer units[SIZE]
```

As you will see later in this chapter, many array processing techniques require you to refer to the array's size. When you use a named constant as an array's size declarator, you can use the constant to refer to the size of the array in your algorithms. If you ever need to modify the program so the array is a different size, you need only to change the value of the named constant.



**NOTE:** In this book, we use brackets [] in an array declaration to enclose the size declarator. Some languages use parentheses instead.

## Array Elements and Subscripts

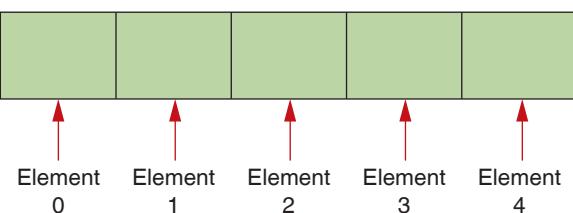
The storage locations in an array are known as *elements*. In memory, an array's elements are usually located in consecutive memory locations. Each element in an array is assigned a unique number known as a *subscript*. (Subscripts are also known as *indexes*.) Subscripts are used to identify specific elements in an array. In most languages, the first element is assigned the subscript 0, the second element is assigned the subscript 1, and so forth. For example, suppose a pseudocode program has the following declarations:

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE]
```

As shown in Figure 8-1, the *numbers* array has five elements. The elements are assigned the subscripts 0 through 4. (Because subscript numbering starts at zero, the subscript of the last element in an array is one less than the total number of elements in the array.)

**Figure 8-1** Array subscripts

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE]
```



**NOTE:** In some languages, subscript numbering starts at 1. It is more common, however, for subscript numbering to start at 0, so that is the convention we follow in this book.

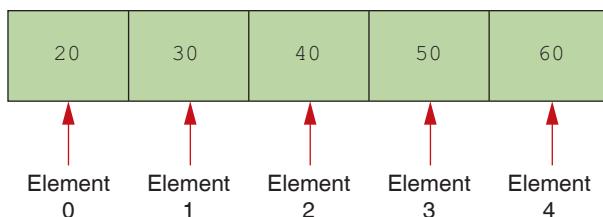
## Assigning Values to Array Elements

You access the individual elements in an array by using their subscripts. For example, assuming numbers is the Integer array just described, the following pseudocode assigns the values to each of its five elements.

```
Set numbers[0] = 20
Set numbers[1] = 30
Set numbers[2] = 40
Set numbers[3] = 50
Set numbers[4] = 60
```

This pseudocode assigns the value 20 to element 0, the value 30 to element 1, and so forth. Figure 8-2 shows the contents of the array after these statements execute.

**Figure 8-2** Values assigned to each element



**NOTE:** The expression numbers[0] is pronounced “numbers sub zero.”

## Inputting and Outputting Array Contents

You can read values from the keyboard and store them in an array element just as you can a regular variable. You can also output the contents of an array element. The pseudocode in Program 8-1 shows an array being used to store and display values entered by the user.

### Program 8-1



```
1 // Create a constant for the number of employees.
2 Constant Integer SIZE = 3
3
4 // Declare an array to hold the number of hours
5 // worked by each employee.
6 Declare Integer hours[SIZE]
7
8 // Get the hours worked by employee 1.
9 Display "Enter the hours worked by employee 1."
10 Input hours[0]
11
12 // Get the hours worked by employee 2.
13 Display "Enter the hours worked by employee 2."
14 Input hours[1]
15
```

```
16 // Get the hours worked by employee 3.
17 Display "Enter the hours worked by employee 3."
18 Input hours[2]
19
20 // Display the values entered.
21 Display "The hours you entered are:"
22 Display hours[0]
23 Display hours[1]
24 Display hours[2]
```

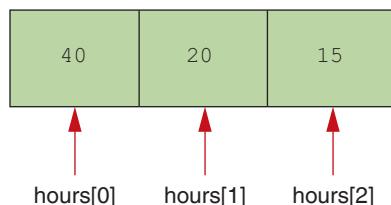
### Program Output (with Input Shown in Bold)

```
Enter the hours worked by employee 1.
40 [Enter]
Enter the hours worked by employee 2.
20 [Enter]
Enter the hours worked by employee 3.
15 [Enter]
The hours you entered are:
40
20
15
```

Let's take a closer look at the program. A named constant, `SIZE`, is declared in line 2 and initialized with the value 3. Then, an `Integer` array named `hours` is declared in line 6. The `SIZE` constant is used as the array size declarator, so the `hours` array will have 3 elements. The `Input` statements in lines 10, 14, and 18 read values from the keyboard and store those values in the elements of the `hours` array. Then, the `Display` statements in lines 22 through 24 output the values stored in each array element.

In the sample running of the program, the user entered the values 40, 20, and 15, which were stored in the `hours` array. Figure 8-3 shows the contents of the array after these values are stored in it.

**Figure 8-3** Contents of the `hours` array



VideoNote

Using a Loop to Step Through an Array

### Using a Loop to Step Through an Array

Most programming languages allow you to store a number in a variable and then use that variable as a subscript. This makes it possible to use a loop to step through an entire array, performing the same operation on each element. For example, look at the pseudocode in Program 8-2.

**Program 8-2**

```

1 // Declare an Integer array with 10 elements.
2 Declare Integer series[10]
3
4 // Declare a variable to use in the loop.
5 Declare Integer index
6
7 // Set each array element to 100.
8 For index = 0 To 9
9 Set series[index] = 100
10 End For

```

In line 2, an Integer array named `series` is declared with 10 elements, and in line 5 an Integer variable named `index` is declared. The `index` variable is used as a counter in the `For` loop that appears in lines 8 through 10. In the loop, the `index` variable takes on the values 0 through 9. The first time the loop iterates, `index` is set to 0, so the statement in line 9 causes the array element `series[0]` to be set to 100. The second time the loop iterates, `index` is set to 1, so the array element `series[1]` is set to 100. This continues until the last loop iteration, in which `series[9]` is set to 100.

Let's look at another example. Program 8-1 could be simplified by using two `For` loops: one for inputting the values into the array and the other for displaying the contents of the array. This is shown in Program 8-3.

**Program 8-3**

```

1 // Create a constant for the size of the array.
2 Constant Integer SIZE = 3
3
4 // Declare an array to hold the number of hours
5 // worked by each employee.
6 Declare Integer hours[SIZE]
7
8 // Declare a variable to use in the loops.
9 Declare Integer index
10
11 // Get the hours for each employee.
12 For index = 0 To SIZE - 1
13 Display "Enter the hours worked by"
14 Display "employee number ", index + 1
15 Input hours[index]
16 End For
17
18 // Display the values entered.
19 Display "The hours you entered are:"
20 For index = 0 To SIZE - 1
21 Display hours[index]
22 End For

```

**Program Output (with Input Shown in Bold)**

```
Enter the hours worked by
employee number 1
40 [Enter]
Enter the hours worked by
employee number 2
20 [Enter]
Enter the hours worked by
employee number 3
15 [Enter]
The hours you entered are:
40
20
15
```

Let's take a closer look at the first For loop, which appears in lines 12 through 16. Here is the first line of the loop:

```
For index = 0 To SIZE - 1
```

This specifies that the `index` variable will be assigned the values 0 through 2 as the loop executes. Why did we use the expression `SIZE - 1` as the ending value for the `index` variable? Remember, the subscript of the last element in an array is one less than the size of the array. In this case, the subscript of the last element of the `hours` array is 2, which is the value of the expression `SIZE - 1`.

Notice that inside the loop, in line 15, the `index` variable is used as a subscript:

```
Input hours[index]
```

During the loop's first iteration, the `index` variable will be set to 0, so the user's input is stored in `hours[0]`. During the next iteration, the user's input is stored in `hours[1]`. Then, during the last iteration the user's input is stored in `hours[2]`. Notice that the loop correctly starts and ends the `index` variable with valid subscript values (0 through 2).

There is one last thing to point out about Program 8-3. This program reads the number of hours worked by three employees referred to as "employee number 1," "employee number 2," and "employee number 3." Here are the `Display` statements that appear inside the first For loop, in lines 13 and 14:

```
Display "Enter the hours worked by"
Display "employee number ", index + 1
```

Notice that the second `Display` statement uses the expression `index + 1` to display the employee number. What do you think would happen if we left out the `+ 1` part of the expression, and the statements were written like this?

```
Display "Enter the hours worked by"
Display "employee number ", index
```

Because the `index` variable is assigned the values 0, 1, and 2 as the loop runs, these statements would cause the program to refer to the employees as "employee number 0," "employee number 1," and "employee number 2." Most people find it unnatural to

start with 0 when counting people or things, so we used the expression `index + 1` to start the employee numbers at 1.

## Processing the Elements of an Array

Processing array elements is no different than processing other variables. In the previous programs you saw how you can assign values to array elements, store input in array elements, and display the contents of array elements. The following *In the Spotlight* section shows how array elements can be used in math expressions.

### In the Spotlight: Using Array Elements in a Math Expression



Megan owns a small neighborhood coffee shop, and she has six employees who work as baristas (coffee bartenders). All of the employees have the same hourly pay rate. Megan has asked you to design a program that will allow her to enter the number of hours worked by each employee and then display the amounts of all the employees' gross pay. You determine that the program should perform the following steps:

1. For each employee: get the number of hours worked and store it in an array element.
2. For each array element: use the value stored in the element to calculate an employee's gross pay. Display the amount of the gross pay.

Program 8-4 shows the pseudocode for the program, and Figure 8-4 shows a flowchart.

### Program 8-4

```

1 // Constant for the size of the array.
2 Constant Integer SIZE = 6
3
4 // Array to hold each employee's hours.
5 Declare Real hours[SIZE]
6
7 // Variable to hold the hourly pay rate.
8 Declare Real payRate
9
10 // Variable to hold a gross pay amount.
11 Declare Real grossPay
12
13 // Variable to use as a loop counter.
14 Declare Integer index
15
16 // Get each employee's hours worked.
17 For index = 0 To SIZE - 1
18 Display "Enter the hours worked by"
19 Display "employee ", index + 1, "."
20 Input hours[index]
21 End For
22
23 // Get the hourly pay rate.
24 Display "Enter the hourly pay rate."
25 Input payRate
26

```

```
27 // Display each employee's gross pay.
28 Display "Here is each employee's gross pay."
29 For index = 0 To SIZE - 1
30 Set grossPay = hours[index] * payRate
31 Display "Employee ", index + 1, ": $",
32 currencyFormat(grossPay)
33 End For
```

### Program Output (with Input Shown in Bold)

```
Enter the hours worked by
employee 1
10 [Enter]
Enter the hours worked by
employee 2
20 [Enter]
Enter the hours worked by
employee 3
15 [Enter]
Enter the hours worked by
employee 4
40 [Enter]
Enter the hours worked by
employee 5
20 [Enter]
Enter the hours worked by
employee 6
18 [Enter]
Enter the hourly pay rate.
12.75 [Enter]
Here is each employee's gross pay.
Employee 1: $127.50
Employee 2: $255.00
Employee 3: $191.25
Employee 4: $510.00
Employee 5: $255.00
Employee 6: $229.50
```

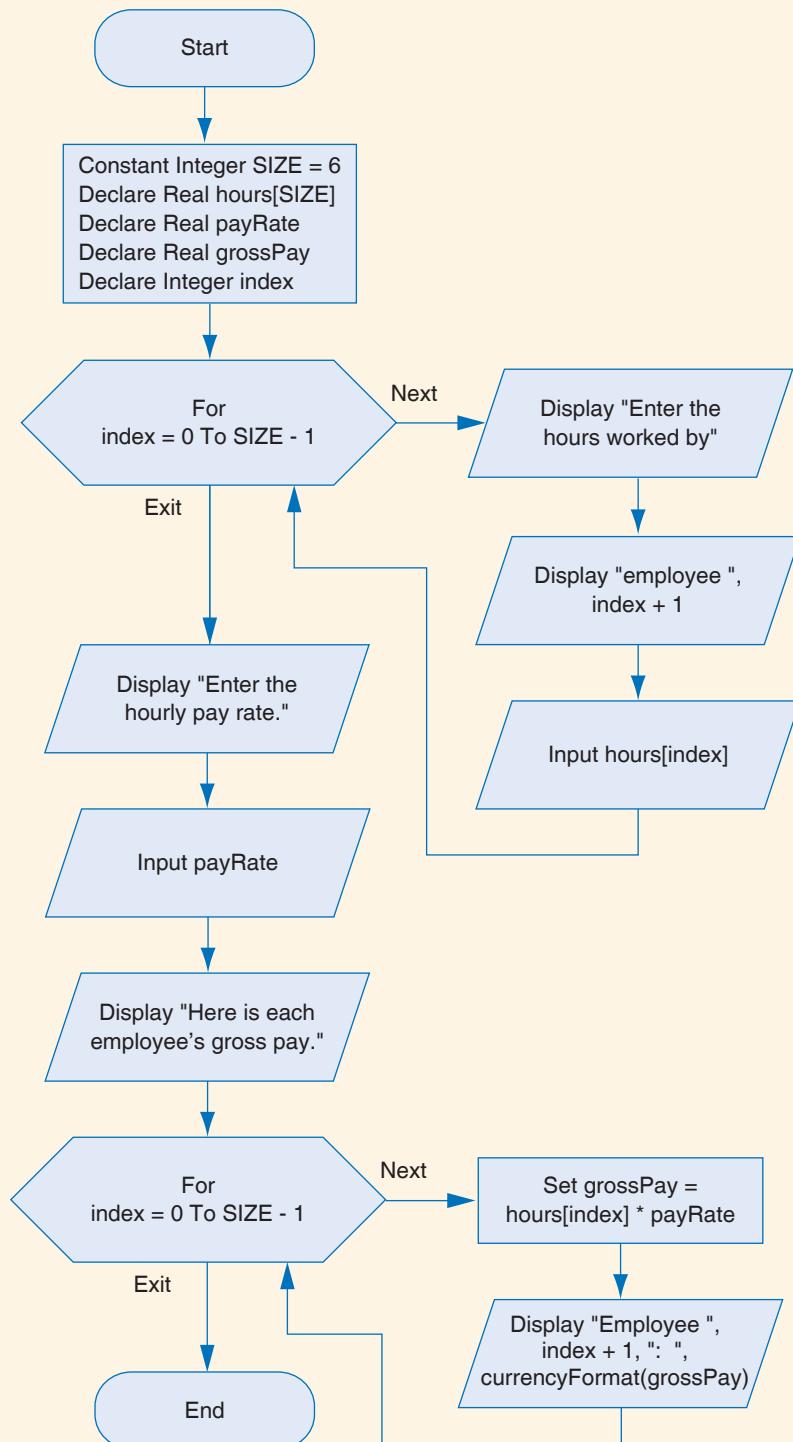


**NOTE:** Suppose Megan's business increases and she has to hire two additional baristas. This would require you to change the program so it processes 8 employees instead of 6. Because you used a named constant for the array size, this is a simple modification—you just have to change the statement in line 2 to read:

```
Constant Integer SIZE = 8
```

Because the SIZE constant is used as the array size declarator in line 5, the size of the hours array will automatically become 8. Also, because you used the SIZE constant to control the loop iterations in lines 17 and 29, the loops will automatically iterate 8 times, once for each employee.

Imagine how much more difficult this modification would be if you had not used a named constant to specify the array size. You would have to change each individual statement in the program that refers to the array size. Not only would this require more work, but it would open the possibility for errors. If you overlooked only one of the statements that refer to the array size, a bug would occur.

**Figure 8-4** Flowchart for Program 8-4



**TIP:** Programs 8-1, 8-3, and 8-4 show how values can be read from the keyboard into array elements. When a large amount of data is stored in an array, it is usually read from another source, such as a file on the computer's disk drive. In Chapter 10 you will learn how to read data from a file and store it in an array.

## Array Initialization

Most languages allow you to initialize an array with values when you declare it. In this book's pseudocode, we will initialize arrays in the following manner:

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE] = 10, 20, 30, 40, 50
```

The series of values separated with commas is called an *initialization list*. These values are stored in the array elements in the order they appear in the list. (The first value, 10, is stored in `numbers[0]`, the second value, 20, is stored in `numbers[1]`, and so forth.) Here is another example:

```
Constant Integer SIZE = 7
Declare String days[SIZE] = "Sunday", "Monday", "Tuesday",
 "Wednesday", "Thursday", "Friday",
 "Saturday"
```

This pseudocode declares `days` as an array of 7 `Strings`, and initializes `days[0]` with "Sunday", `days[1]` with "Monday", and so forth.

## Array Bounds Checking

Most programming languages perform *array bounds checking*, which means they do not allow a program to use an invalid array subscript. For example, look at the following pseudocode:

```
// Create an array.
Constant Integer SIZE = 5
Declare Integer numbers[SIZE]

// ERROR! This statement uses an invalid subscript!
Set numbers[5] = 99
```

This pseudocode declares an array with 5 elements. The subscripts for the array's elements are 0 through 4. The last statement will cause an error in most languages because it attempts to assign a value in `numbers[5]`, a nonexistent element.



**NOTE:** Array bounds checking typically happens at runtime, which is while the program is running.

## Watch for Off-by-One Errors

Because array subscripts start at 0 rather than 1, you have to be careful not to perform an off-by-one error. An *off-by-one error* occurs when a loop iterates one time too many or one time too few. For example, look at the following pseudocode:

```

// This code has an off-by-one error.
Constant Integer SIZE = 100;
Declare Integer numbers[SIZE]
Declare Integer index
For index = 1 To SIZE - 1
 Set numbers[index] = 0
End For

```

The intent of this pseudocode is to create an array of integers with 100 elements, and store the value 0 in each element. However, this code has an off-by-one error. The loop uses its counter variable, `index`, as a subscript with the `numbers` array. During the loop's execution, the `index` variable takes on the values 1 through 99, when it should take on the values 0 through 99. As a result, the first element, which is at subscript 0, is skipped.

Assuming `numbers` is the same array as previously declared, the following loop also performs an off-by-one error. This loop correctly starts with the subscript 0, but it iterates one too many times, ending with the subscript 100:

```

// ERROR!
For index = 0 To SIZE
 Set numbers[index] = 0
End For

```

Because the last subscript in this array is 99, this loop will cause a bounds-checking error.

## Partially Filled Arrays

Sometimes you need to store a series of items in an array, but you do not know the number of items in the series. As a result, you do not know the exact number of elements needed for the array. One solution is to make the array large enough to hold the largest possible number of items. This can lead to another problem, however. If the actual number of items stored in the array is less than the number of elements, the array will be only partially filled. When you process a partially filled array, you must process only the elements that contain valid data items.

A partially filled array is normally used with an accompanying integer variable that holds the number of items that are actually stored in the array. If the array is empty, then 0 is stored in this variable because there are no items in the array. Each time an item is added to the array, the variable is incremented. When code steps through the array's elements, the value of this variable is used instead of the array's size to determine the maximum subscript. Program 8-5 shows a demonstration.

### Program 8-5

```

1 // Declare a constant for the array size.
2 Constant Integer SIZE = 100
3
4 // Declare an array to hold integer values.
5 Declare Integer values[SIZE]
6
7 // Declare an Integer variable to hold the number of items

```

```
8 // that are actually stored in the array.
9 Declare Integer count = 0
10
11 // Declare an Integer variable to hold the user's input.
12 Declare Integer number
13
14 // Declare a variable to step through the array.
15 Declare Integer index
16
17 // Prompt the user to enter a number. If the user enters the
18 // sentinel value - 1 we will stop accepting input.
19 Display "Enter a number or - 1 to quit."
20 Input number
21
22 // If the input is not - 1 and the array is not
23 // full, process the input.
24 While (number != - 1 AND count < SIZE)
25 // Store the input in the array.
26 Set values[count] = number
27
28 // Increment count.
29 count = count + 1
30
31 // Prompt the user for the next number.
32 Display "Enter a number or - 1 to quit."
33 Input number
34 End While
35
36 // Display the values stored in the array.
37 Display "Here are the numbers you entered:"
38 For index = 0 To count - 1
39 Display values[index]
40 End For
```

### Program Output (with Input Shown in Bold)

```
Enter a number or - 1 to quit.
2 [Enter]
Enter a number or - 1 to quit.
4 [Enter]
Enter a number or - 1 to quit.
6 [Enter]
Enter a number or - 1 to quit.
- 1 [Enter]
Here are the numbers you entered:
2
4
6
```

Let's examine the pseudocode in detail. Line 2 declares a constant, **SIZE**, initialized with the value 100. Line 5 declares an **Integer** array named **values**, using **SIZE** as the size declarator. As a result, the **values** array will have 100 elements. Line 9 declares an **Integer** variable named **count**, which will hold the number of items that are stored in the **values** array. Notice that **count** is initialized with 0 because there are no values stored in the array. Line 12 declares an **Integer** variable named **number** that will hold

values entered by the user, and line 15 declares an Integer variable named `index` that will be used in a loop to step through the array, displaying its elements.

Line 19 prompts the user to enter a number or `-1` to quit. This program uses the value `-1` as a sentinel value. When the user enters `-1`, the program will stop reading input. Line 20 reads the user's input and stores it in the `number` variable. A `While` loop begins in line 24. The loop iterates as long as `number` is not `-1` and `count` is less than the size of the array. Inside the loop, in line 26 the `numbers` variable is assigned to `values[count]`, and in line 29 the `count` variable is incremented. (Each time a number is assigned to an array element, the `count` variable is incremented. As a result, the `count` variable will hold the number of items that are stored in the array.) Then, line 32 prompts the user to enter another number (or `-1` to quit) and line 33 reads the user's input into the `number` variable. The loop then starts over.

When the user enters `-1`, or `count` reaches the size of the array, the `While` loop stops. The `For` loop that begins in line 38 displays all of the items that are stored in the array. Rather than stepping through all of the elements in the array, however, the loop steps through only the elements that contain values. Notice that the `index` variable's starting value is `0`, and its ending value is `count - 1`. By setting the ending value to `count - 1` rather than `SIZE - 1`, the loop will stop when the element containing the last valid value has been displayed, not when the end of the array has been reached.

## Optional Topic: The For Each Loop

Several programming languages provide a specialized version of the `For` loop that is known as the `For Each` loop. The `For Each` loop can simplify array processing when your task is simply to step through an array, retrieving the value of each element. The `For Each` loop is typically used in the following general format:

```
For Each var In array
 statement
 statement
 statement
 etc.
End For
```

In the general format, `var` is the name of a variable and `array` is the name of an array. The loop will iterate once for every element in the array. Each time the loop iterates, it copies an array element to the `var` variable. For example, the first time the loop iterates, `var` will contain the value of `array[0]`, the second time the loop iterates `var` will contain the value of `array[1]`, and so forth. This continues until the loop has stepped through all of the elements in the array. For example, suppose we have the following declarations:

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE] = 5, 10, 15, 20, 25
Declare Integer num
```

The following `For Each` loop can be used to display all of the values stored in the `numbers` array:

```
For Each num In numbers
 Display num
End For
```



**NOTE:** The For Each loop is not available in all languages, so we will continue to use the regular For loop in our example programs.



## Checkpoint

- 8.1 Can you store a mixture of data types in an array?
- 8.2 What is an array size declarator?
- 8.3 In most languages, can the size of an array be changed while the program is running?
- 8.4 What is an array element?
- 8.5 What is a subscript?
- 8.6 What is usually the first subscript in an array?
- 8.7 Look at the following pseudocode and answer questions a through d.

```
Constant Integer SIZE = 7
Declare Real numbers[SIZE]
a. What is the name of the array that is being declared?
b. What is the size of the array?
c. What data type are the array elements?
d. What is the subscript of the last element in the array?
```
- 8.8 What does “array bounds checking” mean?
- 8.9 What is an off-by-one error?

8.2

## Sequentially Searching an Array

**CONCEPT:** The sequential search algorithm is a simple technique for finding an item in an array. It steps through the array, beginning at the first element, and compares each element to the item being searched for. The search stops when the item is found or the end of the array is reached.

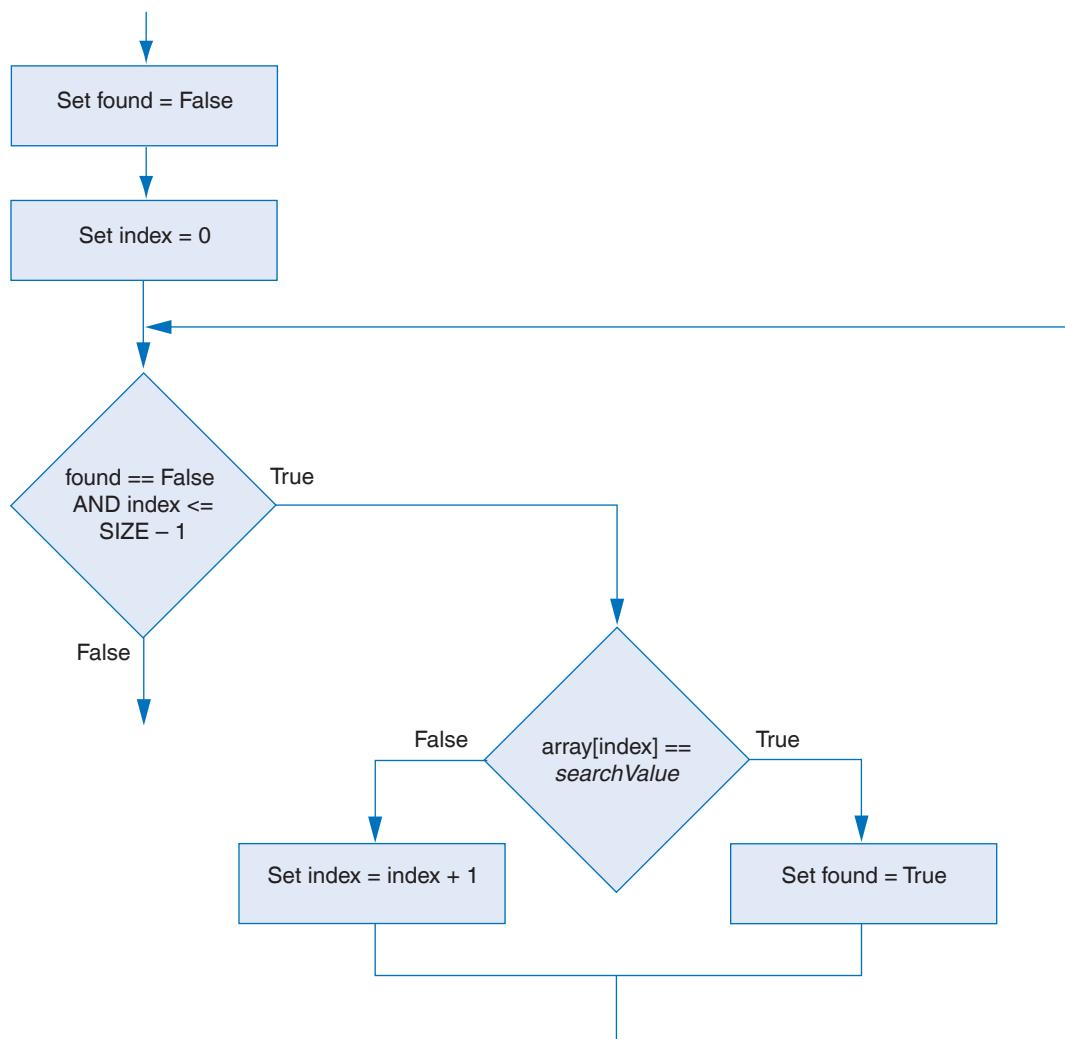
Programs commonly need to search for data that is stored in an array. Various techniques known as *search algorithms* have been developed to locate a specific item in a larger collection of data, such as an array. This section shows you how to use the simplest of all search algorithms—the sequential search. The *sequential search algorithm* uses a loop to sequentially step through an array, starting with the first element. It compares each element with the value being searched for and stops when the value is found or the end of the array is encountered. If the value being searched for is not in the array, the algorithm unsuccessfully searches to the end of the array.

Figure 8-5 shows the general logic of the sequential search algorithm. Here is a summary of the data items in the figure:

- array is the array being searched.
- *searchValue* is the value that the algorithm is searching for.
- found is a Boolean variable that is used as a flag. Setting found to False indicates that *searchValue* has not been found. Setting found to True indicates that *searchValue* has been found.
- index is an Integer variable used as a loop counter.

When the algorithm finishes, the found variable will be set to True if the *searchValue* was found in the array. When this is the case, the index variable will be set to the

**Figure 8-5** Sequential search logic



subscript of the element containing the *searchValue*. If the *searchValue* was not found in the array, *found* will be set to *False*. The following shows how you can express this logic in pseudocode:

```
Set found = False
Set index = 0
While found == False AND index <= SIZE - 1
 If array[index] == searchValue Then
 Set found = True
 Else
 Set index = index + 1
 End If
End While
```

The pseudocode in Program 8-6 demonstrates how to implement the sequential search in a program. This program has an array that holds test scores. It sequentially searches the array for a score of 100. If a score of 100 is found, the program displays the test number.

### Program 8-6



```
1 // Constant for the array size.
2 Constant Integer SIZE = 10
3
4 // Declare an array to hold test scores.
5 Declare Integer scores[SIZE] = 87, 75, 98, 100, 82,
6 72, 88, 92, 60, 78
7
8 // Declare a Boolean variable to act as a flag.
9 Declare Boolean found
10
11 // Declare a variable to use as a loop counter.
12 Declare Integer index
13
14 // The flag must initially be set to False.
15 Set found = False
16
17 // Set the counter variable to 0.
18 Set index = 0
19
20 // Step through the array searching for a
21 // score equal to 100.
22 While found == False AND index <= SIZE - 1
23 If scores[index] == 100 Then
24 Set found = True
25 Else
26 Set index = index + 1
27 End If
28 End While
29
30 // Display the search results.
31 If found Then
32 Display "You earned 100 on test number ", index + 1
```

```

33 Else
34 Display "You did not earn 100 on any test."
35 End If

```

### Program Output

You earned 100 on test number 4

## Searching a String Array

Program 8-6 demonstrates how to use the sequential search algorithm to find a specific number in an **Integer** array. As shown in Program 8-7, you can also use the algorithm to find a string in a **String** array.

### Program 8-7



```

1 // Declare a constant for the array size.
2 Constant Integer SIZE = 6
3
4 // Declare a String array initialized with values.
5 Declare String names[SIZE] = "Ava Fischer", "Alex Prieto",
6 "Ingrid Olen", "Matt Hoyle",
7 "Rose Harrison", "Giovanni Ricci"
8
9 // Declare a variable to hold the search value.
10 Declare String searchValue
11
12 // Declare a Boolean variable to act as a flag.
13 Declare Boolean found
14
15 // Declare a counter variable for the array.
16 Declare Integer index
17
18 // The flag must initially be set to False.
19 Set found = False
20
21 // Set the counter variable to 0.
22 Set index = 0
23
24 // Get the string to search for.
25 Display "Enter a name to search for in the array."
26 Input searchValue
27
28 // Step through the array searching for
29 // the specified name.
30 While found == False AND index <= SIZE - 1
31 If names[index] == searchValue Then
32 Set found = True
33 Else
34 Set index = index + 1
35 End If
36 End While
37

```

```
38 // Display the search results.
39 If found Then
40 Display "That name was found at subscript ", index
41 Else
42 Display "That name was not found in the array."
43 End If
```

### Program Output (with Input Shown in Bold)

```
Enter a name to search for in the array.
Matt Hoyle [Enter]
That name was found at subscript 3.
```

### Program Output (with Input Shown in Bold)

```
Enter a name to search for in the array.
Matt [Enter]
That name was not found in the array.
```

This program finds a string in the array only if the user types the complete string, exactly as it appears in the array. For example, in the first sample run the user enters “Matt Hoyle” as the search string and the program locates it at subscript 3. But, in the second sample run the user enters “Matt” and the program reports that the name was not found in the array. This is because the string “Matt” is not equal to the string “Matt Hoyle”.

Often, programs must be designed to search for partial string matches. Most languages provide a library function that can determine whether a string partially matches another string. In pseudocode you can use the `contains` function to implement this. Recall from Chapter 6 that the `contains` function accepts two strings as arguments, and it returns True if the first string contains the second string; otherwise, the function returns False. The pseudocode in Program 8-8 shows how you can modify Program 8-7 to use the `contains` function. This version of the program will find strings in the array that partially match the string entered by the user.

### Program 8-8

```
1 // Declare a constant for the array size.
2 Constant Integer SIZE = 6
3
4 // Declare a String array initialized with values.
5 Declare String names[SIZE] = "Ava Fischer", "Alex Prieto",
6 "Ingrid Olen", "Matt Hoyle",
7 "Rose Harrison", "Giovanni Ricci"
8
9 // Declare a variable to hold the search value.
10 Declare String searchValue
11
12 // Declare a Boolean variable to act as a flag.
13 Declare Boolean found
14
```

```
15 // Declare a counter variable for the array.
16 Declare Integer index
17
18 // The flag must initially be set to False.
19 Set found = False
20
21 // Set the counter variable to 0.
22 Set index = 0
23
24 // Get the string to search for.
25 Display "Enter a name to search for in the array."
26 Input searchValue
27
28 // Step through the array searching for
29 // the specified name.
30 While found == False AND index <= SIZE - 1
31 If contains(names[index], searchValue) Then
32 Set found = True
33 Else
34 Set index = index + 1
35 End If
36 End While
37
38 // Display the search results.
39 If found Then
40 Display "That name matches the following element:"
41 Display names[index]
42 Else
43 Display "That name was not found in the array."
44 End If
```

### Program Output (with Input Shown in Bold)

```
Enter a name to search for in the array.
Matt [Enter]
That name matches the following element:
Matt Hoyle
```



### Checkpoint

- 8.10 What is a search algorithm?
- 8.11 Which array element does the sequential search algorithm first look at?
- 8.12 What does the loop do in the sequential search algorithm? What happens when the value being searched for is found?
- 8.13 How many elements does the sequential search algorithm look at in the case that the search value is not found in the array?
- 8.14 How do you look for a partial string match when searching an array of strings for a value?

**8.3**

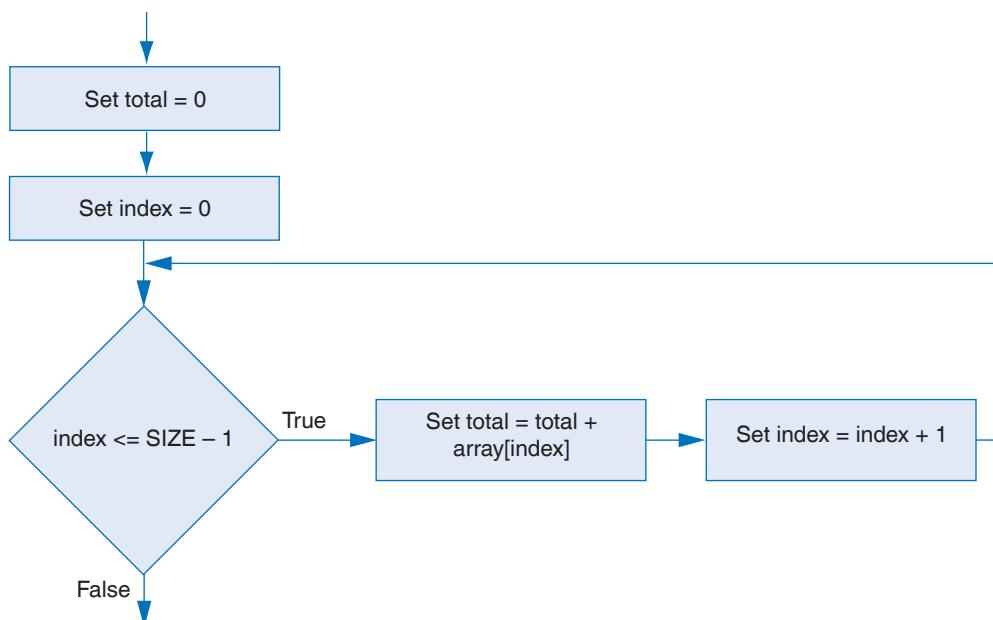
## Processing the Contents of an Array

In this chapter you've seen several examples of how loops are used to step through the elements of an array. There are many operations that you can perform on an array using a loop, and this section examines several such algorithms.

### Totaling the Values in an Array

To calculate the total of the values in an array, you use a loop with an accumulator variable. The loop steps through the array, adding the value of each array element to the accumulator. Figure 8-6 shows the logic of the algorithm. In the algorithm `total` is an accumulator variable, `index` is a loop counter, and `array` is an array containing numeric values.

**Figure 8-6** Algorithm for totaling the values in an array



The pseudocode in Program 8-9 demonstrates the algorithm with an Integer array named `numbers`.

#### Program 8-9

```
1 // Declare a constant for the array size.
2 Constant Integer SIZE = 5
3
4 // Declare an array initialized with values.
5 Declare Integer numbers[SIZE] = 2, 4, 6, 8, 10
6
7 // Declare and initialize an accumulator variable.
8 Declare Integer total = 0
9
```

```

10 // Declare a counter variable for the loop.
11 Declare Integer index
12
13 // Calculate the total of the array elements.
14 For index = 0 To SIZE - 1
15 Set total = total + numbers[index]
16 End For
17
18 // Display the sum of the array elements.
19 Display "The sum of the array elements is ", total

```

**Program Output**

The sum of the array elements is 30

**Averaging the Values in an Array**

The first step in calculating the average of the values in an array is to get the total of the values. You saw how to do that with a loop in the preceding section. The second step is to divide the total by the number of elements in the array. The pseudocode in Program 8-10 demonstrates the algorithm.

**Program 8-10**

```

1 // Declare a constant for the array size.
2 Constant Integer SIZE = 5
3
4 // Declare an array initialized with values.
5 Declare Real scores[SIZE] = 2.5, 8.3, 6.5, 4.0, 5.2
6
7 // Declare and initialize an accumulator variable.
8 Declare Real total = 0
9
10 // Declare a variable to hold the average.
11 Declare Real average
12
13 // Declare a counter variable for the loop.
14 Declare Integer index
15
16 // Calculate the total of the array elements.
17 For index = 0 To SIZE - 1
18 Set total = total + numbers[index]
19 End For
20
21 // Calculate the average of the array elements.
22 Set average = total / SIZE
23
24 // Display the average of the array elements.
25 Display "The average of the array elements is ", average

```

**Program Output**

The average of the array elements is 5.3

## Finding the Highest Value in an Array

Some programming tasks require you to find the highest value in a set of data. Examples include programs that report the highest sales amount for a given time period, the highest test score in a set of test scores, the highest temperature for a given set of days, and so forth.

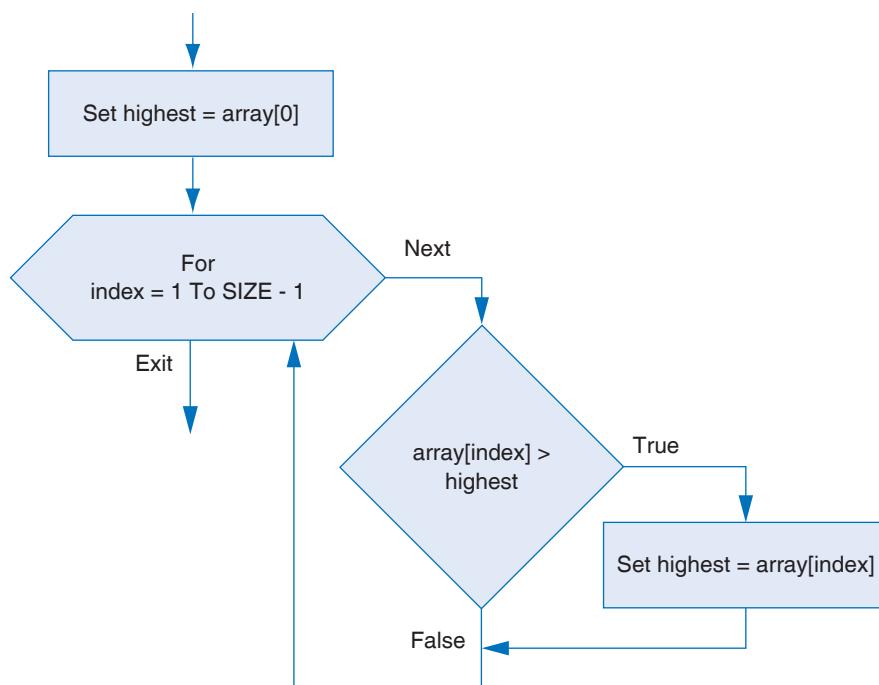
The algorithm for finding the highest value in an array works like this: You create a variable to hold the highest value (the following examples name this variable `highest`). Then, you assign the value at element 0 to the `highest` variable. Next, you use a loop to step through the rest of the array elements, beginning at element 1. Each time the loop iterates, it compares an array element to the `highest` variable. If the array element is greater than the `highest` variable, then the value in the array element is assigned to the `highest` variable. When the loop finishes, the `highest` variable will contain the highest value in the array. The flowchart in Figure 8-7 illustrates this logic. The pseudocode in Program 8-11 shows a simple demonstration of the algorithm.

### Program 8-11

```
1 // Declare a constant for the array size.
2 Constant Integer SIZE = 5
3
4 // Declare an array initialized with values.
5 Declare Integer numbers[SIZE] = 8, 1, 12, 6, 2
6
7 // Declare a counter variable for the array.
8 Declare Integer index
9
10 // Declare a variable to hold the highest value.
11 Declare Integer highest
12
13 // Assign the first element to highest.
14 Set highest = numbers[0]
15
16 // Step through the rest of the array,
17 // beginning at element 1. When a value
18 // greater than highest is found, assign
19 // that value to highest.
20 For index = 1 To SIZE - 1
21 If numbers[index] > highest Then
22 Set highest = numbers[index]
23 End If
24 End For
25
26 // Display the highest value.
27 Display "The highest value in the array is ", highest
```

### Program Output

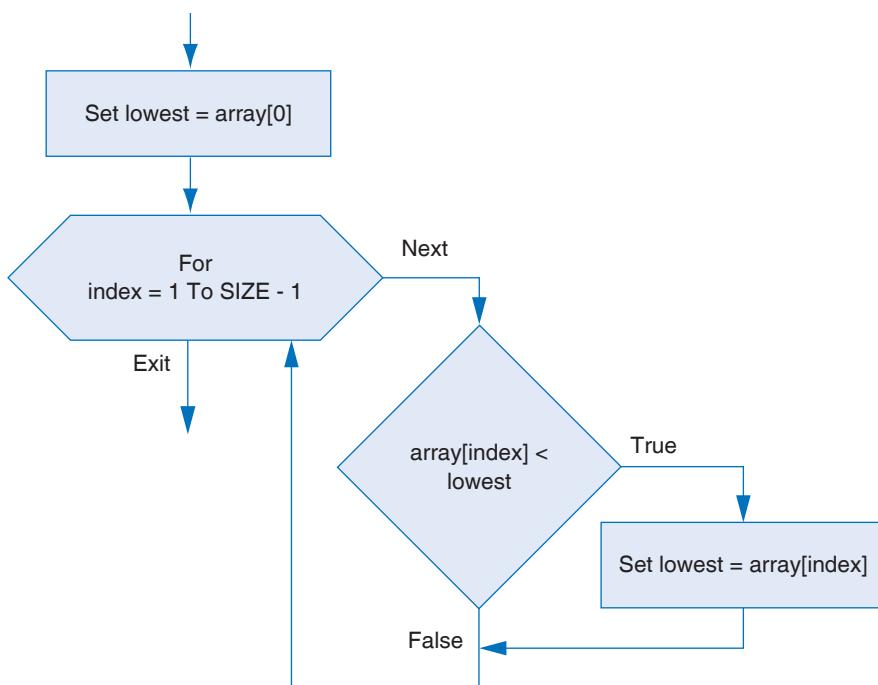
The highest value in the array is 12

**Figure 8-7** Flowchart for finding the highest value in an array

## Finding the Lowest Value in an Array

In some programs you are more interested in finding the lowest value than the highest value in a set of data. For example, suppose you are designing a program that stores several players' golf scores in an array and you need to find the best score. In golf, the lower the score the better, so you would need an algorithm that finds the lowest value in the array.

The algorithm for finding the lowest value in an array is very similar to the algorithm for finding the highest score. It works like this: You create a variable to hold the lowest value (the following examples name this variable `lowest`). Then, you assign the value at element 0 to the `lowest` variable. Next, you use a loop to step through the rest of the array elements, beginning at element 1. Each time the loop iterates, it compares an array element to the `lowest` variable. If the array element is less than the `lowest` variable, then the value in the array element is assigned to the `lowest` variable. When the loop finishes, the `lowest` variable will contain the lowest value in the array. The flowchart in Figure 8-8 illustrates this logic. The pseudocode in Program 8-12 shows a simple demonstration of the algorithm.

**Figure 8-8** Flowchart for finding the lowest value in an array**Program 8-12**

```
1 // Declare a constant for the array size.
2 Constant Integer SIZE = 5
3
4 // Declare an array initialized with values.
5 Declare Integer numbers[SIZE] = 8, 1, 12, 6, 2
6
7 // Declare a counter variable for the array.
8 Declare Integer index
9
10 // Declare a variable to hold the lowest value.
11 Declare Integer lowest
12
13 // Assign the first element to lowest.
14 Set lowest = numbers[0]
15
16 // Step through the rest of the array,
17 // beginning at element 1. When a value
18 // less than lowest is found, assign
19 // that value to lowest.
20 For index = 1 To SIZE - 1
21 If numbers[index] < lowest Then
22 Set lowest = numbers[index]
23 End If
24 End For
```

```

25
26 // Display the lowest value.
27 Display "The lowest value in the array is ", lowest

```

### Program Output

The lowest value in the array is 1

## Copying an Array

In most programming languages, if you need to copy the contents of one array to another you have to assign the individual elements of the array that you are copying to the elements of the other array. Usually, this is best done with a loop. For example, look at the following pseudocode:

```

Constant Integer SIZE = 5
Declare Integer firstArray[SIZE] = 100, 200, 300, 400, 500
Declare Integer secondArray[SIZE]

```

Suppose you want to copy the values in `firstArray` to `secondArray`. The following pseudocode assigns each element of `firstArray` to the corresponding element in `secondArray`.

```

Declare Integer index
For index = 0 To SIZE - 1
 Set secondArray[index] = firstArray[index]
End For

```

## Passing an Array as an Argument to a Module or a Function

Most languages allow you to pass an array as an argument to a module or a function. This gives you the ability to modularize many of the operations that you perform on an array. Passing an array as an argument typically requires that you pass two arguments: (1) the array itself, and (2) an integer that specifies the number of elements in the array. The pseudocode in Program 8-13 shows an example of a function that accepts an `Integer` array as an argument. The function returns the total of the array's elements.

### Program 8-13



```

1 Module main()
2 // A constant for the array size.
3 Constant Integer SIZE = 5
4
5 // An array initialized with values.
6 Declare Integer numbers[SIZE] = 2, 4, 6, 8, 10
7
8 // A variable to hold the sum of the elements.
9 Declare Integer sum
10
11 // Get the sum of the elements.

```

```
12 Set sum = getTotal(numbers, SIZE)
13
14 // Display the sum of the array elements.
15 Display "The sum of the array elements is ", sum
16 End Module
17
18 // The getTotal function accepts an Integer array and the
19 // array's size as arguments. It returns the total of the
20 // array elements.
21 Function Integer getTotal(Integer array[], Integer arraySize)
22 // Loop counter
23 Declare Integer index
24
25 // Accumulator, initialized to 0
26 Declare Integer total = 0
27
28 // Calculate the total of the array elements.
29 For index = 0 To arraySize - 1
30 Set total = total + array[index]
31 End For
32
33 // Return the total.
34 Return total
35 End Function
```

### Program Output

The sum of the array elements is 30

In the `main` module, an `Integer` array is declared in line 6 and initialized with five values. In line 12, the following statement calls the `getTotal` function and assigns its return value to the `sum` variable:

```
Set sum = getTotal(numbers, SIZE)
```

This statement passes two arguments to the `getTotal` function: the `numbers` array and the value of the `SIZE` constant. Here is the first line of the `getTotal` function, which appears in line 21:

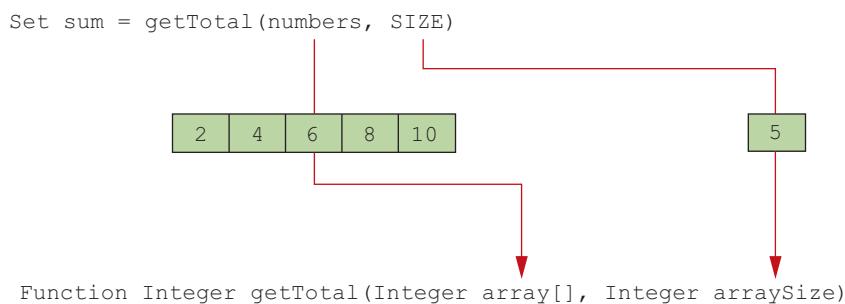
```
Function Integer getTotal(Integer array[], Integer arraySize)
```

Notice that the function has the following two parameters.

- `Integer array[]`—This parameter accepts an array of `Integers` as an argument.
- `Integer arraySize`—This parameter accepts an `Integer` that specifies the number of elements in the array.

When the function is called in line 12, it passes the `numbers` array into the `array` parameter, and the value of the `SIZE` constant into the `arraySize` parameter. This is shown in Figure 8-9. The function then calculates the total of the values in `array` and returns that value.

**Figure 8-9** Passing arguments to the getTotal function



## In the Spotlight: Processing an Array



Dr. LaClaire gives four exams during the semester in her chemistry class. At the end of the semester she drops each student's lowest test score before averaging the scores. She has asked you to design a program that will read a student's four test scores as input, and calculate the average with the lowest score dropped. Here is the algorithm that you developed:

1. Read the student's four test scores.
  2. Calculate the total of the scores.
  3. Find the lowest score.
  4. Subtract the lowest score from the total. This gives the adjusted total.
  5. Divide the adjusted total by 3. This is the average.
  6. Display the average.

Program 8-14 shows the pseudocode for the program, which is modularized. Rather than presenting the entire program at once, let's first examine the `main` module, and then each additional module and function separately. Here is the `main` module:

## **Program 8-14**

## **Score calculation program: main module**

```
1 Module main()
2 // Constant for the array size.
3 Constant Integer SIZE = 4
4
5 // Array to hold test scores.
6 Declare Real testScores[SIZE]
7
8 // Variable to hold the total of scores.
9 Declare Real total
10
11 // Variable to hold the lowest score.
12 Declare Real lowestScore
```

```
13 // Variable to hold the average score.
14 Declare Real average
15
16 // Get the test scores from the user.
17 Call getTestScores(testScores, SIZE)
18
19 // Get the total of the test scores.
20 Set total = getTotal(testScores, SIZE)
21
22 // Get the lowest test score.
23 Set lowestScore = getLowest(testScores, SIZE)
24
25 // Subtract the lowest score from the total.
26 Set total = total - lowestScore
27
28 // Calculate the average. Divide by 3
29 // because the lowest score was dropped.
30 Set average = total / (SIZE - 1)
31
32 // Display the average.
33 Display "The average with the lowest score"
34 Display "dropped is ", average
35
36 End Module
37
```

Lines 3 through 15 declare the following items:

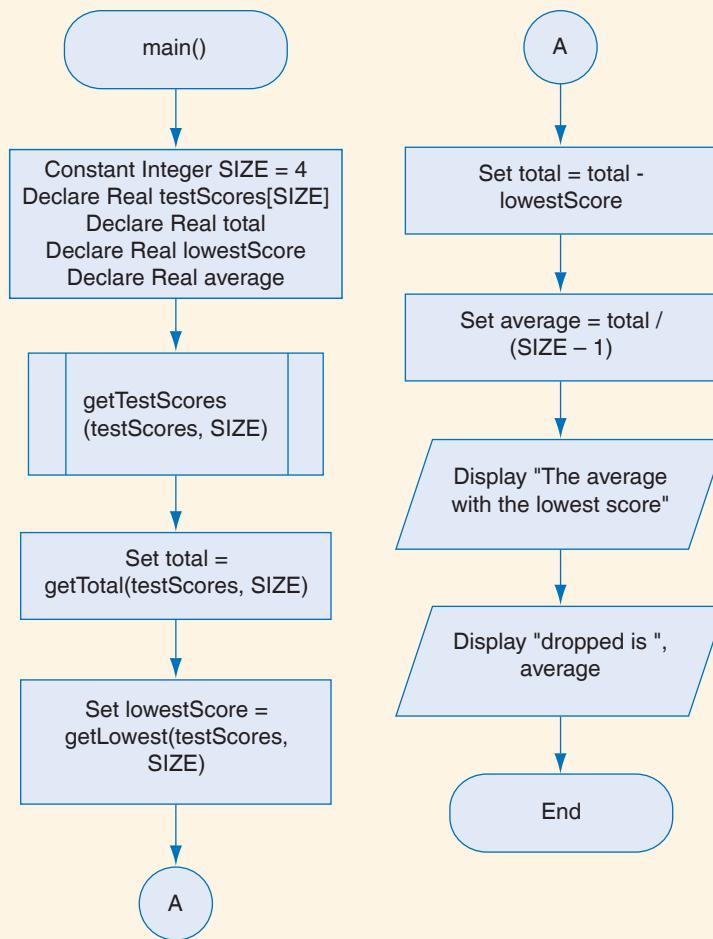
- **SIZE**, a constant that is used as an array size declarator
- **testScores**, a **Real** array to hold the test scores
- **total**, a **Real** variable that will hold the test score totals
- **lowestScore**, a **Real** variable that will hold the lowest test score
- **average**, a **Real** variable that will hold the average of the test scores

Line 18 calls the **getTestScores** module, passing the **testScores** array and the value of the **SIZE** constant as arguments. As you will see in a moment, the **testScores** array is passed by reference. The module gets the test scores from the user and stores them in the array.

Line 21 calls the **getTotal** function, passing the **testScores** array and the value of the **SIZE** constant as arguments. The function returns the total of the values in the array. This value is assigned to the **total** variable.

Line 24 calls the **getLowest** function, passing the **testScores** array and the value of the **SIZE** constant as arguments. The function returns the lowest value in the array. This value is assigned to the **lowestScore** variable.

Line 27 subtracts the lowest test score from the **total** variable. Then, line 31 calculates the average by dividing **total** by **SIZE - 1**. (The program divides by **SIZE - 1** because the lowest test score was dropped.) Lines 34 and 35 display the average. Figure 8-10 shows a flowchart for the **main** module.

**Figure 8-10** Flowchart for the main module

Next is the `getTestScores` module definition.

**Program 8-14****Score calculation program (continued):  
getTestScores module**

```

38 // The getTestScores module accepts an array (by reference)
39 // and its size as arguments. It prompts the user to enter
40 // test scores, which are stored in the array.
41 Module getTestScores(Real Ref scores[], Integer arraySize)
42 // Loop counter
43 Declare Integer index
44
45 // Get each test score.
46 For index = 0 To arraySize - 1
47 Display "Enter test score number ", index + 1
48 Input scores[index]
49 End For
50 End Module
51

```

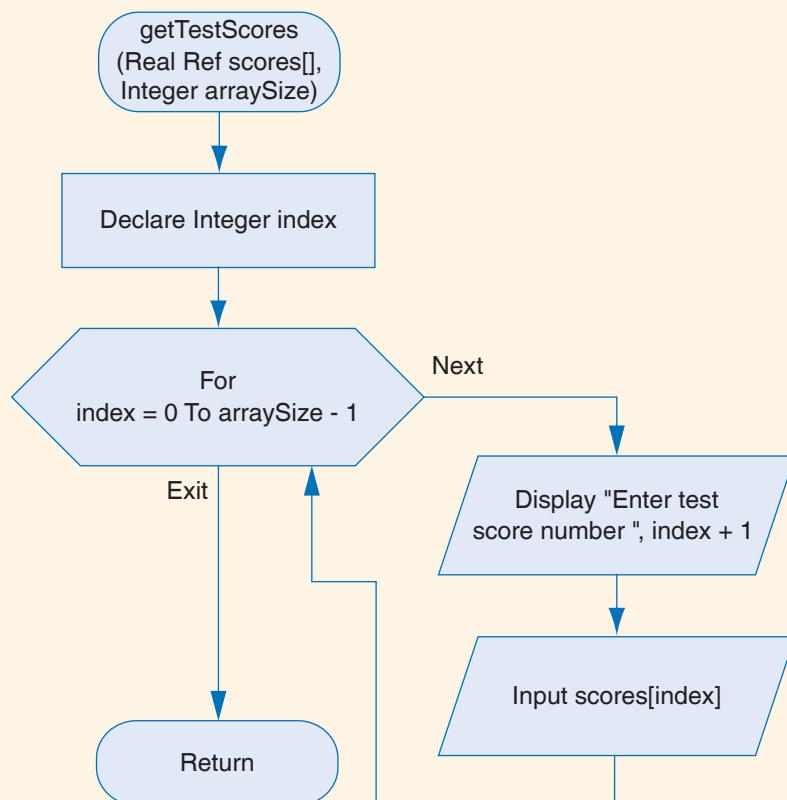
The `getTestScores` module has two parameters:

- `scores[]`—A `Real` array is passed by reference into this parameter.
- `arraySize`—An `Integer` specifying the size of the array is passed into this parameter.

The purpose of this module is to get a student's test scores from the user and store them in the array that is passed as an argument into the `scores[]` parameter. Figure 8-11 shows a flowchart for this module.

The `getTotal` function definition appears next.

**Figure 8-11** Flowchart for the `getTestScores` module



#### Program 8-14

#### Score calculation program (continued): getTotal function

```
52 // The getTotal function accepts a Real array and its
53 // size as arguments. It returns the total of the
54 // array elements.
55 Function Real getTotal(Real array[], Integer arraySize)
56 // Loop counter
57 Declare Integer index
```

```
58
59 // Accumulator, initialized to 0
60 Declare Real total = 0
61
62 // Calculate the total of the array elements.
63 For index = 0 To arraySize - 1
64 Set total = total + array[index]
65 End For
66
67 // Return the total.
68 Return total
69 End Function
70
```

The `getTotal` function has two parameters:

- `array[]`—A `Real` array
- `arraySize`—An `Integer` specifying the size of the array

This function returns the total of the values in the array that is passed as an argument into the `array[]` parameter. Figure 8-12 shows a flowchart for this module.

The program continues by defining the `getLowest` function.

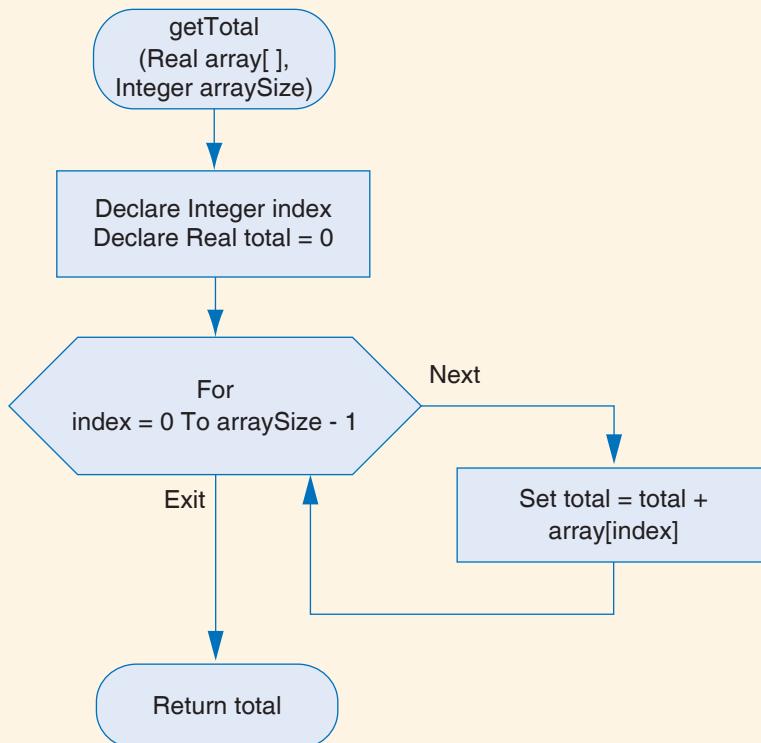
#### Program 8-14

#### Score calculation program (continued): getLowest function

```
71 // The getLowest function accepts a Real array and its
72 // size as arguments and returns the lowest value in
73 // the array.
74 Function Real getLowest(Real array[], Integer arraySize)
75 // Variable to hold the lowest value.
76 Declare Real lowest
77
78 // Loop counter
79 Declare Integer index
80
81 // Get the first element of the array.
82 Set lowest = array[0]
83
84 // Step through the rest of the array. When a value
85 // less than lowest is found, assign it to lowest.
86 For index = 1 To arraySize - 1
```

```
87 If array[index] < lowest Then
88 Set lowest = array[index]
89 End If
90 End For
91
92 // Return the lowest value.
93 Return lowest
94 End Function
```

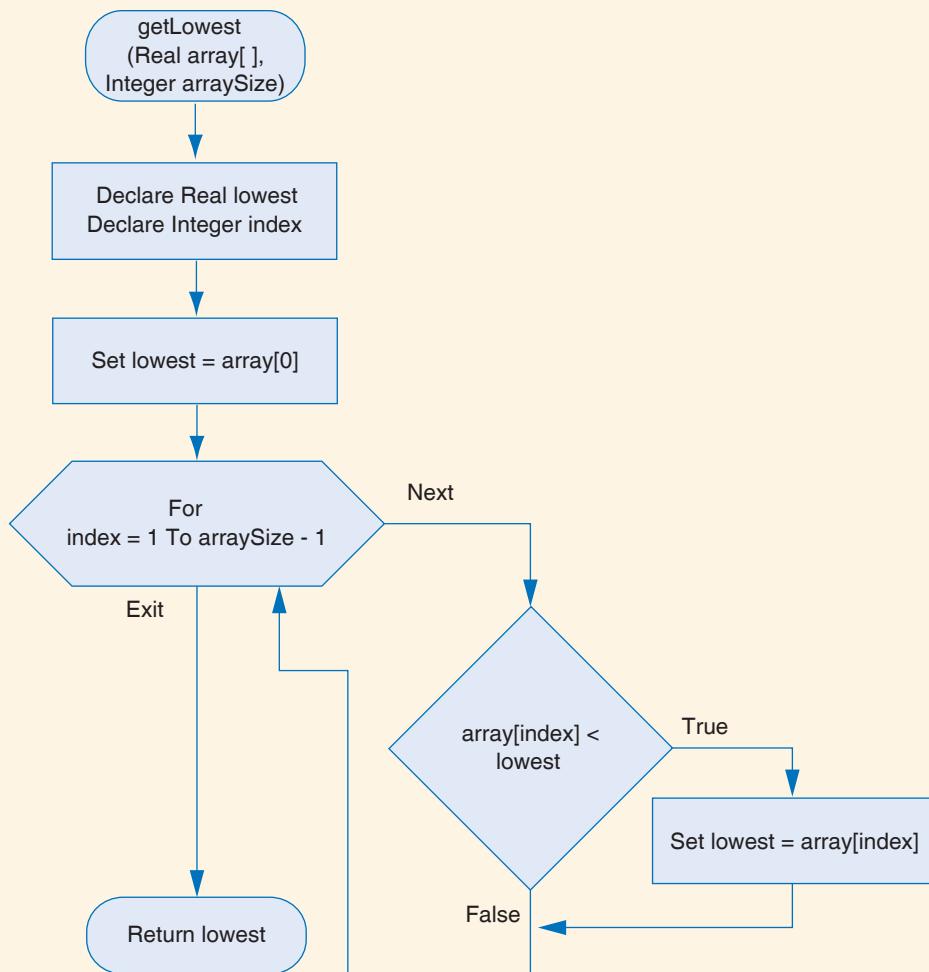
**Figure 8-12** Flowchart for the getTotal function



The getlowest function has two parameters:

- `array[]`—A Real array
- `arraySize`—An Integer specifying the size of the array

This function returns the lowest value in the array that is passed as an argument into the `array[]` parameter. Figure 8-13 shows a flowchart for this module.

**Figure 8-13** Flowchart for the getLowest function**Program Output (with Input Shown in Bold)**

```
Enter test score number 1
92 [Enter]
Enter test score number 2
67 [Enter]
Enter test score number 3
75 [Enter]
Enter test score number 4
88 [Enter]
The average with the lowest score
dropped is 85
```



**NOTE:** In many of the most common programming languages (including Java, C++, and C#), arrays are *always* passed by reference. This is because it is inefficient to make a copy of an entire array each time it is passed as an argument to a module or function. In such languages, when you pass an array as an argument, the parameter variable in the module or function becomes a reference to the array. That means the module or function has access to the original data in the array (not a copy). When using one of these languages, take care that in modules and functions you do not unintentionally modify an array that has been passed as an argument.



## Checkpoint

- 8.15 Briefly describe how you calculate the total of the values in an array.
- 8.16 Briefly describe how you get the average of the values in an array.
- 8.17 Describe the algorithm for finding the highest value in an array.
- 8.18 Describe the algorithm for finding the lowest value in an array.
- 8.19 How do you copy the contents of one array to another array?

### 8.4

## Parallel Arrays

**CONCEPT:** By using the same subscript, you can establish relationships between data stored in two or more arrays.



VideoNote  
Parallel Arrays

Sometimes it is useful to store related data in two or more arrays. For example, assume you have designed a program with the following array declarations:

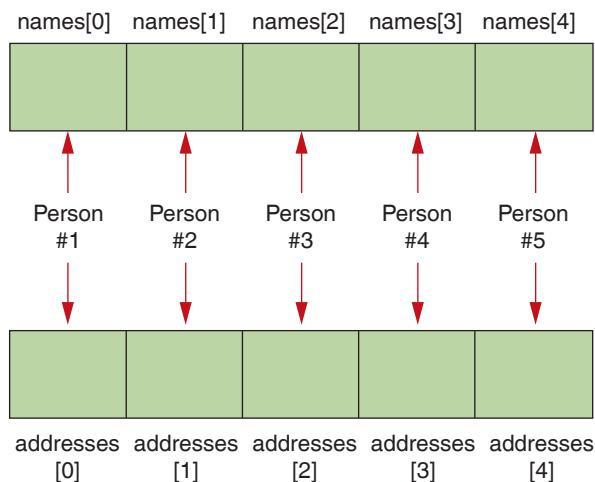
```
Constant Integer SIZE = 5
Declare String names[SIZE]
Declare String addresses[SIZE]
```

The `names` array stores the names of five people, and the `addresses` array stores the addresses of the same five people. The data for each person is stored in the same relative location in each array. For instance, the first person's name is stored in `names[0]`, and that same person's address is stored in `addresses[0]`. Figure 8-14 illustrates this.

To access the data, you use the same subscript with both arrays. For example, the loop in the following pseudocode displays each person's name and address:

```
Declare Integer index
For index = 0 To SIZE - 1
 Display names[index]
 Display addresses[index]
End For
```

The `names` and `addresses` arrays are examples of parallel arrays. *Parallel arrays* are two or more arrays that hold related data, and the related elements in each array are accessed with a common subscript.

**Figure 8-14** The names and addresses arrays

## In the Spotlight: Using Parallel Arrays

In this chapter's first *In the Spotlight* section (see Program 8-4), Megan asked you to design a program that allows her to enter the number of hours worked by each of her employees and then displays each employee's gross pay. As it is currently designed, the program refers to the employees as "employee 1," employee 2," and so on. Megan has asked you to modify the program so she can enter employees' names along with their hours, and then it should display each employee's name along with their gross pay.

Currently, the program has an array named `hours` that holds each employee's hours worked. You decide to add a parallel array named `names` that will hold each employee's name. The first employee's data will appear in `names[0]` and in `hours[0]`, the second employee's data will appear in `names[1]` and in `hours[1]`, and so on.

Here is the updated algorithm:

1. For each employee:
  - a. Get the employee's name and store it in the `names` array.
  - b. Get the employee's number of hours worked and store it in the corresponding element of the `hours` array.
2. Step through each set of elements in the parallel arrays and display the employee's name and gross pay.

Program 8-15 shows the pseudocode for the revised program, and Figure 8-15 shows a flowchart.

### Program 8-15

```

1 // Constant for the array sizes.
2 Constant Integer SIZE = 6
3
4 // Array to hold each employee's name.
5 Declare String names[SIZE]
6

```

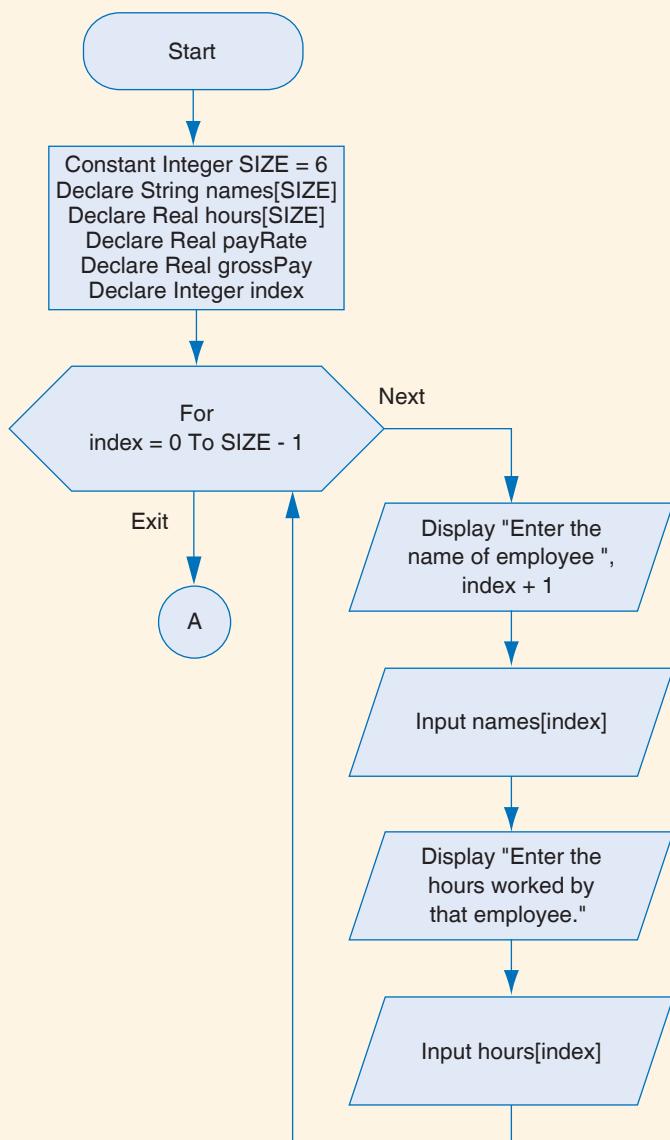
```
7 // Array to hold each employee's hours.
8 Declare Real hours[SIZE]
9
10 // Variable to hold the hourly pay rate.
11 Declare Real payRate
12
13 // Variable to hold a gross pay amount.
14 Declare Real grossPay
15
16 // Variable to use as a loop counter.
17 Declare Integer index
18
19 // Get each employee's data.
20 For index = 0 To SIZE - 1
21 // Get an employee's name.
22 Display "Enter the name of employee ", index + 1
23 Input names[index]
24
25 // Get the employee's hours.
26 Display "Enter the hours worked by that employee."
27 Input hours[index]
28 End For
29
30 // Get the hourly pay rate.
31 Display "Enter the hourly pay rate."
32 Input payRate
33
34 // Display each employee's gross pay.
35 Display "Here is each employee's gross pay."
36 For index = 0 To SIZE - 1
37 Set grossPay = hours[index] * payRate
38 Display names[index], ": ", currencyFormat(grossPay)
39 End For
```

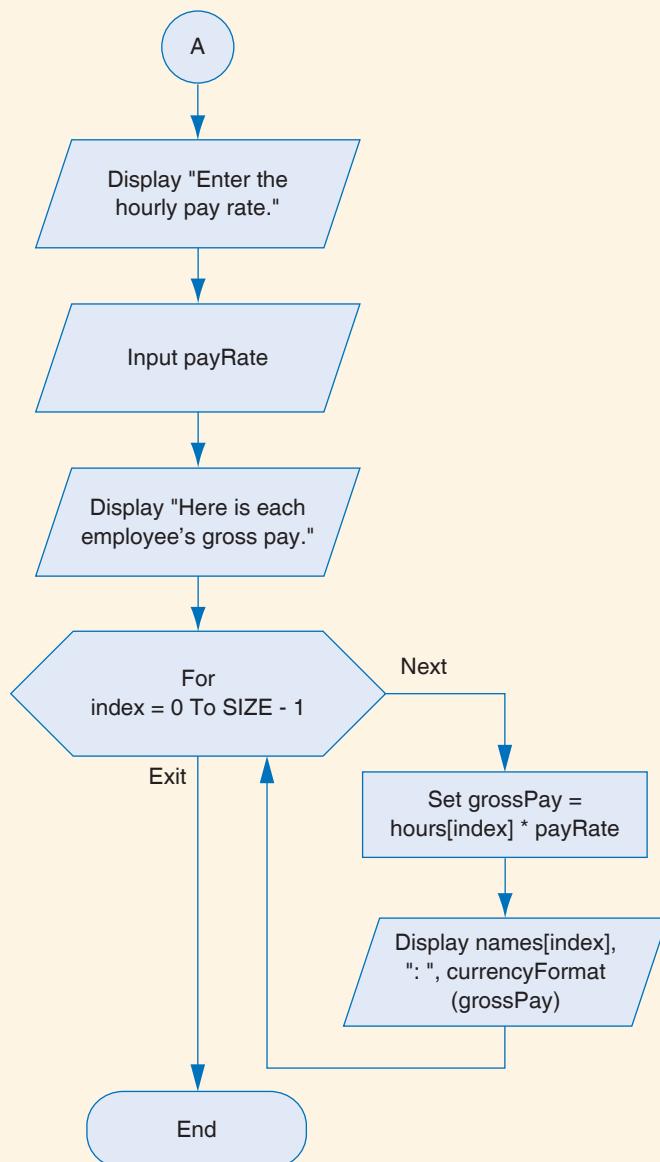
### Program Output (with Input Shown in Bold)

```
Enter the name of employee 1
Jamie Lynn [Enter]
Enter the hours worked by that employee.
10 [Enter]
Enter the name of employee 2
Courtney [Enter]
Enter the hours worked by that employee.
20 [Enter]
Enter the name of employee 3
Ashley [Enter]
Enter the hours worked by that employee.
15 [Enter]
Enter the name of employee 4
Brian [Enter]
Enter the hours worked by that employee.
40 [Enter]
Enter the name of employee 5
Jane [Enter]
Enter the hours worked by that employee.
20 [Enter]
Enter the name of employee 6
```

```
Ian [Enter]
Enter the hours worked by that employee.
18 [Enter]
Enter the hourly pay rate.
12.75 [Enter]
Here is each employee's gross pay.
Jamie Lynn: $127.50
Courtney: $255.00
Ashley: $191.25
Brian: $510.00
Jane: $255.00
Ian: $229.50
```

**Figure 8-15** Flowchart for Program 8-15



**Figure 8-15 (continued)****Checkpoint**

- 8.20 How do you establish a relationship between the data stored in two parallel arrays?
- 8.21 A program uses two parallel arrays: `names` and `creditScore`. The `names` array holds customer names and the `creditScore` array holds customer credit scores. If a particular customer's name is stored in `names[82]`, where would that customer's credit score be stored?

**8.5**

## Two-Dimensional Arrays

**CONCEPT:** A two-dimensional array is like several identical arrays put together. It is useful for storing multiple sets of data.

The arrays that you have studied so far are known as one-dimensional arrays. They are called *one dimensional* because they can hold only one set of data. Two-dimensional arrays, which are also called *2D arrays*, can hold multiple sets of data. Think of a two-dimensional array as having rows and columns of elements, as shown in Figure 8-16. This figure shows a two-dimensional array having three rows and four columns. Notice that the rows are numbered 0, 1, and 2, and the columns are numbered 0, 1, 2, and 3. There is a total of 12 elements in the array.

**Figure 8-16** A two-dimensional array

|       | Column 0 | Column 1 | Column 2 | Column 3 |
|-------|----------|----------|----------|----------|
| Row 0 |          |          |          |          |
| Row 1 |          |          |          |          |
| Row 2 |          |          |          |          |

Two-dimensional arrays are useful for working with multiple sets of data. For example, suppose you are designing a grade-averaging program for a teacher. The teacher has six students, and each student takes five exams during the semester. One approach would be to create six one-dimensional arrays, one for each student. Each of these arrays would

**Figure 8-17** Two-dimensional array with six rows and five columns

|                                    | This column contains scores for exam #1 | This column contains scores for exam #2 | This column contains scores for exam #3 | This column contains scores for exam #4 | This column contains scores for exam #5 |
|------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|
|                                    | Column 0                                | Column 1                                | Column 2                                | Column 3                                | Column 4                                |
| This row is for student #1 → Row 0 |                                         |                                         |                                         |                                         |                                         |
| This row is for student #2 → Row 1 |                                         |                                         |                                         |                                         |                                         |
| This row is for student #3 → Row 2 |                                         |                                         |                                         |                                         |                                         |
| This row is for student #4 → Row 3 |                                         |                                         |                                         |                                         |                                         |
| This row is for student #5 → Row 4 |                                         |                                         |                                         |                                         |                                         |
| This row is for student #6 → Row 5 |                                         |                                         |                                         |                                         |                                         |

have five elements, one for each exam score. This approach would be cumbersome, however, because you would have to separately process each of the arrays. A better approach would be to use a two-dimensional array with six rows (one for each student) and five columns (one for each exam score), as shown in Figure 8-17.

## Declaring a Two-Dimensional Array

To declare a two-dimensional array, two size declarators are required: The first one is for the number of rows and the second one is for the number of columns. The following pseudocode shows an example of how to declare a two-dimensional array:

```
Declare Integer values[3][4]
```

This statement declares a two-dimensional `Integer` array with three rows and four columns. The name of the array is `values`, and there are a total of 12 elements in the array. As with one-dimensional arrays, it is best to use named constants as the size declarators. Here is an example:

```
Constant Integer ROWS = 3
Constant Integer COLS = 4
Declare Integer values[ROWS][COLS]
```

When processing the data in a two-dimensional array, each element has two subscripts: one for its row and another for its column. In the `values` array, the elements in row 0 are referenced as follows:

```
values[0][0]
values[0][1]
values[0][2]
values[0][3]
```

The elements in row 1 are as follows:

```
values[1][0]
values[1][1]
values[1][2]
values[1][3]
```

And the elements in row 2 are as follows:

```
values[2][0]
values[2][1]
values[2][2]
values[2][3]
```

Figure 8-18 illustrates the array with the subscripts shown for each element.

**Figure 8-18** Subscripts for each element of the `values` array

|       | Column 0     | Column 1     | Column 2     | Column 3     |
|-------|--------------|--------------|--------------|--------------|
| Row 0 | values[0][0] | values[0][1] | values[0][2] | values[0][3] |
| Row 1 | values[1][0] | values[1][1] | values[1][2] | values[1][3] |
| Row 2 | values[2][0] | values[2][1] | values[2][2] | values[2][3] |

## Accessing the Elements in a Two-Dimensional Array

To access one of the elements in a two-dimensional array, you must use both subscripts. For example, the following pseudocode statement assigns the number 95 to `values[2][1]`:

```
Set values[2][1] = 95
```

Programs that process two-dimensional arrays commonly do so with nested loops. The pseudocode in Program 8-16 shows an example. It declares an array with three rows and four columns, prompts the user for values to store in each element, and then displays the values in each element.

### Program 8-16



```

1 // Create a 2D array.
2 Constant Integer ROWS = 3
3 Constant Integer COLS = 4
4 Declare Integer values[ROWS][COLS]
5
6 // Counter variables for rows and columns.
7 Declare Integer row, col
8
9 // Get values to store in the array.
10 For row = 0 To ROWS - 1
11 For col = 0 To COLS - 1
12 Display "Enter a number."
13 Input values[row][col]
14 End For
15 End For
16
17 // Display the values in the array.
18 Display "Here are the values you entered."
19 For row = 0 To ROWS - 1
20 For col = 0 To COLS - 1
21 Display values[row][col]
22 End For
23 End For

```

### Program Output (with Input Shown in Bold)

```

Enter a number.
1 [Enter]
Enter a number.
2 [Enter]
Enter a number.
3 [Enter]
Enter a number.
4 [Enter]
Enter a number.
5 [Enter]
Enter a number.
6 [Enter]

```

```
Here are the values you entered.
```

```
1
2
3
4
5
6
```



**TIP:** Most languages allow you to initialize a two-dimensional array with data when you declare the array. The syntax varies from language to language. Here is an example of how you can initialize a two-dimensional array in pseudocode:

```
Declare Integer testScores[3][4] = 88, 72, 90, 92,
 67, 72, 91, 85,
 79, 65, 72, 84
```

In this declaration the value 88 is stored in `testScores[0][0]`, the value 72 is stored in `testScores[0][1]`, the value 90 is stored in `testScores[0][2]`, and so forth.

The following *In the Spotlight* section shows another example of a two-dimensional array. This program adds all of the elements of a two-dimensional array to an accumulator.

## In the Spotlight: Using a Two-Dimensional Array



Unique Candy Inc. has three divisions: division 1 (East Coast), division 2 (Midwest), and division 3 (West Coast). The sales manager has asked you to design a program that will read as input each division's sales for each quarter of the year, and then display the total sales for all divisions.

This program requires you to process three sets of data:

- The sales amounts for division 1
- The sales amounts for division 2
- The sales amounts for division 3

Each of these sets of data contains four items:

- The sales for quarter 1
- The sales for quarter 2
- The sales for quarter 3
- The sales for quarter 4

You decide to store the sales amounts in a two-dimensional array. The array will have three rows (one for each division) and four columns (one for each quarter). Figure 8-19 shows how the sales data will be organized in the array.

**Figure 8-19** Two-dimensional array to hold sales data

|       | Column 0                                            | Column 1                                            | Column 2                                            | Column 3                                            |
|-------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| Row 0 | sales[0][0]<br>Holds data for division 1, quarter 1 | sales[0][1]<br>Holds data for division 1, quarter 2 | sales[0][2]<br>Holds data for division 1, quarter 3 | sales[0][3]<br>Holds data for division 1, quarter 4 |
| Row 1 | sales[1][0]<br>Holds data for division 2, quarter 1 | sales[1][1]<br>Holds data for division 2, quarter 2 | sales[1][2]<br>Holds data for division 2, quarter 3 | sales[1][3]<br>Holds data for division 2, quarter 4 |
| Row 2 | sales[2][0]<br>Holds data for division 3, quarter 1 | sales[2][1]<br>Holds data for division 3, quarter 2 | sales[2][2]<br>Holds data for division 3, quarter 3 | sales[2][3]<br>Holds data for division 3, quarter 4 |

The program will use a pair of nested loops to read the sales amounts. It will then use a pair of nested loops to add all of the array elements to an accumulator variable. Here is an overview of the algorithm:

1. For each division:
  - For each quarter:
    - Read the amount of sales for the quarter and store it in the array.
2. For each row in the array:
  - For each column in the array:
    - Add the amount in the column to an accumulator.
3. Display the amount in the accumulator.

Program 8-17 shows the pseudocode for the program.

### Program 8-17

```

1 // Constants for the array sizes.
2 Constant Integer ROWS = 3
3 Constant Integer COLS = 4
4
5 // An array to hold company sales.
6 Declare Real sales[ROWS][COLS]
7
8 // Counter variables
9 Declare Integer row, col
10
11 // Accumulator
12 Declare Real total = 0
13
14 // Display instructions.
15 Display "This program calculates the company's"
16 Display "total sales. Enter the quarterly sales"
17 Display "amounts for each division when prompted."
18
19 // Nested loops to fill the array with quarterly

```

```
20 // sales amounts for each division.
21 For row = 0 To ROWS - 1
22 For col = 0 To COLS - 1
23 Display "Division ", row + 1, " quarter ", col + 1
24 Input sales[row][col]
25 End For
26 // Display a blank line.
27 Display
28 End For
29
30 // Nested loops to add all of the array elements.
31 For row = 0 To ROWS - 1
32 For col = 0 To COLS - 1
33 Set total = total + sales[row][col]
34 End For
35 End For
36
37 // Display the total sales.
38 Display "The total company sales are: $",
39 currencyFormat(total)
```

### Program Output (with Input Shown in Bold)

This program calculates the company's total sales. Enter the quarterly sales amounts for each division when prompted.

```
Division 1 quarter 1
1000.00 [Enter]
Division 1 quarter 2
1100.00 [Enter]
Division 1 quarter 3
1200.00 [Enter]
Division 1 quarter 4
1300.00 [Enter]
```

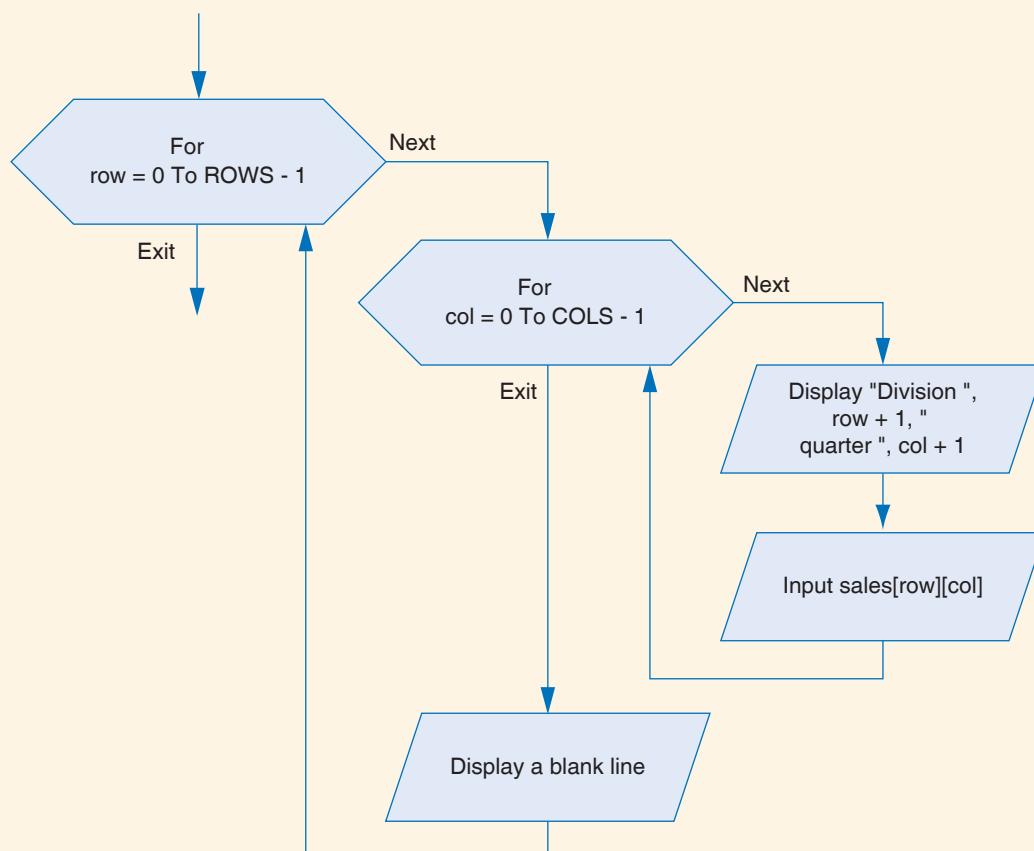
```
Division 2 quarter 1
2000.00 [Enter]
Division 2 quarter 2
2100.00 [Enter]
Division 2 quarter 3
2200.00 [Enter]
Division 2 quarter 4
2300.00 [Enter]
```

```
Division 3 quarter 1
3000.00 [Enter]
Division 3 quarter 2
3100.00 [Enter]
Division 3 quarter 3
3200.00 [Enter]
Division 3 quarter 4
3300.00 [Enter]
```

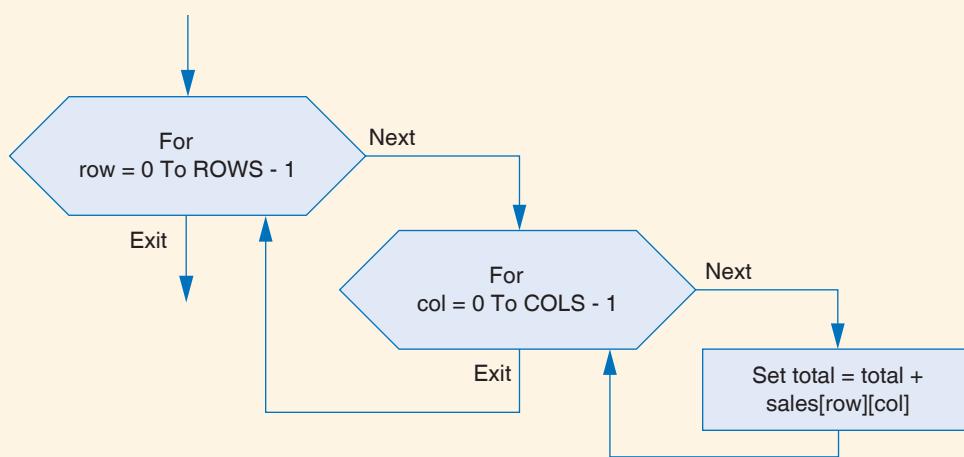
```
The total company sales are: $25,800.00
```

The first set of nested loops appears in lines 21 through 28. This part of the program prompts the user for each quarter's sales amount for each division. Figure 8-20 shows a flowchart for this set of loops.

**Figure 8-20** Flowchart for the first set of nested loops (lines 21 through 28)



The second set of nested loops appears in lines 31 through 35. This part of the program steps through the `sales` array, adding the value of each element to the `total` variable, which is an accumulator. Figure 8-21 shows a flowchart for this set of loops. After these loops finish running, the `total` variable will contain the total of all the elements in the `sales` array.

**Figure 8-21** Flowchart for the second set of nested loops (lines 31 through 35)

### Checkpoint

8.22 How many rows and how many columns are in the following array?

```
Declare Integer points[88][100]
```

8.23 Write a pseudocode statement that assigns the value 100 to the very last element in the points array declared in Checkpoint 8.22.

8.24 Write a pseudocode declaration for a two-dimensional array initialized with the following table of data:

|    |    |    |    |    |
|----|----|----|----|----|
| 12 | 24 | 32 | 21 | 42 |
| 14 | 67 | 87 | 65 | 90 |
| 19 | 1  | 24 | 12 | 8  |

8.25 Assume a program has the following declarations:

```
Constant Integer ROWS = 100
Constant Integer COLS = 50
Declare Integer info[ROWS][COLS]
```

Write pseudocode with a set of nested loops that stores the value 99 in each element of the info array.

## 8.6

### Arrays of Three or More Dimensions

**CONCEPT:** To model data that occurs in multiple sets, most languages allow you to create arrays with multiple dimensions.

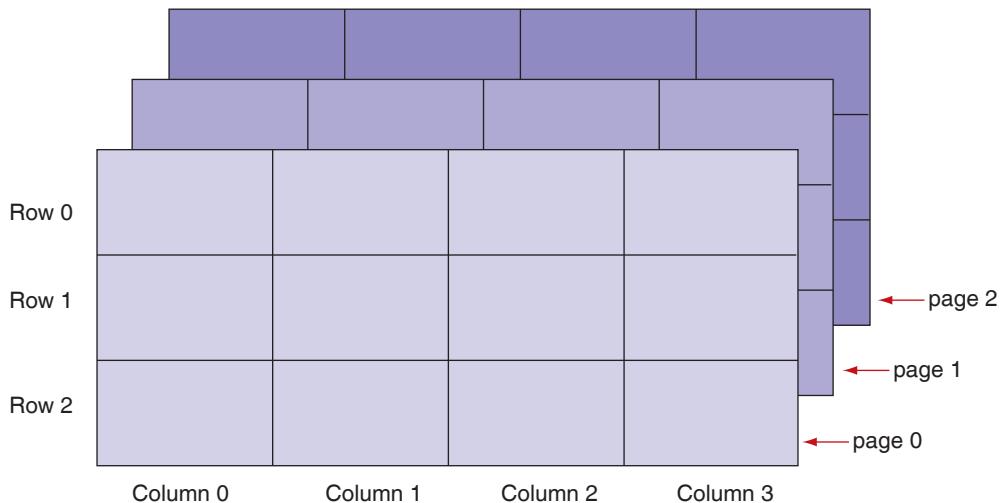
In the last section you saw examples of two-dimensional arrays. Most languages also allow you to create arrays with three or more dimensions. Here is an example of a three-dimensional array declaration in pseudocode:

```
Declare Real seats [3][5][8]
```

You can think of this array as three sets of five rows, with each row containing eight elements. The array might be used to store the prices of seats in an auditorium, where there are eight seats in a row, five rows in a section, and a total of three sections.

Figure 8-22 illustrates the concept of a three-dimensional array as “pages” of two-dimensional arrays.

**Figure 8-22** A three-dimensional array



Arrays with more than three dimensions are difficult to visualize, but they can be useful in some programming problems. For example, in a factory warehouse where cases of widgets are stacked on pallets, an array with four dimensions could be used to store a part number for each widget. The four subscripts of each element could represent the pallet number, case number, row number, and column number of each widget. Similarly, an array with five dimensions could be used if there were multiple warehouses.



### Checkpoint

- 8.26 A bookstore keeps books on 50 racks with 10 shelves each. Each shelf holds 25 books. Declare a 3D String array to hold the names of all the books in the store. The array’s three dimensions should represent the racks, shelves, and books in the store.

**8.7**

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

#### Arrays

##### Java Array Declarations

Here is an example of an array declaration in Java:

```
int[] numbers = new int[6];
```

This statement declares `numbers` as an `int` array. The size declarator specifies that the array has 6 elements. As mentioned earlier in this chapter, it is a good practice to use a named constant for the size declarator, as shown here:

```
final int SIZE = 6;
int[] numbers = new int[SIZE];
```

Here is another example:

```
final int SIZE = 200;
double[] temperatures = new double[SIZE];
```

This code snippet declares `temperatures` as an array of 200 `doubles`. Here is one more:

```
final int SIZE = 10;
String[] names = new String[SIZE];
```

This declares `names` as an array of 10 `Strings`.

##### Array Elements and Subscripts in Java

You access each element of an array with a subscript. The first element's subscript is 0, the second element's subscript is 1, and so forth. The last element's subscript is the array size minus 1. For example, the following code declares an `int` array with three elements, and then assigns values to each element. The subscripts for the elements are 0, 1, and 2.

```
final int SIZE = 3;
int[] numbers = new int[SIZE];
numbers[0] = 10;
numbers[1] = 20;
numbers[2] = 30;
```

##### Initializing an Array in Java

You can initialize an array with values when you declare it. Here is an example:

```
int[] days = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
```

This statement declares `days` as an array of `ints`, and stores initial values in the array. The series of values inside the braces and separated with commas is called an initialization list. These values are stored in the array elements in the order they appear in the list. (The first value, 31, is stored in `days[0]`, the second value, 28, is stored in `days[1]`, and so forth.) Note that you do not use the `new` key word when you use an initialization list. Java automatically creates the array and stores the values in the initialization list in it.

The Java compiler determines the size of the array by the number of items in the initialization list. Because there are 12 items in the example statement's initialization list, the array will have 12 elements.

### The `length` Attribute

Each array in Java has an attribute named `length`. The value of the attribute is the number of elements in the array. For example, consider the array created by the following statement:

```
double[] temperatures = new double[25];
```

Because the `temperatures` array has 25 elements, the following statement would assign 25 to the variable `size`:

```
size = temperatures.length;
```

The `length` attribute can be useful when processing the entire contents of an array. For example, the following loop steps through an array and displays the contents of each element. The array's `length` attribute is used in the test expression as the upper limit for the loop control variable:

```
for (int i = 0; i < temperatures.length; i++)
 System.out.println(temperatures[i]);
```

Be careful not to cause an off-by-one error when using the `length` attribute as the upper limit of a subscript. The `length` attribute contains the number of elements in an array. The largest subscript in an array is `length - 1`.

### Passing an Array as an Argument to a Method in Java

When passing an array as an argument to a method in Java, it is not necessary to pass a separate argument indicating the array's size. This is because arrays in Java have the `length` attribute that reports the array's size. The following code shows a method that has been written to accept an array as an argument:

```
public static void showArray(int[] array)
{
 for (int i = 0; i < array.length; i++)
 System.out.print(array[i] + " ");
}
```

Notice that the parameter variable, `array`, is declared as an `int` array. When we call this method we must pass an `int` array to it as an argument. Assuming that `numbers` is the name of an `int` array, here is an example of a method call that passes the `numbers` array as an argument to the `showArray` method:

```
showArray(numbers);
```

## Two-Dimensional Arrays in Java

Here is an example declaration of a two-dimensional array with three rows and four columns:

```
double[][] scores = new double[3][4];
```

The two sets of brackets in the data type indicate that the `scores` variable will reference a two-dimensional array. The numbers 3 and 4 are size declarators. The first size declarator specifies the number of rows, and the second size declarator specifies the number of columns. Notice that each size declarator is enclosed in its own set of brackets.

When processing the data in a two-dimensional array, each element has two subscripts: one for its row and another for its column. In the `scores` array, the elements in row 0 are referenced as follows:

```
scores[0][0]
scores[0][1]
scores[0][2]
scores[0][3]
```

The elements in row 1 are as follows:

```
scores[1][0]
scores[1][1]
scores[1][2]
scores[1][3]
```

And the elements in row 2 are as follows:

```
scores[2][0]
scores[2][1]
scores[2][2]
scores[2][3]
```

To access one of the elements in a two-dimensional array, you must use both subscripts. For example, the following statement stores the number 95 in `scores[2][1]`:

```
scores[2][1] = 95;
```

Programs that process two-dimensional arrays can do so with nested loops. For example, the following code prompts the user to enter a score, once for each element in the array:

```
final int ROWS = 3;
final int COLS = 4;
double[][] scores = new double[ROWS][COLS];
for (int row = 0; row < ROWS; row++)
{
 for (int col = 0; col < COLS; col++)
 {
 System.out.print("Enter a score: ");
 scores[row][col] = keyboard.nextDouble();
 }
}
```

And the following code displays all the elements in the `scores` array:

```
for (int row = 0; row < ROWS; row++)
```

```

{
 for (int col = 0; col < COLS; col++)
 {
 System.out.println(scores[row][col]);
 }
}

```

### Arrays with Three or More Dimensions in Java

Java allows you to create arrays with virtually any number of dimensions. Here is an example of a three-dimensional array declaration:

```
double[][][] seats = new double[3][5][8];
```

This array can be thought of as three sets of five rows, with each row containing eight elements. The array might be used to store the prices of seats in an auditorium, where there are eight seats in a row, five rows in a section, and a total of three sections.

## Python

### Lists

In Python, you create lists instead of arrays. A *list* is similar to an array, but provides many more capabilities than a traditional array. A list is an object that contains multiple data items. Each item that is stored in a list is called an *element*. Here is a statement that creates a list of integers:

```
even_numbers = [2, 4, 6, 8, 10]
```

The items that are enclosed in brackets and separated by commas are the values of the list elements. The following is another example:

```
names = ['Molly', 'Steven', 'Will', 'Alicia', 'Adriana']
```

This statement creates a list of 5 strings.

You can use the `print` function to display an entire list, as shown here:

```
numbers = [5, 10, 15, 20]
print(numbers)
```

When the `print` function is called in the second statement, it will display the elements of the list like this:

```
[5, 10, 15, 20]
```

### List Elements and Subscripts in Python

You access each element of a list with a subscript. As discussed in your textbook, the first element's subscript is 0, the second element's subscript is 1, and so forth. The last element's subscript is the array size minus 1. For example, the following code creates a list named `numbers`, with three elements that are all set to the value 0. It then assigns different values to each element. The subscripts for the elements are 0, 1, and 2.

```
numbers = [0, 0, 0]
```

```
numbers[0] = 10
numbers[1] = 20
numbers[2] = 30
```

### Using the len Function with Lists in Python

An error will occur if you use an invalid index with a list. For example, look at the following code:

```
This code will cause an error.
my_list = [10, 20, 30, 40]
index = 0
while index < 5:
 print(my_list[index])
 index += 1
```

The last time that this loop iterates, the `index` variable will be assigned the value 4, which is an invalid index for the list. As a result, the statement that calls the `print` function will cause an error.

You can use the `len` function to get the length of a list in Python. When you pass a list as an argument, the `len` function returns the number of elements in the list. The previously shown code, which causes an error, can be modified as follows to prevent the error:

```
my_list = [10, 20, 30, 40]
index = 0
while index < len(my_list):
 print(my_list[index])
 index += 1
```

### Iterating Over a List with the for Loop in Python

In Python, you can easily iterate over the contents of a list with the `for` loop, as shown here:

```
numbers = [99, 100, 101, 102]
for n in numbers:
 print(n)
```

The `for` statement executes in the following manner: The variable `n` is assigned a copy of the first value in the list, and then the statements that appear in the block are executed. Then, the variable `n` is assigned a copy of the next value in the list, and the statements in the block are executed again. This continues until the variable has been assigned the last value in the list. If we run this code, it will print:

```
99
100
101
102
```

Keep in mind that as the `for` loop executes, the `n` variable is assigned a copy of the list elements, and any changes made to the `n` variable do not affect the list. To demonstrate, look at the following:

```

1 numbers = [99, 100, 101, 102]
2 for n in my_list:
3 n = 0
4
5 print(my_list)

```

The statement in line 3 merely reassigns the `n` variable to a different value (0). It does not change the list element that `n` referred to before the statement executed. When this code executes, the statement in line 5 will print:

```

99
100
101
102

```

### **Passing List as an Argument to a Function in Python**

When passing a list as an argument to a function in Python, it is not necessary to pass a separate argument indicating the list's size. This is because Python provides the `len` function that reports the list's size. The following code shows a function that has been written to accept a list as an argument:

```

def set_to_zero(numbers):
 index = 0
 while index < len(numbers):
 numbers[index] = 0
 index = index + 1

```

The function's parameter, `numbers`, is used to refer to a list. When you call this function and pass a list as an argument, the loop sets each element to 0. Here is an example of a code that calls the function:

```

my_list = [1, 2, 3, 4, 5]
set_to_zero(my_list)
print(my_list)

```

The last statement will print:

```

0
0
0
0
0

```

### **Two-Dimensional Lists in Python**

In Python, you can create a list of lists, which acts much like a two-dimensional array. Here is an example:

```

numbers = [[1, 2, 3], [10, 20, 30]]

```

This creates a list named `numbers`, with two elements. The first element is the following list:

```
[1, 2, 3]
```

The second element is the following list:

```
[10, 20, 30]
```

The following statement prints the contents of `numbers[0]`, which is the first element:

```
print(numbers[0])
```

If we execute this statement, the following be displayed:

```
[1, 2, 3]
```

The following statement prints the contents of `numbers[1]`, which is the second element:

```
print(numbers[1])
```

If we execute this statement, the following be displayed:

```
[10, 20, 30]
```

### Rows and Columns

As discussed earlier in this chapter, we normally think of two-dimensional arrays as having rows and columns. We can use this metaphor with two-dimensional lists as well. For example, let's say the following two-dimensional list contains sets of test scores:

```
scores = [[70, 80, 90],
 [80, 60, 75],
 [85, 75, 95]]
```

By declaring the list this way (with each list that is an element shown on a separate line) it's easy to see how we can think of the list as a set of rows and columns.

When processing the data in a two-dimensional list, we use two subscripts: one for the row and another for the column. In the `scores` list, the elements in row 0 are referenced as follows:

```
scores[0][0]
scores[0][1]
scores[0][2]
```

The elements in row 1 are as follows:

```
scores[1][0]
scores[1][1]
scores[1][2]
```

And the elements in row 2 are as follows:

```
scores[2][0]
scores[2][1]
scores[2][2]
```

To access one of the elements in a two-dimensional list, you use both subscripts. For example, the following statement prints the number in `scores[0][2]`:

```
print(scores[0][2])
```

And the following statement assigns the number 95 to `scores[2][1]`:

```
scores[2][1] = 95
```

Programs that process two-dimensional lists can do so with nested loops. For example, the following code displays all the elements in the `scores` list:

```
NUM_ROWS = 3
NUM_COLS = 3

row = 0
while row < NUM_ROWS:
 col = 0
 while col < NUM_COLS:
 print(scores[row][col])
 col = col + 1
 row = row + 1
```

And the following code prompts the user to enter a score, once for each element in the list:

```
NUM_ROWS = 3
NUM_COLS = 3

row = 0
while row < NUM_ROWS:
 col = 0
 while col < NUM_COLS:
 scores[row][col] = int(input('Enter a score: '))
 col = col + 1
 row = row + 1
```

## C++

### Arrays

#### C++ Array Declarations

Here is an example of an array declaration in C++:

```
int numbers[6];
```

This statement declares `numbers` as an `int` array. The size declarator specifies that the array has 6 elements. As mentioned in your textbook, it is a good practice to use a named constant for the size declarator, as shown here:

```
const int SIZE = 6;
int numbers[SIZE];
```

Here is another example:

```
const int SIZE = 200;
double temperatures[SIZE];
```

This code snippet declares `temperatures` as an array of 200 `doubles`. Here is one more:

```
const int SIZE = 10;
string names[SIZE];
```

This declares `names` as an array of 10 `strings`.

### Array Elements and Subscripts in C++

You access each element of an array with a subscript. As discussed in your textbook, the first element's subscript is 0, the second element's subscript is 1, and so forth. The last element's subscript is the array size minus 1. For example, the following code declares an `int` array with three elements, and then assigns values to each element. The subscripts for the elements are 0, 1, and 2.

```
const int SIZE = 3;
int numbers[SIZE];
numbers[0] = 10;
numbers[1] = 20;
numbers[2] = 30;
```

### Initializing an Array in C++

You can initialize an array with values when you declare it. Here is an example:

```
const int SIZE = 12;
int days[SIZE] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
```

This statement declares `days` as an array of `int`s, and stores initial values in the array. The series of values inside the braces and separated with commas is called an *initialization list*. These values are stored in the array elements in the order they appear in the list. (The first value, 31, is stored in `days[0]`, the second value, 28, is stored in `days[1]`, and so forth.)

When initializing an array, it is not necessary to specify a size declarator. The C++ compiler will determine the size of the array by counting the number of items in the initialization list. For example, the previous declaration could be written like this:

```
int days[] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
```

### Passing an Array as an Argument to a Function in C++

When passing an array as an argument to a function in C++, you should also pass a separate `int` argument indicating the array's size. The following code shows a function that has been written to accept an array as an argument:

```
void showArray(int array[], int size)
{
 for (int i = 0; i < size; i++)
 cout << array[i] << " ";
}
```

Notice that the parameter variable, `array`, is declared as an `int` array, without a size declarator. When we call this function we must pass an `int` array to it as an argument. Let's assume that `numbers` is the name of an `int` array, and `SIZE` is a constant that specifies the size of the array. Here is a statement that calls the `showArray` function, passing the `numbers` array and `SIZE` as arguments:

```
showArray(numbers, SIZE);
```

### Two-Dimensional Arrays in C++

Here is an example declaration of a two-dimensional array with three rows and four columns:

```
double scores[3][4];
```

The two sets of brackets in the data type indicate that the `scores` variable will reference a two-dimensional array. The numbers 3 and 4 are size declarators. The first size declarator specifies the number of rows, and the second size declarator specifies the number of columns. Notice that each size declarator is enclosed in its own set of brackets.

When processing the data in a two-dimensional array, each element has two subscripts: one for its row and another for its column. In the `scores` array, the elements in row 0 are referenced as follows:

```
scores[0][0]
scores[0][1]
scores[0][2]
scores[0][3]
```

The elements in row 1 are as follows:

```
scores[1][0]
scores[1][1]
scores[1][2]
scores[1][3]
```

And the elements in row 2 are as follows:

```
scores[2][0]
scores[2][1]
scores[2][2]
scores[2][3]
```

To access one of the elements in a two-dimensional array, you must use both subscripts. For example, the following statement stores the number 95 in `scores[2][1]`:

```
scores[2][1] = 95;
```

Programs that process two-dimensional arrays can do so with nested loops. For example, the following code prompts the user to enter a score, once for each element in the array:

```
const int ROWS = 3;
const int COLS = 4;
double scores[ROWS][COLS];
for (int row = 0; row < ROWS; row++)
{
 for (int col = 0; col < COLS; col++)
 {
 cout << "Enter a score." << endl;
 cin >> scores[row][col];
 }
}
```

And the following code displays all the elements in the `scores` array:

```
for (int row = 0; row < ROWS; row++)
{
 for (int col = 0; col < COLS; col++)
```

```
{
 cout << scores[row][col] << endl;
}
}
```

### Arrays with Three or More Dimensions in C++

C++ allows you to create arrays with virtually any number of dimensions. Here is an example of a three-dimensional array declaration:

```
double seats[3][5][8];
```

This array can be thought of as three sets of five rows, with each row containing eight elements. The array might be used to store the prices of seats in an auditorium, where there are eight seats in a row, five rows in a section, and a total of three sections.

## Review Questions

### Multiple Choice

1. This appears in an array declaration and specifies the number of elements in the array.
  - a. subscript
  - b. size declarator
  - c. array name
  - d. initialization value
2. To make programs easier to maintain, many programmers use these to specify the size of an array.
  - a. real numbers
  - b. string expressions
  - c. math expressions
  - d. named constants
3. This is an individual storage location in an array.
  - a. element
  - b. bin
  - c. cubby hole
  - d. size declarator
4. This is a number that identifies a storage location in an array.
  - a. element
  - b. subscript
  - c. size declarator
  - d. identifier
5. This is typically the first subscript in an array.
  - a. - 1
  - b. 1
  - c. 0
  - d. The size of the array minus one

6. This is typically the last subscript in an array.
  - a. -1
  - b. 99
  - c. 0
  - d. The size of the array minus one
7. This algorithm uses a loop to step through each element of an array, starting with the first element, searching for a value.
  - a. sequential search
  - b. step-by-step search
  - c. elemental search
  - d. binary search
8. Many programming languages perform this, which means they do not allow a program to use an invalid array subscript.
  - a. memory checking
  - b. bounds checking
  - c. type compatibility checking
  - d. syntax checking
9. This term describes two or more arrays that hold related data, and the related elements in each array are accessed with a common subscript.
  - a. synchronous arrays
  - b. asynchronous arrays
  - c. parallel arrays
  - d. two-dimensional arrays
10. You typically think of a two-dimensional array as containing
  - a. lines and statements
  - b. chapters and pages
  - c. rows and columns
  - d. horizontal and vertical elements

### True or False

1. You can store a mixture of different data types in an array.
2. In most languages, an array's size cannot be changed while the program is running.
3. Array bounds checking typically occurs while a program is running.
4. You can do many things with arrays, but you cannot pass one as an argument to a module or a function.
5. A declaration for a two-dimensional array requires only one size declarator.

### Short Answer

1. What is an off-by-one error?
2. Look at the following pseudocode:

```
Constant Integer SIZE = 10
Declare Integer values[SIZE]
```

- a. How many elements does the array have?
  - b. What is the subscript of the first element in the array?
  - c. What is the subscript of the last element in the array?
3. Look at the following pseudocode:
- ```
Constant Integer SIZE = 3
Declare Integer numbers[SIZE] = 1, 2, 3
```
- a. What value is stored in numbers[2]?
 - b. What value is stored in numbers[0]?
4. A program uses two parallel arrays named `customerNumbers` and `balances`. The `customerNumbers` array holds customer numbers and the `balances` array holds customer account balances. If a particular customer's customer number is stored in `customerNumbers[187]`, where would that customer's account balance be stored?
5. Look at the following pseudocode array declaration:
- ```
Declare Real sales[8][10]
```
- a. How many rows does the array have?
  - b. How many columns does the array have?
  - c. How many elements does the array have?
  - d. Write a pseudocode statement that stores a number in the last column of the last row in the array.

### Algorithm Workbench

1. Write a pseudocode declaration for a `String` array initialized with the following strings: "Einstein", "Newton", "Copernicus", and "Kepler".
2. Assume `names` is an `Integer` array with 20 elements. Design a `For` loop that displays each element of the array.
3. Assume the arrays `numberArray1` and `numberArray2` each have 100 elements. Design an algorithm that copies the values in `numberArray1` to `numberArray2`.
4. Draw a flowchart showing the general logic for totaling the values in an array.
5. Draw a flowchart showing the general logic for finding the highest value in an array.
6. Draw a flowchart showing the general logic for finding the lowest value in an array.
7. Assume the following declarations appear in a pseudocode program:

```
Constant Integer SIZE = 100
Declare Integer firstArray[SIZE]
Declare Integer secondArray[SIZE]
```

Also, assume that values have been stored in each element of `firstArray`. Design an algorithm that copies the contents of `firstArray` to `secondArray`.

8. Design an algorithm for a function that accepts an `Integer` array as an argument and returns the total of the values in the array.
9. Write a pseudocode algorithm that uses the `For Each` loop to display all of the values in the following array:

```
Constant Integer SIZE = 10
Declare Integer values[SIZE] = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
```

## Debugging Exercises

1. What is the error in the following pseudocode?

```
// This program uses an array to display five names.
Constant Integer SIZE = 5
Declare String names[SIZE] = "Meg", "Jack", "Steve",
 "Bill", "Lisa"
Declare Integer index
For index = 0 To SIZE
 Display names[index]
End For
```

2. What is the error in the following pseudocode?

```
// This program displays the highest value in the array.
Declare Integer SIZE = 3
Declare Integer values[SIZE] = 1, 3, 4
Declare Integer index
Declare Integer highest

For index = 0 To SIZE - 1
 If values[index] > highest Then
 Set highest = values[index]
 End If
End For

Display "The highest number is ", highest
```

3. What is the error in the following pseudocode?

```
// The searchName function accepts a string containing the name
// to search for, an array of strings containing the names, and
// an integer specifying the size of the array. The function
// searches for the name in the array. If the name is found, the
// string containing the name is returned; otherwise a message
// indicating that the name was not found in the array is
// returned.
Function String searchName(String name, String names[],
 Integer size)
 Declare Boolean found
 Declare Integer index
 Declare String result

 // Step through the array searching for the
 // specified name.
 While found == False AND index <= size - 1
 If contains(names[index], name) Then
 Set found = True
 Else
 Set index = index + 1
 End If
 End While
 // Determine the result.
 If found == True Then
 Set result = names[index]
 Else
 Set result = "That name was not found in the array."
 End If
 Return result
End Function
```

## Programming Exercises



### 1. Total Sales

Design a program that asks the user to enter a store's sales for each day of the week. The amounts should be stored in an array. Use a loop to calculate the total sales for the week and display the result.

### 2. Lottery Number Generator

Design a program that generates a 7-digit lottery number. The program should have an `Integer` array with 7 elements. Write a loop that steps through the array, randomly generating a number in the range of 0 through 9 for each element. (Use the `random` function that was discussed in Chapter 6.) Then write another loop that displays the contents of the array.

### 3. Rainfall Statistics

Design a program that lets the user enter the total rainfall for each of 12 months into an array. The program should calculate and display the total rainfall for the year, the average monthly rainfall, and the months with the highest and lowest amounts.

### 4. Number Analysis Program

Design a program that asks the user to enter a series of 20 numbers. The program should store the numbers in an array and then display the following data:

- The lowest number in the array
- The highest number in the array
- The total of the numbers in the array
- The average of the numbers in the array

### 5. Charge Account Validation

Design a program that asks the user to enter a charge account number. The program should determine whether the number is valid by comparing it to the following list of valid charge account numbers:

```
5658845 4520125 7895122 8777541 8451277 1302850
8080152 4562555 5552012 5050552 7825877 1250255
1005231 6545231 3852085 7576651 7881200 4581002
```

These numbers should be stored in an array. Use the sequential search algorithm to locate the number entered by the user. If the number is in the array, the program should display a message indicating the number is valid. If the number is not in the array, the program should display a message indicating the number is invalid.

### 6. Days of Each Month

Design a program that displays the number of days in each month. The program's output should be similar to this:

```
January has 31 days.
February has 28 days.
March has 31 days.
April has 30 days.
May has 31 days.
June has 30 days.
```

```
July has 31 days.
August has 31 days.
September has 30 days.
October has 31 days.
November has 30 days.
December has 31 days.
```

The program should have two parallel arrays: a 12-element `String` array that is initialized with the names of the months, and a 12-element `Integer` array that is initialized with the number of days in each month. To produce the output specified, use a loop to step through the arrays getting the name of a month and the number of days in that month.

## 7. Phone Number Lookup

Design a program that has two parallel arrays: a `String` array named `people` that is initialized with the names of seven of your friends, and a `String` array named `phoneNumbers` that is initialized with your friends' phone numbers. The program should allow the user to enter a person's name (or part of a person's name). It should then search for that person in the `people` array. If the person is found, it should get that person's phone number from the `phoneNumbers` array and display it. If the person is not found in the `people` array, the program should display a message indicating so.

## 8. Payroll

Design a program that uses the following parallel arrays:

- `empId`: An array of seven `Integers` to hold employee identification numbers. The array should be initialized with the following numbers:

```
56588 45201 78951 87775 84512 13028 75804
```

- `hours`: An array of seven `Integers` to hold the number of hours worked by each employee.
- `payRate`: An array of seven `Reals` to hold each employee's hourly pay rate.
- `wages`: An array of seven `Reals` to hold each employee's gross wages.

The program should relate the data in each array through the subscripts. For example, the number in element 0 of the `hours` array should be the number of hours worked by the employee whose identification number is stored in element 0 of the `empId` array. That same employee's pay rate should be stored in element 0 of the `payRate` array.

The program should display each employee number and ask the user to enter that employee's hours and pay rate. It should then calculate the gross wages for that employee (hours times pay rate), which should be stored in the `wages` array. After the data has been entered for all the employees, the program should display each employee's identification number and gross wages.

## 9. Driver's License Exam

The local driver's license office has asked you to design a program that grades the written portion of the driver's license exam. The exam has 20 multiple choice questions. Here are the correct answers:

- |       |        |        |        |
|-------|--------|--------|--------|
| (1) B | (6) A  | (11) B | (16) C |
| (2) D | (7) B  | (12) C | (17) C |
| (3) A | (8) A  | (13) D | (18) B |
| (4) A | (9) C  | (14) A | (19) D |
| (5) C | (10) D | (15) D | (20) A |

Your program should store these correct answers in an array. (Store each question's correct answer in an element of a `String` array.) The program should ask the user to enter the student's answers for each of the 20 questions, which should be stored in another array. After the student's answers have been entered, the program should display a message indicating whether the student passed or failed the exam. (A student must correctly answer 15 of the 20 questions to pass the exam.) It should then display the total number of correctly answered questions, the total number of incorrectly answered questions, and a list showing the question numbers of the incorrectly answered questions.

## 10. Saddle Points

Design a program that has a two-dimensional integer array with 7 rows and 7 columns. The program should store a random number in each element. Then, the program should search the array for saddle points. A saddle point is an element whose value is less than or equal to all the other values in the same row, and greater than or equal to all the other values in the same column. The program should display all of the saddle point values found in the array (if any).

## 11. Tic-Tac-Toe Game

Design a program that allows two players to play a game of tic-tac-toe. Use a two-dimensional `String` array with three rows and three columns as the game board. Each element of the array should be initialized with an asterisk (\*). The program should run a loop that does the following:

- a. Displays the contents of the board array.
- b. Allows player 1 to select a location on the board for an X. The program should ask the user to enter the row and column number.
- c. Allows player 2 to select a location on the board for an O. The program should ask the user to enter the row and column number.
- d. Determines whether a player has won or if a tie has occurred. If a player has won, the program should declare that player the winner and end. If a tie has occurred, the program should say so and end.
- e. Player 1 wins when there are three Xs in a row on the game board. Player 2 wins when there are three Os in a row on the game board. The winning Xs or Os can appear in a row, in a column, or diagonally across the board. A tie occurs when all of the locations on the board are full, but there is no winner.

## 12. Lo Shu Magic Square

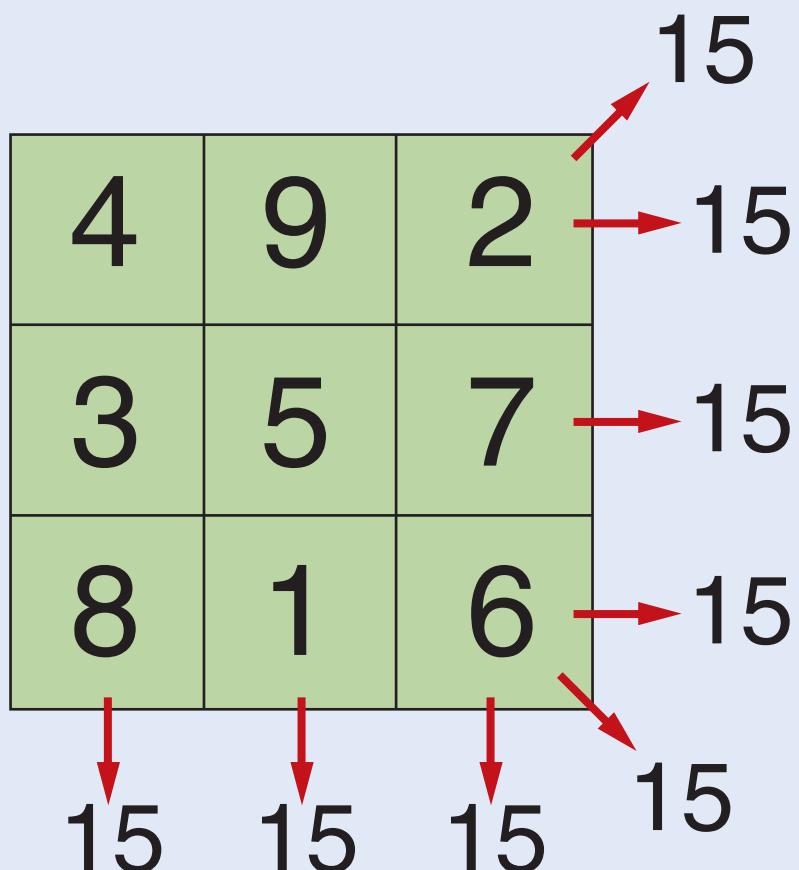
The Lo Shu Magic Square is a grid with 3 rows and 3 columns shown in Figure 8-23. The Lo Shu Magic Square has the following properties:

- The grid contains the numbers 1 through 9 exactly.
- The sum of each row, each column, and each diagonal all add up to the same number. This is shown in Figure 8-24.

In a program, you can simulate a magic square using a two-dimensional array. Design a program that initializes a two-dimensional array with values entered by the user. The program should determine whether the array is a Lo Shu Magic Square.

**Figure 8-23** Lo Shu Magic Square

|   |   |   |
|---|---|---|
| 4 | 9 | 2 |
| 3 | 5 | 7 |
| 8 | 1 | 6 |

**Figure 8-24** Row, column, and diagonal sums in the Lo Shu Magic Square

## TOPICS

- |                                  |                                               |
|----------------------------------|-----------------------------------------------|
| 9.1 The Bubble Sort Algorithm    | 9.4 The Binary Search Algorithm               |
| 9.2 The Selection Sort Algorithm | 9.5 Focus on Languages: Java, Python, and C++ |
| 9.3 The Insertion Sort Algorithm |                                               |

## 9.1

## The Bubble Sort Algorithm

**CONCEPT:** A sorting algorithm rearranges the contents of an array so they appear in a specific order. The bubble sort is a simple sorting algorithm.

### Sorting Algorithms

Many programming tasks require that the data in an array be sorted in some order. Customer lists, for instance, are commonly sorted in alphabetical order, student grades might be sorted from highest to lowest, and product codes could be sorted so all the products of the same color are stored together. To sort the data in an array, the programmer must use an appropriate sorting algorithm. A *sorting algorithm* is a technique for stepping through an array and rearranging its contents in some order.

The data in an array can be sorted in either ascending or descending order. If an array is sorted in *ascending order*, it means the values in the array are stored from lowest to highest. If the values are sorted in *descending order*, they are stored from highest to lowest. This chapter discusses three sorting algorithms that you can use to sort the data in an array: the *bubble sort*, the *selection sort*, and the *insertion sort*. This section examines the bubble sort algorithm.

## The Bubble Sort

The bubble sort is an easy way to arrange data in ascending or descending order. It is called the *bubble sort* algorithm because as it makes passes through and compares the elements of the array, certain values “bubble” toward the end of the array with each pass. For example, if you are using the algorithm to sort an array in ascending order, the larger values move toward the end. If you are using the algorithm to sort an array in descending order, the smaller values move toward the end. In this section, you will see how the bubble sort algorithm can be used to sort an array in ascending order.

Suppose we have the array shown in Figure 9-1. Let’s see how the bubble sort can be used in arranging the array’s elements in ascending order.

**Figure 9-1** An array

|           |           |           |           |           |           |
|-----------|-----------|-----------|-----------|-----------|-----------|
| 7         | 2         | 3         | 8         | 9         | 1         |
| Element 0 | Element 1 | Element 2 | Element 3 | Element 4 | Element 5 |

The bubble sort starts by comparing the first two elements in the array. If element 0 is greater than element 1, they are swapped. The array would then appear as shown in Figure 9-2.

**Figure 9-2** Elements 0 and 1 are swapped

These elements are swapped.

|           |           |           |           |           |           |
|-----------|-----------|-----------|-----------|-----------|-----------|
| 2         | 7         | 3         | 8         | 9         | 1         |
| Element 0 | Element 1 | Element 2 | Element 3 | Element 4 | Element 5 |

This method is repeated with elements 1 and 2. If element 1 is greater than element 2, they are swapped. The array would then appear as shown in Figure 9-3.

**Figure 9-3** Elements 1 and 2 are swapped

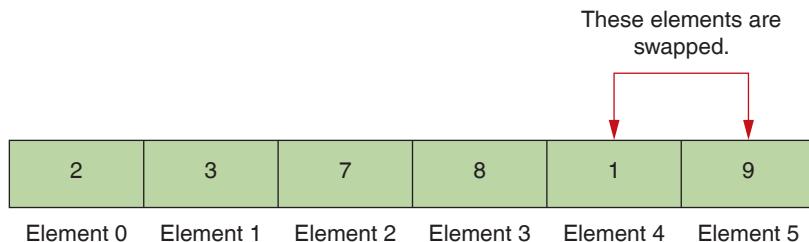
These elements are swapped.

|           |           |           |           |           |           |
|-----------|-----------|-----------|-----------|-----------|-----------|
| 2         | 3         | 7         | 8         | 9         | 1         |
| Element 0 | Element 1 | Element 2 | Element 3 | Element 4 | Element 5 |

Next, elements 2 and 3 are compared. In this array, these elements are already in the proper order (element 2 is less than element 3), so no values are swapped. As the cycle continues, elements 3 and 4 are compared. Once again, it is not necessary to swap the values because they are already in the proper order.

When elements 4 and 5 are compared, however, they must be swapped because element 4 is greater than element 5. The array now appears as shown in Figure 9-4.

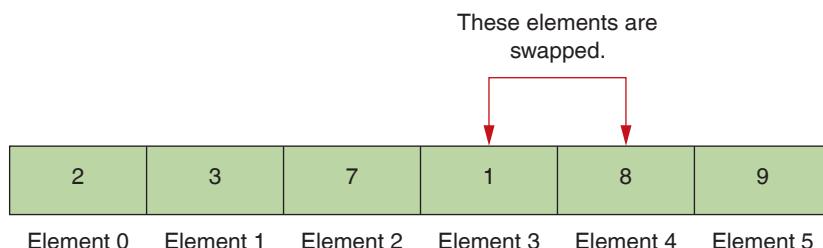
**Figure 9-4** Elements 4 and 5 are swapped



At this point, the entire array has been scanned once, and the largest value, 9, is in the correct position. There are other elements, however, that are not yet in their final positions. So, the algorithm will make another pass through the array, comparing each element with its neighbor. In the next pass it will stop comparing after reaching the next-to-last element because the last element already contains the correct value.

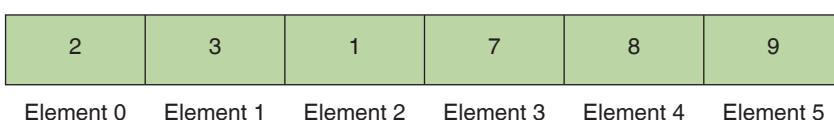
The second pass starts by comparing elements 0 and 1. Because those two are in the proper order, they are not swapped. Elements 1 and 2 are compared next, but once again, they are not swapped. This continues until elements 3 and 4 are compared. Because element 3 is greater than element 4, they are swapped. Element 4 is the last element that is compared during this pass, so this pass stops. The array now appears as shown in Figure 9-5.

**Figure 9-5** Elements 3 and 4 are swapped



At the end of the second pass, the last two elements in the array contain the correct values. The third pass starts now, comparing each element with its neighbor. The third pass will not involve the last two elements, however, because they have already been sorted. When the third pass is finished, the last three elements will hold the correct values, as shown in Figure 9-6.

**Figure 9-6** The array after the third pass



Each time the algorithm makes a pass through the array, the portion of the array that is scanned is decreased in size by one element, and the largest value in the scanned

portion of the array is moved to its final position. When all of the passes have been made, the array will appear as shown in Figure 9-7.

**Figure 9-7** The array with all elements sorted

|           |           |           |           |           |           |
|-----------|-----------|-----------|-----------|-----------|-----------|
| 1         | 2         | 3         | 7         | 8         | 9         |
| Element 0 | Element 1 | Element 2 | Element 3 | Element 4 | Element 5 |

## Swapping Array Elements

As you saw in the description of the bubble sort algorithm, certain elements are swapped as the algorithm steps through the array. Let's briefly discuss the process of swapping two items in computer memory. Assume we have the following variable declarations:

```
Declare Integer a = 1
Declare Integer b = 9
```

Suppose we want to swap the values in these variables so the variable *a* contains 9 and the variable *b* contains 1. At first, you might think that we only need to assign the variables to each other, like this:

```
// ERROR! The following does NOT swap the variables.
Set a = b
Set b = a
```

To understand why this doesn't work, let's step through the pseudocode. The first statement is *Set a = b*. This causes the value 9 to be assigned to *a*. But, what happens to the value 1 that was previously stored in *a*? Remember, when you assign a new value to a variable, the new value replaces any value that was previously stored in the variable. So, the old value, 1, will be thrown away. Then the next statement is *Set b = a*. Because the variable *a* contains 9, this assigns 9 to *b*. After these statements execute, the variables *a* and *b* will both contain the value 9.

To successfully swap the contents of two variables, we need a third variable that can serve as a temporary storage location:

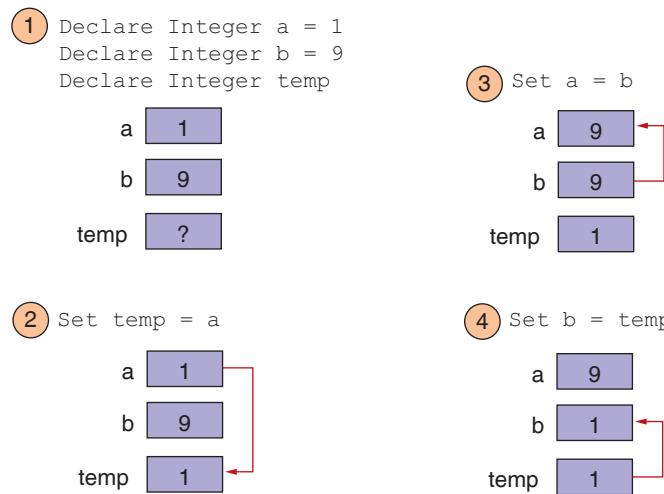
```
Declare Integer temp
```

Then we can perform the following steps to swap the values in the variables *a* and *b*:

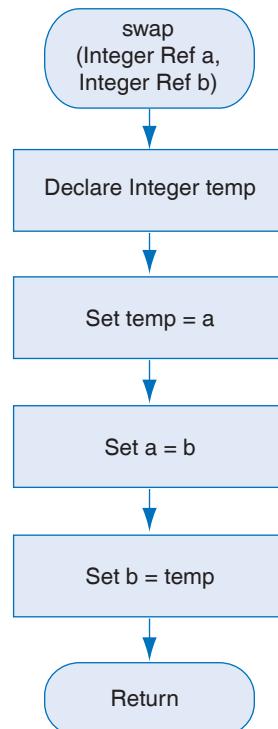
- Assign the value of *a* to *temp*.
- Assign the value of *b* to *a*.
- Assign the value of *temp* to *b*.

Figure 9-8 shows the contents of these variables as we perform each of these steps. Notice that after the steps are finished, the values in *a* and *b* are swapped.

Let's create a module named *swap* that will swap two items in memory. We will use the module in the bubble sort algorithm. Figure 9-9 shows a flowchart for the *swap* module. Notice that the module has two reference parameters, *a* and *b*. When we call the module, we pass two variables (or array elements) as arguments. When the module is finished, the values of the arguments will be swapped.

**Figure 9-8** Swapping the values of a and b

**NOTE:** It is critical that we use reference parameters in the swap module, because the module must be able to change the values of the items that are passed to it as arguments.

**Figure 9-9** Flowchart for a swap module

Here is the pseudocode for the swap module:

```
Module swap(Integer Ref a, Integer Ref b)
 // Local variable for temporary storage.
 Declare Integer temp

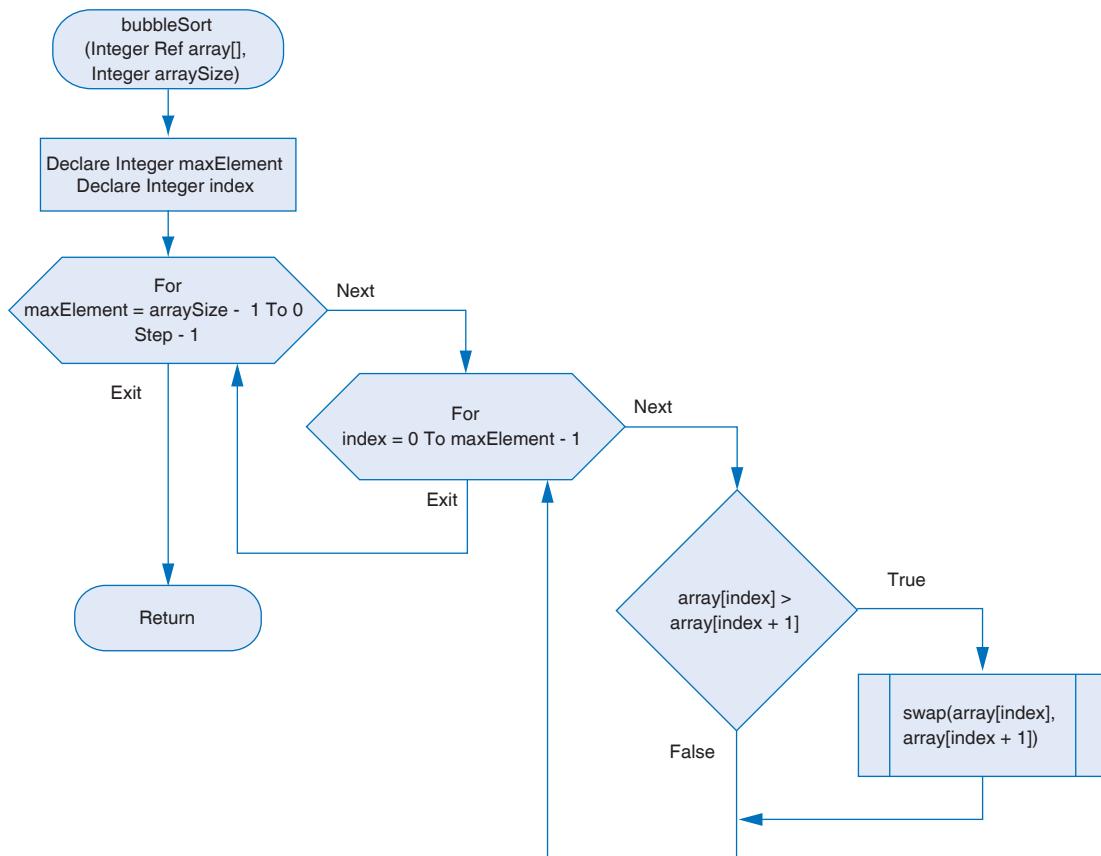
 // Swap the values in a and b.
 Set temp = a
 Set a = b
 Set b = temp
End Module
```

Of course, this version of the `swap` module works only with `Integer` arguments. If we want to swap the contents of other types of variables, we would have to change the data type of the `a` and `b` parameters as well as the `temp` variable.

## Designing the Bubble Sort Algorithm

The bubble sort algorithm is usually incorporated into a program as a module. When you need to sort an array, pass the array to the module and it sorts the array. Figure 9-10 shows a flowchart for a `bubbleSort` module that sorts an array of integers. Program 9-1 shows the pseudocode for the module. (Note that the pseudocode shown in Program 9-1 is only the `bubbleSort` module and not a complete program.)

**Figure 9-10** Flowchart for the bubble sort algorithm



**Program 9-1****bubbleSort module  
(not a complete program)**

```
1 Module bubbleSort(Integer Ref array[], Integer arraySize)
2 // The maxElement variable will contain the subscript
3 // of the last element in the array to compare.
4 Declare Integer maxElement
5
6 // The index variable will be used as a counter
7 // in the inner loop.
8 Declare Integer index
9
10 // The outer loop positions maxElement at the last
11 // element to compare during each pass through the
12 // array. Initially maxElement is the index of the
13 // last element in the array. During each iteration,
14 // it is decreased by one.
15 For maxElement = arraySize - 1 To 0 Step - 1
16
17 // The inner loop steps through the array, comparing
18 // each element with its neighbor. All of the
19 // elements from index 0 through maxElement are
20 // involved in the comparison. If two elements are
21 // out of order, they are swapped.
22 For index = 0 To maxElement - 1
23
24 // Compare an element with its neighbor and swap
25 // if necessary.
26 If array[index] > array[index + 1] Then
27 Call swap(array[index], array[index + 1])
28 End If
29 End For
30 End For
31 End Module
```

In lines 4 and 8 the following variables are declared:

- The **maxElement** variable will hold the subscript of the last element that is to be compared to its immediate neighbor.
- The **index** variable is used as an array subscript in one of the loops.

The module uses two **For** loops, one nested inside another. The outer loop begins in line 15 as follows:

```
For maxElement = arraySize - 1 To 0 Step - 1
```

This loop will iterate once for each element in the array. It causes the **maxElement** variable to take on all of the array's subscripts, from the highest subscript down to 0. After each iteration, **maxElement** is decremented by one.

The second loop, which is nested inside the first loop, begins in line 22 as follows:

```
For index = 0 To maxElement - 1
```

This loop iterates once for each of the unsorted array elements. It starts `index` at 0 and increments it up through `maxElement - 1`. During each iteration, the comparison in line 26 is performed:

```
If array[index] > array[index + 1] Then
```

This `If` statement compares the element at `array[index]` with its neighbor `array[index + 1]`. If the element's neighbor is greater, then the two are swapped in line 27. (The `swap` module must also appear in any program that uses the `bubbleSort` module.) The following *In the Spotlight* section shows how the bubble sort algorithm is used in a complete program.

## In the Spotlight: Using the Bubble Sort Algorithm



After Kathryn grades a set of exams, she likes to see a list of the exam scores sorted from lowest to highest. She has asked you to design a program that will allow her to input a set of test scores and will then display the scores sorted in ascending order. Here are the general steps in the algorithm:

1. Get the test scores from the user and store them in an array.
2. Sort the array in ascending order.
3. Display the contents of the array.

For testing purposes, you ask Kathryn whether you can first design the program for her smallest class, which has only six students. If she is satisfied with the program, you can modify it to work with her other classes. She agrees with your plan.

Program 9-2 shows the pseudocode for the program, which is modularized. Rather than presenting the entire program at once, we will first examine the `main` module, and then we will look at the additional modules separately. Here is the `main` module:

### Program 9-2 Ascending score program: main module

```

1 Module main()
2 // Constant for the array size
3 Constant Integer SIZE = 6
4
5 // Array to hold test scores
6 Declare Integer testScores[SIZE]
7
8 // Get the test scores.
9 getTestScores(testScores, SIZE)
10
11 // Sort the test scores.
12 bubbleSort(testScores, SIZE)
13
14 // Display the test scores.
15 Display "Here are the test scores"
16 Display "sorted from lowest to highest."
17 showTestScores(testScores, SIZE)
18 End Module
19

```

Line 3 declares a constant, SIZE, that will be used as an array size declarator. The testScores array, which will hold the test scores, is declared in line 6. In line 9 the testScores array and the SIZE constant are passed to the getTestScores module. As you will see in a moment, the testScores array is passed by reference. The module gets the test scores from the user and stores them in the array.

Line 12 passes the testScores array and the SIZE constant to the bubbleSort module. (The array is passed by reference.) When the module finishes, the values in the array will be sorted in ascending order.

Line 17 passes the testScores array and the SIZE constant to the showTestScores module. This module displays the values in the array.

Next is the definition of the getTestScores module, which is shown here:

**Program 9-2****Ascending score program (continued):  
getTestScores module**

```
20 // The getTestScores module prompts the user
21 // to enter test scores into the array that is
22 // passed as an argument.
23 Module getTestScores(Integer Ref array[], Integer arraySize)
24 // Counter variable
25 Declare Integer index
26
27 // Get the test scores.
28 For index = 0 to arraySize - 1
29 Display "Enter score number ", index + 1
30 Input array[index]
31 End For
32 End Module
33
```

The getTestScores module has two parameters:

- array[]—An Integer array is passed by reference into this parameter.
- arraySize—An Integer specifying the size of the array is passed into this parameter.

The purpose of this module is to get a student's test scores from the user and store them in the array that is passed as an argument into the array[] parameter.

The definitions of the bubbleSort and swap modules appear next. These modules are the same as presented earlier in this chapter.

**Program 9-2****Ascending score program (continued):  
the bubbleSort and swap modules**

```
34 // The bubbleSort module accepts an array of Integers
35 // and the array's size as arguments. When the module
36 // is finished, the values in the array will be sorted
37 // in ascending order.
38 Module bubbleSort(Integer Ref array[], Integer arraySize)
```

```

39 // The maxElement variable will contain the subscript
40 // of the last element in the array to compare.
41 Declare Integer maxElement
42
43 // The index variable will be used as a counter
44 // in the inner loop.
45 Declare Integer index
46
47 // The outer loop positions maxElement at the last
48 // element to compare during each pass through the
49 // array. Initially maxElement is the index of the
50 // last element in the array. During each iteration,
51 // it is decreased by one.
52 For maxElement = arraySize - 1 To 0 Step - 1
53
54 // The inner loop steps through the array, comparing
55 // each element with its neighbor. All of the
56 // elements from index 0 through maxElement are
57 // involved in the comparison. If two elements are
58 // out of order, they are swapped.
59 For index = 0 To maxElement - 1
60
61 // Compare an element with its neighbor and swap
62 // if necessary.
63 If array[index] > array[index + 1] Then
64 Call swap(array[index], array[index + 1])
65 End If
66 End For
67 End For
68 End Module
69
70 // The swap module accepts two Integer arguments
71 // and swaps their contents.
72 Module swap(Integer Ref a, Integer Ref b)
73 // Local variable for temporary storage.
74 Declare Integer temp
75
76 // Swap the values in a and b.
77 Set temp = a
78 Set a = b
79 Set b = temp
80 End Module
81

```

The definition of the showTestScore module appears next.

### Program 9-2

### Ascending score program (continued): the showTestScores module

```

82 // The showTestScores module displays the contents
83 // of the array that is passed as an argument.
84 Module showTestScores(Integer array[], Integer arraySize)
85 // Counter variable
86 Declare Integer index

```

```
87
88 // Display the test scores.
89 For index = 0 to arraySize - 1
90 Display array[index]
91 End For
92 End Module
```

The `showTestScores` module has two parameters:

- `array[]`—An `Integer` array is passed by reference into this parameter.
- `arraySize`—An `Integer` specifying the size of the array is passed into this parameter.

The purpose of this module is to display the contents of the array that is passed into the `array` parameter.

### Program Output (with Input Shown in Bold)

```
Enter score number 1
88 [Enter]
Enter score number 2
92 [Enter]
Enter score number 3
73 [Enter]
Enter score number 4
69 [Enter]
Enter score number 5
98 [Enter]
Enter score number 6
79 [Enter]
Here are the test scores
sorted from lowest to highest.
69
73
79
88
92
98
```

## Sorting an Array of Strings

Recall from Chapter 3 that most languages allow you to determine whether one string is greater than, less than, equal to, or not equal to another string. As a result, you can design the bubble sort algorithm to work with an array of strings. This gives you the ability to sort an array of strings in alphabetical (ascending) order. The pseudocode in Program 9-3 shows an example. Notice that this program's versions of the `bubbleSort` and `swap` modules have been designed to work with `String` arrays.

### Program 9-3

```
1 Module main()
2 // Constant for the array size
3 Constant Integer SIZE = 6
```

```
4
5 // An array of strings
6 Declare String names[SIZE] = "David", "Abe", "Megan",
7 // "Beth", "Jeff", "Daisy"
8
9 // Loop counter
10 Declare Integer index
11
12 // Display the array in its original order.
13 Display "Original order:"
14 For index = 0 To SIZE - 1
15 Display names[index]
16 End For
17
18 // Sort the names.
19 Call bubbleSort(names, SIZE)
20
21 // Display a blank line.
22 Display
23
24 // Display the sorted array.
25 Display "Sorted order:"
26 For index = 0 To SIZE - 1
27 Display names[index]
28 End For
29 End Module
30
31 // The bubbleSort module accepts an array of Strings
32 // and the array's size as arguments. When the module
33 // is finished, the values in the array will be sorted
34 // in ascending order.
35 Module bubbleSort(String Ref array[], Integer arraySize)
36 // The maxElement variable will contain the subscript
37 // of the last element in the array to compare.
38 Declare Integer maxElement
39
40 // The index variable will be used as a counter
41 // in the inner loop.
42 Declare Integer index
43
44 // The outer loop positions maxElement at the last
45 // element to compare during each pass through the
46 // array. Initially maxElement is the index of the
47 // last element in the array. During each iteration,
48 // it is decreased by one.
49 For maxElement = arraySize - 1 To 0 Step - 1
50
51 // The inner loop steps through the array, comparing
52 // each element with its neighbor. All of the
53 // elements from index 0 through maxElement are
54 // involved in the comparison. If two elements are
55 // out of order, they are swapped.
56 For index = 0 To maxElement - 1
57
```

```
58 // Compare an element with its neighbor and swap
59 // if necessary.
60 If array[index] > array[index + 1] Then
61 Call swap(array[index], array[index + 1])
62 End If
63 End For
64 End For
65 End Module
66
67 // The swap module accepts two String arguments
68 // and swaps their contents.
69 Module swap(String Ref a, String Ref b)
70 // Local variable for temporary storage
71 Declare String temp
72
73 // Swap the values in a and b.
74 Set temp = a
75 Set a = b
76 Set b = temp
77 End Module
```

### Program Output (with Input Shown in Bold)

Original order:

David  
Abe  
Megan  
Beth  
Jeff  
Daisy

Sorted order:

Abe  
Beth  
Daisy  
David  
Jeff  
Megan



**TIP:** All of the algorithms presented in this chapter can be designed to work with strings, as long as the language you are using allows you to compare string values.

## Sorting in Descending Order

The bubble sort algorithm can be easily modified to sort an array in descending order, which means that the values will be ordered from highest to lowest. For example, the pseudocode in Program 9-4 is a modified version of Program 9-3. This version sorts the `names` array in descending order. The only modification to the bubble sort algorithm is in line 60. The comparison has been changed to determine whether `array[index]` is less than `array[index + 1]`.

**Program 9-4**

```
1 Module main()
2 // Constant for the array size
3 Constant Integer SIZE = 6
4
5 // An array of strings
6 Declare String names[SIZE] = "David", "Abe", "Megan",
7 // "Beth", "Jeff", "Daisy"
8
9 // Loop counter
10 Declare Integer index
11
12 // Display the array in its original order.
13 Display "Original order:"
14 For index = 0 To SIZE - 1
15 Display names[index]
16 End For
17
18 // Sort the names.
19 Call bubbleSort(names, SIZE)
20
21 // Display a blank line.
22 Display
23
24 // Display the sorted array.
25 Display "Sorted in descending order:"
26 For index = 0 To SIZE - 1
27 Display names[index]
28 End For
29 End Module
30
31 // The bubbleSort module accepts an array of Strings
32 // and the array's size as arguments. When the module
33 // is finished, the values in the array will be sorted
34 // in descending order.
35 Module bubbleSort(String Ref array[], Integer arraySize)
36 // The maxElement variable will contain the subscript
37 // of the last element in the array to compare.
38 Declare Integer maxElement
39
40 // The index variable will be used as a counter
41 // in the inner loop.
42 Declare Integer index
43
44 // The outer loop positions maxElement at the last
45 // element to compare during each pass through the
46 // array. Initially maxElement is the index of the
47 // last element in the array. During each iteration,
48 // it is decreased by one.
49 For maxElement = arraySize - 1 To 0 Step - 1
50
51 // The inner loop steps through the array, comparing
52 // each element with its neighbor. All of the
53 // elements from index 0 through maxElement are
```

```
54 // involved in the comparison. If two elements are
55 // out of order, they are swapped.
56 For index = 0 To maxElement - 1
57
58 // Compare an element with its neighbor and swap
59 // if necessary.
60 If array[index] < array[index + 1] Then
61 Call swap(array[index], array[index + 1])
62 End If
63 End For
64 End For
65 End Module
66
67 // The swap module accepts two String arguments
68 // and swaps their contents.
69 Module swap(String Ref a, String Ref b)
70 // Local variable for temporary storage
71 Declare String temp
72
73 // Swap the values in a and b.
74 Set temp = a
75 Set a = b
76 Set b = temp
77 End Module
```

### Program Output

Original order:

David  
Abe  
Megan  
Beth  
Jeff  
Daisy

Sorted in descending order:

Megan  
Jeff  
David  
Daisy  
Beth  
Abe

9.2

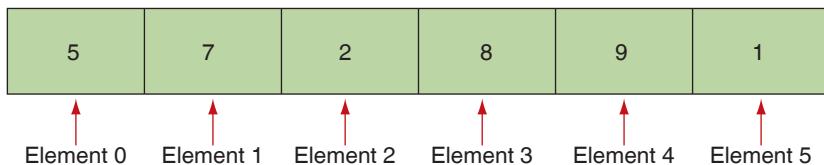
## The Selection Sort Algorithm

**CONCEPT:** The selection sort is a sorting algorithm that is much more efficient than the bubble sort. The selection sort algorithm steps through an array, moving each value to its final sorted position.

The bubble sort algorithm is simple, but it is inefficient because values move by only one element at a time toward their final destination in the array. The *selection sort*

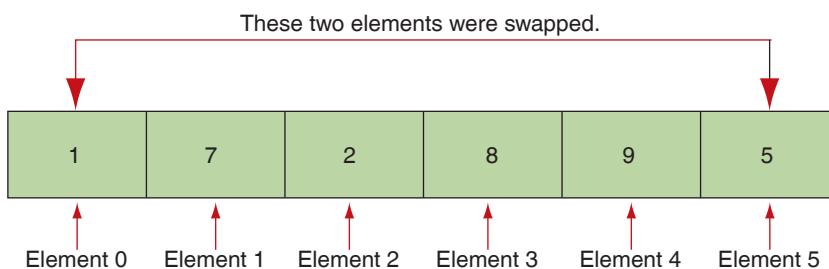
*algorithm* usually performs fewer swaps because it moves items immediately to their final position in the array. The selection sort works like this: The smallest value in the array is located and moved to element 0. Then, the next smallest value is located and moved to element 1. This process continues until all of the elements have been placed in their proper order. Let's see how the selection sort works when arranging the elements of the array in Figure 9-11.

**Figure 9-11** Values in an array



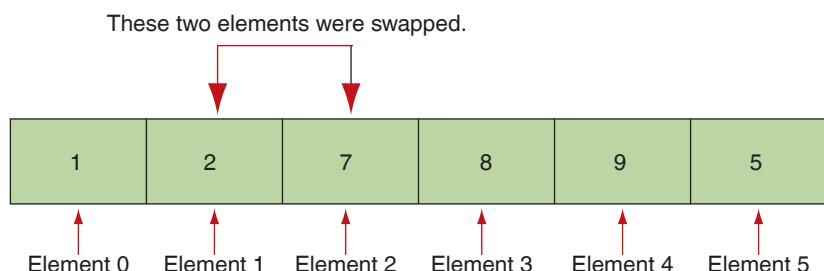
The selection sort scans the array, starting at element 0, and locates the element with the smallest value. Then, the contents of this element are swapped with the contents of element 0. In this example, the 1 stored in element 5 is swapped with the 5 stored in element 0. After the swap, the array appears as shown in Figure 9-12.

**Figure 9-12** Values in the array after the first swap



Then, the algorithm repeats the process, but because element 0 already contains the smallest value in the array, it can be left out of the procedure. This time, the algorithm begins the scan at element 1. In this example, the value in element 2 is swapped with the value in element 1. Then, the array appears as shown in Figure 9-13.

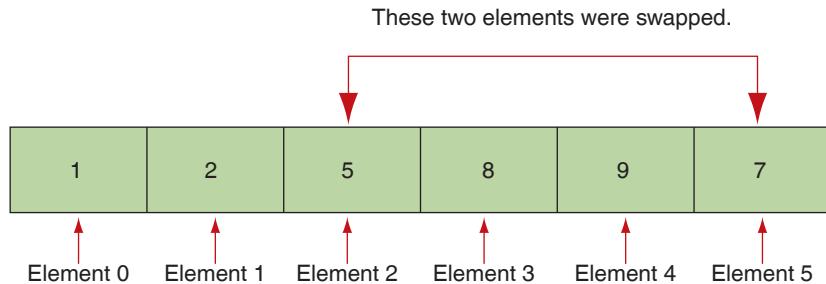
**Figure 9-13** Values in the array after the second swap



Once again the process is repeated, but this time the scan begins at element 2. The algorithm will find that element 5 contains the next smallest value. This element's

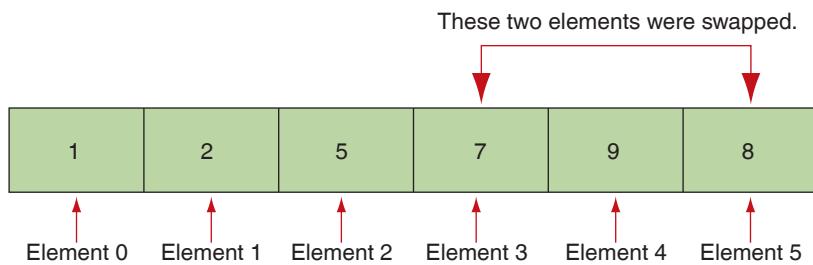
value is swapped with that of element 2, causing the array to appear as shown in Figure 9-14.

**Figure 9-14** Values in the array after the third swap



Next, the scanning begins at element 3. Its value is swapped with that of element 5, causing the array to appear as shown in Figure 9-15.

**Figure 9-15** Values in the array after the fourth swap



At this point there are only two elements left to sort. The algorithm finds that the value in element 5 is smaller than that of element 4, so the two are swapped. This puts the array in its final arrangement, as shown in Figure 9-16.

**Figure 9-16** Values in the array after the fifth swap

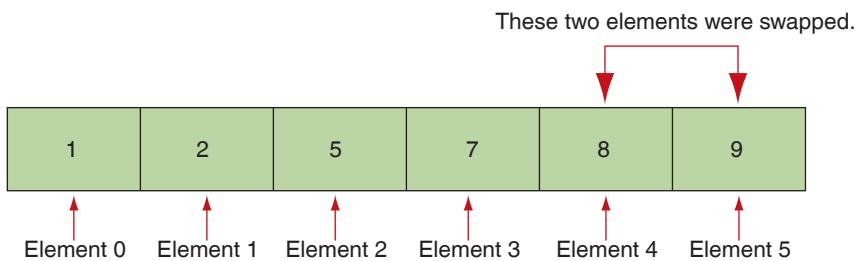


Figure 9-17 shows a flowchart for a module that performs the selection sort algorithm. The module accepts an Integer array (passed by reference) and an Integer that specifies the array's size. When the module is finished executing, the array will be sorted in ascending order. Program 9-5 shows the `selectionSort` module in pseudocode.

**Program 9-5**

```
1 Module main()
2 // Constant for the array size
3 Constant Integer SIZE = 6
4
5 // An array of Integers
6 Declare Integer numbers[SIZE] = 4, 6, 1, 3, 5, 2
7
8 // Loop counter
9 Declare Integer index
10
11 // Display the array in its original order.
12 Display "Original order:"
13 For index = 0 To SIZE - 1
14 Display numbers[index]
15 End For
16
17 // Sort the numbers.
18 Call selectionSort(numbers, SIZE)
19
20 // Display a blank line.
21 Display
22
23 // Display the sorted array.
24 Display "Sorted order:"
25 For index = 0 To SIZE - 1
26 Display numbers[index]
27 End For
28 End Module
29
30 // The selectionSort module accepts an array of integers
31 // and the array's size as arguments. When the module is
32 // finished, the values in the array will be sorted in
33 // ascending order.
34 Module selectionSort(Integer Ref array[], Integer arraySize)
35 // startScan will hold the starting position of the scan.
36 Declare Integer startScan
37
38 // minIndex will hold the subscript of the element with
39 // the smallest value found in the scanned area.
40 Declare Integer minIndex
41
42 // minValue will hold the smallest value found in the
43 // scanned area.
44 Declare Integer minValue
45
46 // index is a counter variable used to hold a subscript.
47 Declare Integer index
48
49 // The outer loop iterates once for each element in the
50 // array, except the last element. The startScan variable
51 // marks the position where the scan should begin.
```

```
52 For startScan = 0 To arraySize - 2
53
54 // Assume the first element in the scannable area
55 // is the smallest value.
56 Set minIndex = startScan
57 Set minValue = array[startScan]
58
59 // Scan the array, starting at the 2nd element in
60 // the scannable area. We are looking for the smallest
61 // value in the scannable area.
62 For index = startScan + 1 To arraySize - 1
63 If array[index] < minValue Then
64 Set minValue = array[index]
65 Set minIndex = index
66 End If
67 End For
68
69 // Swap the element with the smallest value
70 // with the first element in the scannable area.
71 Call swap(array[minIndex], array[startScan])
72 End For
73 End Module
74
75 // The swap module accepts two Integer arguments
76 // and swaps their contents.
77 Module swap(Integer Ref a, Integer Ref b)
78 // Local variable for temporary storage
79 Declare Integer temp
80
81 // Swap the values in a and b.
82 Set temp = a
83 Set a = b
84 Set b = temp
85 End Module
```

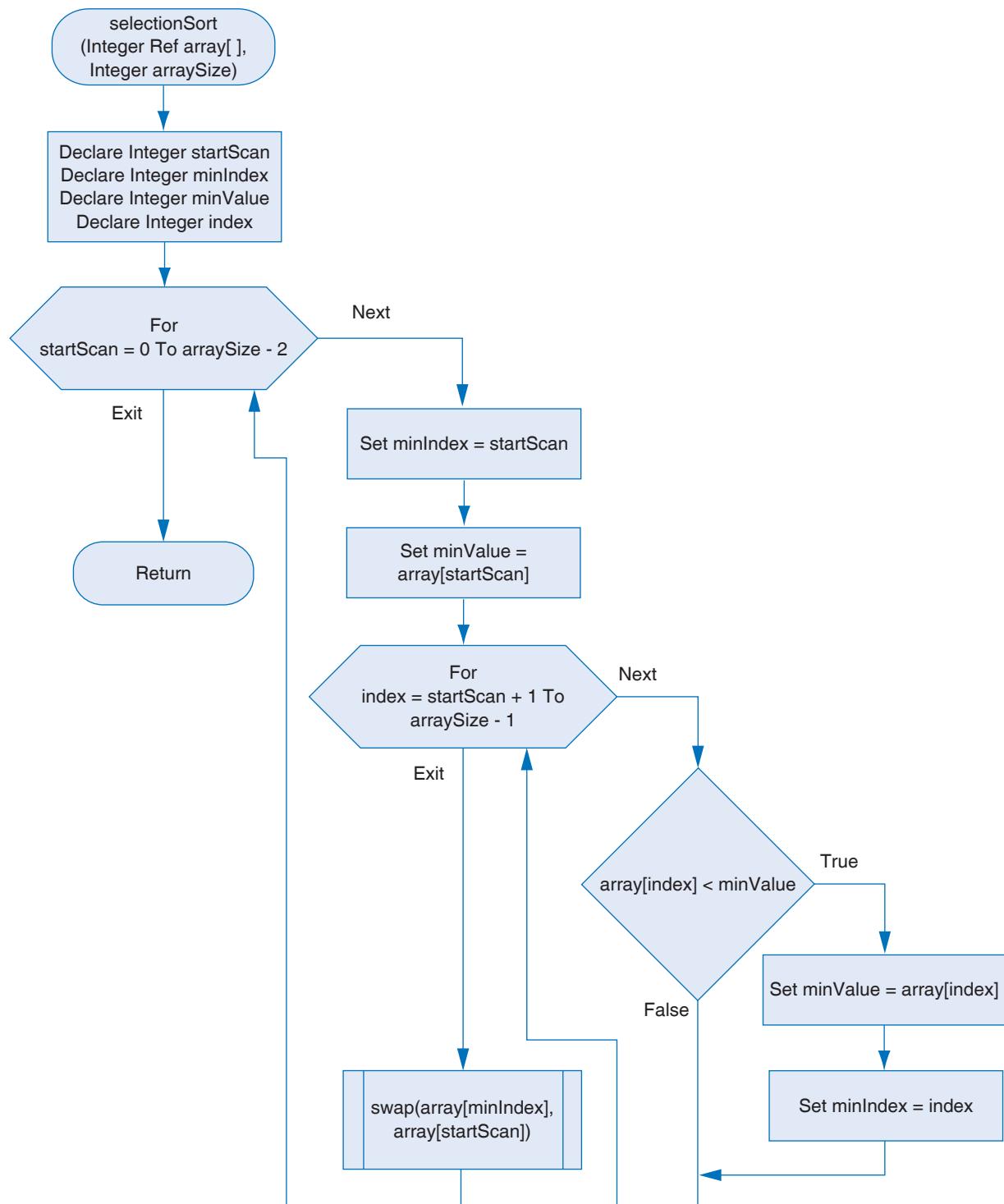
### Program Output

Original order:

```
4
6
1
3
5
2
```

Sorted order:

```
1
2
3
4
5
6
```

**Figure 9-17** Flowchart for the selectionSort module



**NOTE:** You can modify the `selectionSort` module so it sorts the array in descending order by changing the less than operator in line 63 to a greater than operator, as shown here:

```
If array[index] > maxValue Then
```

Notice that we have also changed the name of the `minValue` variable to `maxValue`, which is more appropriate for a descending order sort. You would need to make this change throughout the module.

## 9.3

## The Insertion Sort Algorithm



VideoNote

The Insertion Sort Algorithm

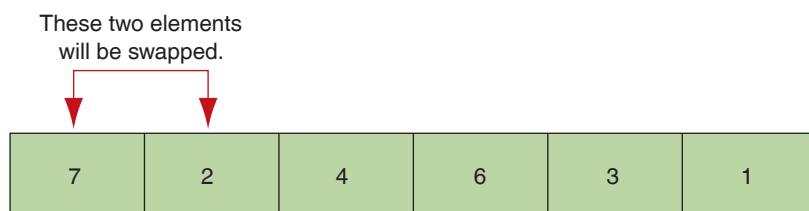
**CONCEPT:** The insertion sort algorithm is also more efficient than the bubble sort algorithm. It sorts the first two elements, which become the sorted part of the array. It then inserts each of the remaining elements, one at a time, into the sorted part of the array at the correct location.

The *insertion sort algorithm* is another sorting algorithm that is also more efficient than the bubble sort. The insertion sort begins sorting the first two elements of the array. It simply compares the elements and, if necessary, swaps them so they are in the proper order. This becomes a sorted subset of the array.

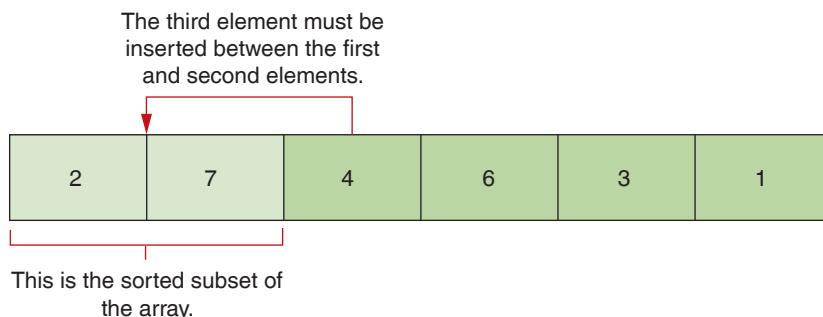
Then, the objective is to incorporate the third element of the array into the sorted subset. This is done by inserting the third element of the array into the proper position relative to the first two elements. If the sort needs to shift either of the first two elements to accommodate the third element, it does so. Once it has inserted the third element into the correct position (relative to the first two elements), the first three elements become the sorted subset of the array.

This process continues with the fourth and subsequent elements, until all of the elements have been inserted into their proper positions. Let's look at an example. Suppose we start with the `Integer` array shown in Figure 9-18. As shown in the figure, the values in the first and second elements are out of order, so they will be swapped.

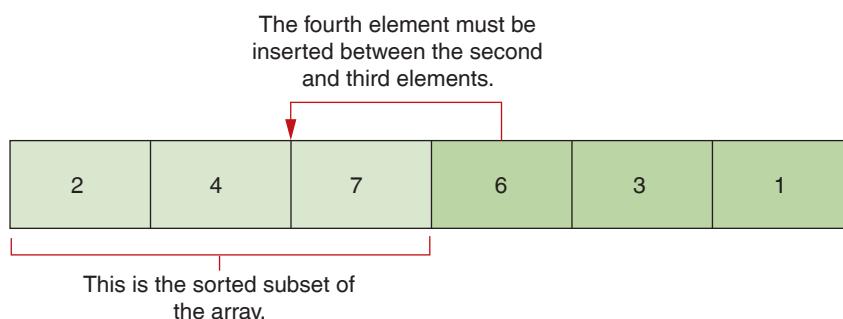
**Figure 9-18** An unsorted array



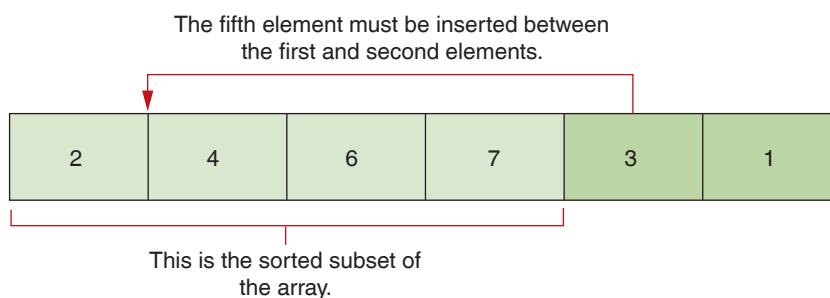
After the swap takes place, the first and second elements will be the sorted subset of the array. The next step is to move the value of the third element so it is in the correct position relative to the first two elements. As shown in Figure 9-19, the value in the third element must be positioned between the values in the first and second elements.

**Figure 9-19** The third element must be moved

After the value in the third element is moved to its new position, the first three elements become the sorted subset of the array. The next step is to move the value of the fourth element so it is in the correct position relative to the first three elements. As shown in Figure 9-20, the value in the fourth element must be positioned between the values in the second and third elements.

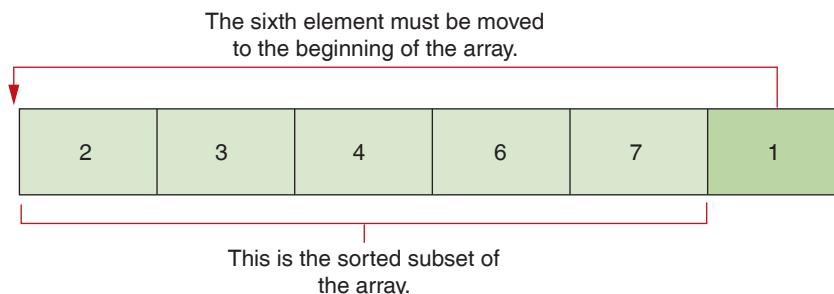
**Figure 9-20** The fourth element must be moved

After the value in the fourth element is moved to its new position, the first four elements become the sorted subset of the array. The next step is to move the value of the fifth element so it is in the correct position relative to the first four elements. As shown in Figure 9-21, the value in the fifth element must be positioned between the values in the first and second elements.

**Figure 9-21** The fifth element must be moved

After the value in the fifth element is moved to its new position, the first five elements become the sorted subset of the array. The next step is to move the value of the sixth element so it is in the correct position relative to the first five elements. As shown in Figure 9-22, the value in the sixth element must be moved to the beginning of the array.

**Figure 9-22** The sixth element must be moved



The sixth element is the last element in the array. Once it is moved to its correct position, the entire array is sorted. This is shown in Figure 9-23.

**Figure 9-23** All of the elements are in the correct positions

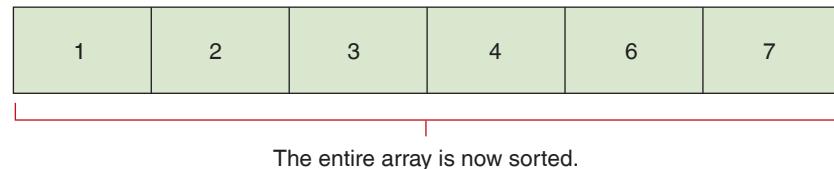


Figure 9-24 shows a flowchart for a module that performs the insertion sort algorithm. The module accepts an Integer array (passed by reference) and an Integer that specifies the array's size. When the module is finished executing, the array will be sorted in ascending order. Program 9-6 shows the `insertionSort` module in pseudocode.

**Program 9-6**

```
1 Module main()
2 // Constant for the array size
3 Constant Integer SIZE = 6
4
5 // An array of Integers
6 Declare Integer numbers[SIZE] = 4, 6, 1, 3, 5, 2
7
8 // Loop counter
9 Declare Integer index
10
11 // Display the array in its original order.
12 Display "Original order:"
13 For index = 0 To SIZE - 1
14 Display numbers[index]
15 End For
16
17 // Sort the numbers.
18 Call insertionSort(numbers, SIZE)
19
20 // Display a blank line.
21 Display
22
23 // Display the sorted array.
24 Display "Sorted order:"
25 For index = 0 To SIZE - 1
26 Display numbers[index]
27 End For
28 End Module
29
30 // The insertionSort module accepts an array of integers
31 // and the array's size as arguments. When the module is
32 // finished, the values in the array will be sorted in
33 // ascending order.
34 Module insertionSort(Integer Ref array[], Integer arraySize)
35 // Loop counter
36 Declare Integer index
37
38 // Variable used to scan through the array.
39 Declare Integer scan
40
41 // Variable to hold the first unsorted value.
42 Declare Integer unsortedValue
43
44 // The outer loop steps the index variable through
45 // each subscript in the array, starting at 1. This
46 // is because element 0 is considered already sorted.
47 For index = 1 To arraySize - 1
48
```

```
49 // The first element outside the sorted subset is
50 // array[index]. Store the value of this element
51 // in unsortedValue.
52 Set unsortedValue = array[index]
53
54 // Start scan at the subscript of the first element
55 // outside the sorted subset.
56 Set scan = index
57
58 // Move the first element outside the sorted subset
59 // into its proper position within the sorted subset.
60 While scan > 0 AND array[scan-1] > unsortedValue
61 Set array[scan] = array[scan-1]
62 Set scan = scan - 1
63 End While
64
65 // Insert the unsorted value in its proper position
66 // within the sorted subset.
67 Set array[scan] = unsortedValue
68 End For
69 End Module
```

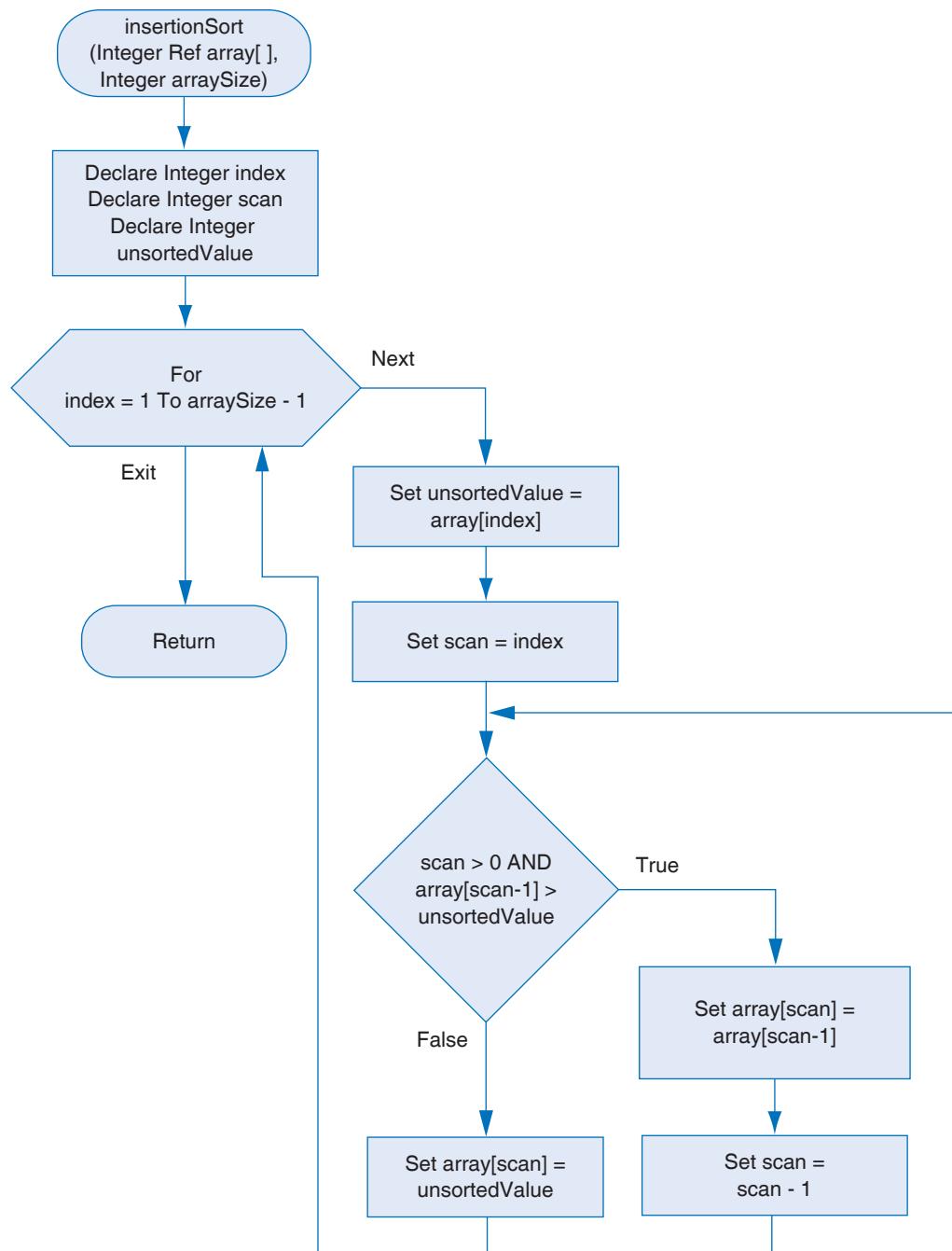
### Program Output

Original order:

```
4
6
1
3
5
2
```

Sorted order:

```
1
2
3
4
5
6
```

**Figure 9-24** Flowchart for the insertionSort module

 **Checkpoint**

- 9.1 Which of the sorting algorithms discussed makes several passes through an array and causes the larger values to move gradually toward the end of the array with each pass?
- 9.2 One of the sorting algorithms discussed works like this: It begins by sorting the first two elements of the array, which becomes a sorted subset. Then the third element is moved to its correct position relative to the first two elements. At that point the first three elements become the sorted subset. This process continues with the fourth and subsequent elements until the entire array is sorted. Which algorithm is this?
- 9.3 One of the sorting algorithms discussed works like this: The smallest value in the array is located and moved to element 0. Then the next smallest value is located and moved to element 1. This process continues until all of the elements have been placed in their proper order. Which algorithm is this?

**9.4**

## The Binary Search Algorithm

**CONCEPT:** The binary search algorithm is much more efficient than the sequential search, which was discussed in Chapter 8. The binary search algorithm locates an item in an array by repeatedly dividing the array in half. Each time it divides the array, it eliminates the half of the array that does not contain the item.

Chapter 8 discussed the sequential search algorithm, which uses a loop to step sequentially through an array, starting with the first element. It compares each element with the value being searched for and stops when the value is found or the end of the array is encountered. If the value being searched for is not in the array, the algorithm unsuccessfully searches to the end of the array.

The advantage of the sequential search is its simplicity: It is very easy to understand and implement. Furthermore, it doesn't require the data in the array to be stored in any particular order. Its disadvantage, however, is its inefficiency. If the array being searched contains 20,000 elements, the algorithm will have to look at all 20,000 elements in order to find a value stored in the last element.

In an average case, an item is just as likely to be found near the beginning of an array as near the end. Typically, for an array of  $n$  items, the sequential search will locate an item in  $n/2$  attempts. If an array has 50,000 elements, the sequential search will make a comparison with 25,000 of them in a typical case. This is assuming, of course, that the search item is consistently found in the array. ( $n/2$  is the average number of comparisons. The maximum number of comparisons is always  $n$ .)

When the sequential search fails to locate an item, it must make a comparison with every element in the array. As the number of failed search attempts increases, so does the average number of comparisons. Although the sequential search algorithm is adequate for small arrays, it should not be used on large arrays if speed is important.

The *binary search* is a clever algorithm that is much more efficient than the sequential search. Its only requirement is that the values in the array must be sorted in ascending order. Instead of testing the array's first element, this algorithm starts with the element in the middle. If that element happens to contain the desired value, then the search is over. Otherwise, the value in the middle element is either greater than or less than the value being searched for. If it is greater, then the desired value (if it is in the list) will be found somewhere in the first half of the array. If it is less, then the desired value (again, if it is in the list) will be found somewhere in the last half of the array. In either case, half of the array's elements have been eliminated from further searching.

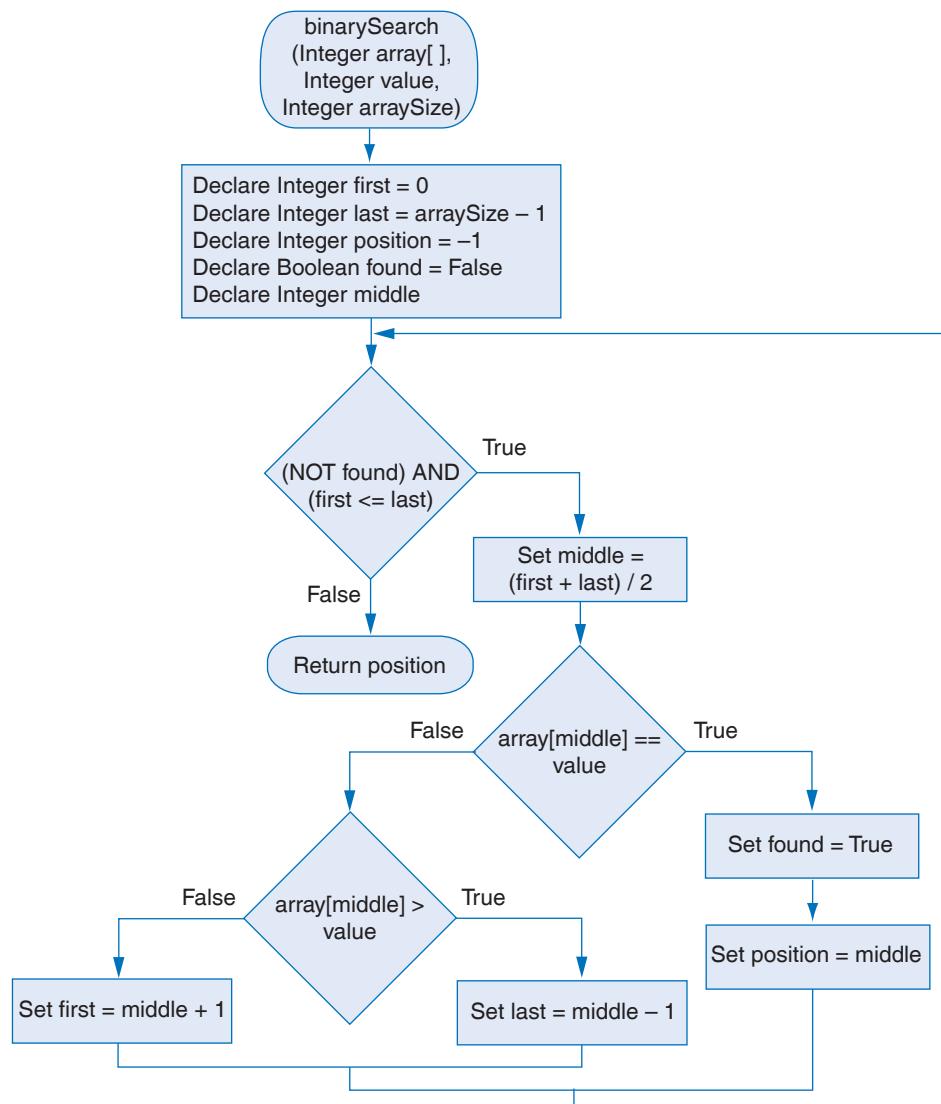
If the desired value isn't found in the middle element, the procedure is repeated for the half of the array that potentially contains the value. For instance, if the last half of the array is to be searched, the algorithm tests *its* middle element. If the desired value isn't found there, the search is narrowed to the quarter of the array that resides before or after that element. This process continues until the value being searched for is either found or there are no more elements to test.

Figure 9-25 shows a flowchart for a function that performs the binary search algorithm. The function accepts an `Integer` array, an `Integer` value to search the array for, and an `Integer` that specifies the array's size. If the value is found in the array, the function returns the subscript of the element containing the value. If the value is not found in the array, the function returns `-1`. Program 9-7 shows the `binarySearch` function in pseudocode. Note that the pseudocode shown in Program 9-7 is only the `binarySearch` function and not a complete program.

This algorithm uses three variables to mark positions within the array: `first`, `last`, and `middle`. The `first` and `last` variables mark the boundaries of the portion of the array currently being searched. They are initialized with the subscripts of the array's `first` and `last` elements. The subscript of the element halfway between `first` and `last` is calculated and stored in the `middle` variable. If the element in the middle of the array does not contain the search value, the `first` and `last` variables are adjusted so that only the top or bottom half of the array is searched during the next iteration. This cuts the portion of the array being searched in half each time the loop fails to locate the search value.

**Program 9-7****binarySearch function  
(not a complete program)**

```
1 // The binarySearch function accepts as arguments an Integer
2 // array, a value to search the array for, and the size
3 // of the array. If the value is found in the array, its
4 // subscript is returned. Otherwise, - 1 is returned,
5 // indicating that the value was not found in the array.
6 Function Integer binarySearch(Integer array[], Integer value,
7 Integer arraySize)
8 // Variable to hold the subscript of the first element.
9 Declare Integer first = 0
10
11 // Variable to hold the subscript of the last element.
12 Declare Integer last = arraySize - 1
13
14 // Position of the search value
15 Declare Integer position = - 1
16
17 // Flag
18 Declare Boolean found = False
19
20 // Variable to hold the subscript of the midpoint.
21 Declare Integer middle
22
23 While (NOT found) AND (first <= last)
24 // Calculate the midpoint.
25 Set middle = (first + last) / 2
26
27 // See if the value is found at the midpoint...
28 If array[middle] == value Then
29 Set found = True
30 Set position = middle
31
32 // Else, if the value is in the lower half...
33 Else If array[middle] > value Then
34 Set last = middle - 1
35
36 // Else, if the value is in the upper half...
37 Else
38 Set first = middle + 1
39 End If
40 End While
41
42 // Return the position of the item, or - 1
43 // if the item was not found.
44 Return position
45 End Function
```

**Figure 9-25** Flowchart for the binarysearch function

## Efficiency of a Binary Search

Obviously, a binary search is much more efficient than a sequential search. Every time a binary search makes a comparison and fails to find the desired item, it eliminates half of the remaining portion of the array that must be searched. For example, consider an array with 1,000 elements. If a binary search fails to find an item on the first attempt, the number of elements that remains to be searched is 500. If the item is not found on the second attempt, the number of elements that remains to be searched is 250. This process continues until the binary search has either located the desired item or determined that it is not in the array. With 1,000 elements this takes no more than 10 comparisons. (Compare this to a sequential search, which would make an average of 500 comparisons!)

## In the Spotlight: Using the Binary Search Algorithm



Constance manages a cooking school that employs six instructors. She has asked you to design a program that she can use to look up an instructor's phone number. You decide to use two parallel arrays: one named `names` that will hold the instructors' last names, and another named `phones` that will hold each instructor's phone number. Here is the general algorithm:

1. Get an instructor's last name from the user.
2. Search for the name in the `names` array.
3. If the name is found, get its subscript. Use the subscript to display the contents of the parallel `phones` array. If the name is not found, display a message indicating so.

Program 9-8 shows the pseudocode for the program. Note that the array contents are already sorted in ascending order. This is important because the program uses the binary search algorithm to locate a name in the `names` array.

### Program 9-8

```
1 Module main()
2 // Constant for array sizes
3 Constant Integer SIZE = 6
4
5 // Array of instructor names, already sorted in
6 // ascending order.
7 Declare String names[SIZE] = "Hall", "Harrison",
8 "Hoyle", "Kimura",
9 "Lopez", "Pike"
10
11 // Parallel array of instructor phone numbers.
12 Declare String phones[SIZE] = "555-6783", "555-0199",
13 "555-9974", "555-2377",
14 "555-7772", "555-1716"
15
16 // Variable to hold the last name to search for.
17 Declare String searchName
18
19 // Variable to hold the subscript of the name.
20 Declare Integer index
21
22 // Variable to control the loop.
23 Declare String again = "Y"
24
25 While (again == "Y" OR again == "y")
26 // Get the name to search for.
27 Display "Enter a last name to search for."
28 Input searchName
29
30 // Search for the last name.
31 index = binarySearch(names, searchName, SIZE)
32
```

```
33 If index != -1 Then
34 // Display the phone number.
35 Display "The phone number is ", phones[index]
36 Else
37 // The name was not found in the array.
38 Display searchName, " was not found."
39 End If
40
41 // Search again?
42 Display "Do you want to search again? (Y=Yes, N=No)"
43 Input again
44 End While
45
46 End Module
47
48 // The binarySearch function accepts as arguments a String
49 // array, a value to search the array for, and the size
50 // of the array. If the value is found in the array, its
51 // subscript is returned. Otherwise, -1 is returned,
52 // indicating that the value was not found in the array.
53 Function Integer binarySearch(String array[], String value,
54 Integer arraySize)
55 // Variable to hold the subscript of the first element.
56 Declare Integer first = 0
57
58 // Variable to hold the subscript of the last element.
59 Declare Integer last = arraySize - 1
60
61 // Position of the search value
62 Declare Integer position = -1
63
64 // Flag
65 Declare Boolean found = False
66
67 // Variable to hold the subscript of the midpoint.
68 Declare Integer middle
69
70 While (NOT found) AND (first <= last)
71 // Calculate the midpoint.
72 Set middle = (first + last) / 2
73
74 // See if the value is found at the midpoint...
75 If array[middle] == value Then
76 Set found = True
77 Set position = middle
78
79 // Else, if the value is in the lower half...
80 Else If array[middle] > value Then
81 Set last = middle - 1
82
83 // Else, if the value is in the upper half...
84 Else
85 Set first = middle + 1
86 End If
87 End While
88
```

```
89 // Return the position of the item, or - 1
90 // if the item was not found.
91 Return position
92 End Function
```

### Program Output (with Input Shown in Bold)

```
Enter a last name to search for.
Lopez [Enter]
The phone number is 555-7772
Do you want to search again? (Y=Yes, N=No)
Y [Enter]
Enter a last name to search for.
Harrison [Enter]
The phone number is 555-0199
Do you want to search again? (Y=Yes, N=No)
Y [Enter]
Enter a last name to search for.
Lee [Enter]
Lee was not found.
Do you want to search again? (Y=Yes, N=No)
N [Enter]
```



### Checkpoint

- 9.4 Describe the difference between a sequential search and a binary search.
- 9.5 On average, with an array of 1,000 elements, how many comparisons will a sequential search perform? (Assume the items being searched for are consistently found in the array.)
- 9.6 With an array of 1,000 elements, what is the maximum number of comparisons a binary search will perform?

9.5

### Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

## Java

### Sorting and Searching Arrays

#### The Bubble Sort in Java

Program 9-9 is only a partial program. It shows the Java version of pseudocode Program 9-1, which is the bubble sort algorithm.

#### Program 9-9

```
1 public class BubbleSortAlgorithm
2 {
3 // Note: This is not a complete program.
4 //
5 // The bubbleSort method uses the bubble sort algorithm
6 // to sort an int array.
7 // Note the following:
8 // (1) We do not have to pass the array size because in
9 // Java arrays have a length field.
10 // (2) We do not have a separate method to swap values.
11 // This is because Java does not allow pass by
12 // reference. The swap is performed inside this method.
13
14 public static void bubbleSort(int[] array)
15 {
16 int maxElement; // Marks the last element to compare
17 int index; // Index of an element to compare
18 int temp; // Used to swap to elements
19
20 // The outer loop positions maxElement at the last element
21 // to compare during each pass through the array. Initially
22 // maxElement is the index of the last element in the array.
23 // During each iteration, it is decreased by one.
24 for (maxElement = array.length - 1; maxElement >= 0; maxElement--)
25 {
26 // The inner loop steps through the array, comparing
27 // each element with its neighbor. All of the elements
28 // from index 0 through maxElement are involved in the
29 // comparison. If two elements are out of order, they
30 // are swapped.
31 for (index = 0; index <= maxElement - 1; index++)
32 {
33 // Compare an element with its neighbor.
34 if (array[index] > array[index + 1])
35 {
36 // Swap the two elements.
37 temp = array[index];
38 array[index] = array[index + 1];
39 array[index + 1] = temp;
40 }
41 }
42 }
43 }
44 }
```

### The Selection Sort in Java

Program 9-10 is also a partial program. It shows the Java version of the `selectionSort` pseudocode module that is shown in Program 9-5.

#### Program 9-10

```
1 public class SelectionSortAlgorithm
2 {
3 // Note: This is not a complete program.
4 //
5 // The selectionSort method performs a selection sort on an
6 // int array. The array is sorted in ascending order.
7
8 public static void selectionSort(int[] array)
9 {
10 int startScan; // Starting position of the scan
11 int index; // To hold a subscript value
12 int minIndex; // Element with smallest value in the scan
13 int minValue; // The smallest value found in the scan
14
15 // The outer loop iterates once for each element in the
16 // array. The startScan variable marks the position where
17 // the scan should begin.
18 for (startScan = 0; startScan < (array.length-1); startScan++)
19 {
20 // Assume the first element in the scannable area
21 // is the smallest value.
22 minIndex = startScan;
23 minValue = array[startScan];
24
25 // Scan the array, starting at the 2nd element in
26 // the scannable area. We are looking for the smallest
27 // value in the scannable area.
28 for(index = startScan + 1; index < array.length; index++)
29 {
30 if (array[index] < minValue)
31 {
32 minValue = array[index];
33 minIndex = index;
34 }
35 }
36
37 // Swap the element with the smallest value
38 // with the first element in the scannable area.
39 array[minIndex] = array[startScan];
40 array[startScan] = minValue;
41 }
42 }
43 }
```

**The Insertion Sort in Java**

Program 9-11 is also a partial program. It shows the Java version of the `insertionSort` pseudocode module that is shown in Program 9-6.

**Program 9-11**

```
1 public class InsertionSortAlgorithm
2 {
3 // Note: This is not a complete program.
4 //
5 // The insertionSort method performs an insertion sort on
6 // an int array. The array is sorted in ascending order.
7
8 public static void insertionSort(int[] array)
9 {
10 int unsortedValue; // The first unsorted value
11 int scan; // Used to scan the array
12
13 // The outer loop steps the index variable through
14 // each subscript in the array, starting at 1. This
15 // is because element 0 is considered already sorted.
16 for (int index = 1; index < array.length; index++)
17 {
18 // The first element outside the sorted subset is
19 // array[index]. Store the value of this element
20 // in unsortedValue.
21 unsortedValue = array[index];
22
23 // Start scan at the subscript of the first element
24 // outside the sorted subset.
25 scan = index;
26
27 // Move the first element outside the sorted subset
28 // into its proper position within the sorted subset.
29 while (scan > 0 && array[scan-1] > unsortedValue)
30 {
31 array[scan] = array[scan - 1];
32 scan--;
33 }
34
35 // Insert the unsorted value in its proper position
36 // within the sorted subset.
37 array[scan] = unsortedValue;
38 }
39 }
40 }
```

### The Binary Search in Java

Program 9-12 is also a partial program. It shows the Java version of the `binarySearch` pseudocode module that is shown in Program 9-7.

#### Program 9-12

```
1 public class BinarySearchAlgorithm
2 {
3 // Note: This is not a complete program.
4 //
5 // The binarySearch method performs a binary search on a
6 // String array. The array is searched for the string passed
7 // to value. If the string is found, its array subscript
8 // is returned. Otherwise, - 1 is returned indicating the
9 // value was not found in the array.
10
11 public static int binarySearch(String[] array, String value)
12 {
13 int first; // First array element
14 int last; // Last array element
15 int middle; // Mid point of search
16 int position; // Position of search value
17 boolean found; // Flag
18
19 // Set the initial values.
20 first = 0;
21 last = array.length - 1;
22 position = - 1;
23 found = false;
24
25 // Search for the value.
26 while (!found && first <= last)
27 {
28 // Calculate mid point
29 middle = (first + last) / 2;
30
31 // If value is found at midpoint...
32 if (array[middle].equals(value))
33 {
34 found = true;
35 position = middle;
36 }
37 // else if value is in lower half...
38 else if (array[middle].compareTo(value) > 0)
39 last = middle - 1;
40 // else if value is in upper half....
41 else
42 first = middle + 1;
43 }
44
45 // Return the position of the item, or - 1
46 // if it was not found.
47 return position;
48 }
49 }
```

## Python

### Sorting and Searching Lists

#### The Bubble Sort in Python

Program 9-13 is only a partial program. It shows the Python version of pseudocode Program 9-1, which is the bubble sort algorithm.

#### Program 9-13

#### (*bubble\_sort.py*)

```
1 # Note: This is not a complete program.
2 #
3 # The bubble_sort function uses the bubble sort algorithm
4 # to sort a list of integers.
5 # Note the following:
6 # (1) We do not have to pass the array size because we
7 # can use the len function.
8 # (2) We do not have a separate method to swap values.
9 # The swap is performed inside this method.
10
11 def bubble_sort(arr):
12 # Set max_element to the length of the arr list, minus
13 # one. This is necessary for the outer loop.
14 max_element = len(arr) - 1
15
16 # The outer loop positions max_element at the last element
17 # to compare during each pass through the list. Initially
18 # max_element is the index of the last element in the array.
19 # During each iteration, it is decreased by one.
20 while max_element >= 0:
21 # Set index to 0, necessary for the inner loop.
22 index = 0
23
24 # The inner loop steps through the list, comparing
25 # each element with its neighbor. All of the elements
26 # from index 0 through max_element are involved in the
27 # comparison. If two elements are out of order, they
28 # are swapped.
29 while index <= max_element - 1:
30 # Compare an element with its neighbor.
31 if arr[index] > arr[index + 1]:
32 # Swap the two elements.
33 temp = arr[index]
34 arr[index] = arr[index + 1]
35 arr[index + 1] = temp
36 # Increment index.
37 index = index + 1
38 # Decrement max_element.
39 max_element = max_element - 1
```

### The Selection Sort in Python

Program 9-14 is also a partial program. It shows the Python version of the selection-Sort pseudocode module that is shown in Program 9-5.

**Program 9-14**

*(selection\_sort.py)*

```
1 # Note: This is not a complete program.
2 #
3 # The selection_sort function performs the selection sort
4 # algorithm on a list of integers.
5
6 def selection_sort(arr):
7 # Set start_scan to 0. This is necessary for
8 # the outer loop. It is the starting position
9 # of the scan.
10 start_scan = 0
11
12 # The outer loop iterates once for each element in the
13 # list. The start_scan variable marks the position where
14 # the scan should begin.
15 while start_scan < len(arr) - 1:
16 # Assume the first element in the scannable area
17 # is the smallest value.
18 min_index = start_scan
19 min_value = arr[start_scan]
20
21 # Initialize index for the inner loop.
22 index = start_scan + 1
23
24 # Scan the list, starting at the 2nd element in
25 # the scannable area. We are looking for the smallest
26 # value in the scannable area.
27 while index < len(arr):
28 if arr[index] < min_value:
29 min_value = arr[index]
30 min_index = index
31 # Increment index.
32 index = index + 1
33
34 # Swap the element with the smallest value
35 # with the first element in the scannable area.
36 arr[min_index] = arr[start_scan]
37 arr[start_scan] = min_value
38
39 # Increment start_scan.
40 start_scan = start_scan + 1
```

**The Insertion Sort in Python**

Program 9-15 is also a partial program. It shows the Python version of the insertion-Sort pseudocode module that is shown in Program 9-6.

**Program 9-15** (*insertion\_sort.py*)

```
1 # Note: this is not a complete program.
2 #
3 # The insertion_sort function performs an insertion sort
4 # algorithm on a list of integers.
5
6 def insertion_sort(arr):
7 # Set index to 1 for the outer loop.
8 index = 1
9
10 # The outer loop steps the index variable through
11 # each subscript in the list, starting at 1. This
12 # is because element 0 is considered already sorted.
13 while index < len(arr):
14 # The first element outside the sorted subset is
15 # arr[index]. Assign the value of this element
16 # to unsorted_value.
17 unsorted_value = arr[index]
18
19 # Start the scan variable at the subscript of the
20 # first element outside the sorted subset.
21 scan = index
22
23 # Move the first element outside the sorted subset
24 # into its proper position within the sorted subset.
25 while scan > 0 and arr[scan - 1] > unsorted_value:
26 arr[scan] = arr[scan - 1]
27 scan = scan - 1
28
29 # Insert the unsorted value in its proper position
30 # within the sorted subset.
31 arr[scan] = unsorted_value
32
33 # Increment index.
34 index = index + 1
```

### The Binary Search in Python

Program 9-16 is also a partial program. It shows the Python version of the `binarySearch` pseudocode module that is shown in Program 9-7.

#### Program 9-16 (`binary_search.py`)

```
1 # Note: This is not a complete program.
2 #
3 # The binary_search function performs a binary search on a
4 # String list. The list is searched for the string passed to
5 # the value parameter. If the string is found, its subscript
6 # is returned. Otherwise, - 1 is returned indicating the value
7 # was not found in the list.
8
9 def binary_search(arr, value):
10 # Set the initial values.
11 first = 0
12 last = len(arr) - 1
13 position = - 1
14 found = False
15
16 # Search for the value
17 while not found and first <= last:
18 # Calculate the mid point.
19 middle = (first + last) / 2
20
21 # If the value is found at the mid point...
22 if arr[middle] == value:
23 found = True
24 position = middle
25 # else if value is in the lower half...
26 elif arr[middle] > value:
27 last = middle - 1
28 # else if value is in the upper half...
29 else:
30 first = middle + 1
31
32 # Return the position of the item, or - 1
33 # if it was not found.
34 return position
```

**C++**

## Sorting and Searching Arrays

### The Bubble Sort in C++

Program 9-17 is only a partial program. It shows the C++ version of pseudocode Program 9-1, which is the bubble sort algorithm.

**Program 9-17 (BubbleSort.cpp)**

```
1 // Note: This is not a complete program.
2 // bubbleSort function
3 void bubbleSort(int array[], int size)
4 {
5 int maxElement; // Marks the last element to compare
6 int index; // Index of an element to compare
7
8 // The outer loop positions maxElement at the last element
9 // to compare during each pass through the array. Initially
10 // maxElement is the index of the last element in the array.
11 // During each iteration, it is decreased by one.
12 for (maxElement = size - 1; maxElement >= 0; maxElement--)
13 {
14 // The inner loop steps through the array, comparing
15 // each element with its neighbor. All of the elements
16 // from index 0 through maxElement are involved in the
17 // comparison. If two elements are out of order, they
18 // are swapped.
19 for (index = 0; index <= maxElement - 1; index++)
20 {
21 // Compare an element with its neighbor.
22 if (array[index] > array[index + 1])
23 {
24 // Swap the two elements.
25 swap(array[index], array[index+1]);
26 }
27 }
28 }
29 }
30
31 // The swap function swaps the contents of the two
32 // arguments passed to it.
33 void swap(int &a, int &b)
34 {
35 int temp;
36 temp = a;
37 a = b;
38 b = temp;
39 }
```

### The Selection Sort in C++

Program 9-18 is also a partial program. It shows the C++ version of the `selectionSort` pseudocode module that is shown in Program 9-5.

#### Program 9-18 (SelectionSort.cpp)

```
1 // Note: This is not a complete program.
2 //
3 // The selectionSort function performs a selection sort on an
4 // int array. The array is sorted in ascending order.
5
6 void selectionSort(int array[], int size)
7 {
8 int startScan; // Starting position of the scan
9 int index; // To hold a subscript value
10 int minIndex; // Element with smallest value in the scan
11 int minValue; // The smallest value found in the scan
12
13 // The outer loop iterates once for each element in the
14 // array. The startScan variable marks the position where
15 // the scan should begin.
16 for (startScan = 0; startScan < (size-1); startScan++)
17 {
18 // Assume the first element in the scannable area
19 // is the smallest value.
20 minIndex = startScan;
21 minValue = array[startScan];
22
23 // Scan the array, starting at the 2nd element in
24 // the scannable area. We are looking for the smallest
25 // value in the scannable area.
26 for(index = startScan + 1; index < size; index++)
27 {
28 if (array[index] < minValue)
29 {
30 minValue = array[index];
31 minIndex = index;
32 }
33 }
34
35 // Swap the element with the smallest value
36 // with the first element in the scannable area.
37 swap(array[minIndex], array[startScan]);
38 }
39 }
40
41 // The swap function swaps the contents of the two
42 // arguments passed to it.
43 void swap(int &a, int &b)
44 {
45 int temp;
46 temp = a;
47 a = b;
48 b = temp;
49 }
```

**The Insertion Sort in C++**

Program 9-19 is also a partial program. It shows the C++ version of the `insertionSort` pseudocode module that is shown in Program 9-6.

**Program 9-19 (InsertionSort.cpp)**

```
1 // Note: This is not a complete program.
2 //
3 // The insertionSort function performs an insertion sort on
4 // an int array. The array is sorted in ascending order.
5
6 void insertionSort(int array[], int size)
7 {
8 int unsortedValue; // The first unsorted value
9 int scan; // Used to scan the array
10
11 // The outer loop steps the index variable through
12 // each subscript in the array, starting at 1. This
13 // is because element 0 is considered already sorted.
14 for (int index = 1; index < size; index++)
15 {
16 // The first element outside the sorted subset is
17 // array[index]. Store the value of this element
18 // in unsortedValue.
19 unsortedValue = array[index];
20
21 // Start scan at the subscript of the first element
22 // outside the sorted subset.
23 scan = index;
24
25 // Move the first element outside the sorted subset
26 // into its proper position within the sorted subset.
27 while (scan > 0 && array[scan-1] > unsortedValue)
28 {
29 array[scan] = array[scan - 1];
30 scan--;
31 }
32
33 // Insert the unsorted value in its proper position
34 // within the sorted subset.
35 array[scan] = unsortedValue;
36 }
37 }
```

### The Binary Search in C++

Program 9-20 is also a partial program. It shows the C++ version of the `binarySearch` pseudocode module that is shown in Program 9-7.

#### Program 9-20 (BinarySearch.cpp)

```
1 // Note: This is not a complete program.
2 //
3 // The binarySearch function performs a binary search on a
4 // string array. The array is searched for the string passed
5 // to value. If the string is found, its array subscript
6 // is returned. Otherwise, -1 is returned indicating the
7 // value was not found in the array.
8
9 int binarySearch(string array[], string value, int size)
10 {
11 int first; // First array element
12 int last; // Last array element
13 int middle; // Midpoint of search
14 int position; // Position of search value
15 bool found; // Flag
16
17 // Set the initial values.
18 first = 0;
19 last = size - 1;
20 position = -1;
21 found = false;
22
23 // Search for the value.
24 while (!found && first <= last)
25 {
26 // Calculate midpoint
27 middle = (first + last) / 2;
28
29 // If value is found at midpoint...
30 if (array[middle] == value)
31 {
32 found = true;
33 position = middle;
34 }
35 // else if value is in lower half...
36 else if (array[middle] > value)
37 last = middle - 1;
38 // else if value is in upper half....
39 else
40 first = middle + 1;
41 }
42
43 // Return the position of the item, or -1
44 // if it was not found.
45 return position;
46 }
```

## Review Questions

### Multiple Choice

1. This type of algorithm rearranges the values stored in an array in some particular order.
  - a. search algorithm
  - b. sorting algorithm
  - c. ordering algorithm
  - d. selection algorithm
2. If an array is sorted in this order, the values are stored from lowest to highest.
  - a. asymptotic
  - b. logarithmic
  - c. ascending
  - d. descending
3. If an array is sorted in this order, the values are stored from highest to lowest.
  - a. asymptotic
  - b. logarithmic
  - c. ascending
  - d. descending
4. This algorithm makes several passes through an array and causes the larger values to gradually move toward the end of the array with each pass.
  - a. bubble sort
  - b. selection sort
  - c. insertion sort
  - d. sequential sort
5. In this algorithm, the smallest value in the array is located and moved to element 0. Then the next smallest value is located and moved to element 1. This process continues until all of the elements have been placed in their proper order.
  - a. bubble sort
  - b. selection sort
  - c. insertion sort
  - d. sequential sort
6. This algorithm begins by sorting the first two elements of the array, which become a sorted subset. Then, the third element is moved to its correct position relative to the first two elements. At that point, the first three elements become the sorted subset. This process continues with the fourth and subsequent elements until the entire array is sorted.
  - a. bubble sort
  - b. selection sort
  - c. insertion sort
  - d. sequential sort

7. This search algorithm steps sequentially through an array, comparing each item with the search value.
  - a. sequential search
  - b. binary search
  - c. natural order search
  - d. selection search
8. This search algorithm repeatedly divides the portion of an array being searched in half.
  - a. sequential search
  - b. binary search
  - c. natural order search
  - d. selection search
9. This search algorithm is adequate for small arrays but not large arrays.
  - a. sequential search
  - b. binary search
  - c. natural order search
  - d. selection search
10. This search algorithm requires that the array's contents be sorted.
  - a. sequential search
  - b. binary search
  - c. natural order search
  - d. selection search

### True or False

1. If data is sorted in ascending order, it means it is ordered from lowest value to highest value.
2. If data is sorted in descending order, it means it is ordered from lowest value to highest value.
3. Regardless of the programming language being used, it is not possible to use the bubble sort algorithm to sort strings.
4. The *average* number of comparisons performed by the sequential search algorithm on an array of  $n$  elements is  $n/2$  (assuming the search values are consistently found).
5. The *maximum* number of comparisons performed by the sequential search algorithm on an array of  $n$  elements is  $n/2$  (assuming the search values are consistently found).

### Algorithm Workbench

1. Design a swap module that accepts two arguments of the `Real` data type and swaps them.
2. What algorithm does the following pseudocode perform?

```
Declare Integer maxElement
Declare Integer index

For maxElement = arraySize - 1 To 0 Step - 1
```

```

For index = 0 To maxElement - 1
 If array[index] > array[index + 1] Then
 Call swap(array[index], array[index + 1])
 End If
End For
End For

```

3. What algorithm does the following pseudocode perform?

```

Declare Integer index
Declare Integer scan
Declare Integer unsortedValue

For index = 1 To arraySize - 1
 Set unsortedValue = array[index]
 Set scan = index

 While scan > 0 AND array[scan-1] < array[scan]
 Call swap(array[scan-1], array[scan])
 Set scan = scan - 1
 End While
 Set array[scan] = unsortedValue
End For

```

4. What algorithm does the following pseudocode perform?

```

Declare Integer startScan
Declare Integer minIndex
Declare Integer minValue
Declare Integer index

For startScan = 0 To arraySize - 2
 Set minIndex = startScan
 Set minValue = array[startScan]

 For index = startScan + 1 To arraySize - 1
 If array[index] < minValue
 Set minValue = array[index]
 Set minIndex = index
 End If
 End For
 Call swap(array[minIndex], array[startScan])
End For

```

### Short Answer

1. If a sequential search function is searching for a value that is stored in the last element of a 10,000-element array, how many elements will the search code have to read to locate the value?
2. In an average case involving an array of  $n$  elements, how many times will a sequential search function have to read the array to locate a specific value?
3. A binary search function is searching for a value that happens to be stored in the middle element of an array. How many times will the function read an element in the array before finding the value?

4. What is the maximum number of comparisons that a binary search function will make when searching for a value in a 1,000-element array?
5. Why is the bubble sort inefficient for large arrays?
6. Why is the selection sort more efficient than the bubble sort on large arrays?
7. List the steps that the selection sort algorithm would make in sorting the following values: 4, 1, 3, 2.
8. List the steps that the insertion sort algorithm would make in sorting the following values: 4, 1, 3, 2.

## Debugging Exercise

1. Assume the following `main` module is in a program that includes the `binarySearch` function that was shown in this chapter. Why doesn't the pseudocode in the `main` module work?

```
// This program uses the binarySearch function to search for a
// name in the array. This program assumes the binarySearch
// function has already been defined.
Module main()
 Constant Integer SIZE = 5

 Declare String names[SIZE] = "Zack", "James", "Pam",
 "Marc", "Susan"
 Declare String searchName
 Declare Integer index

 Display "Enter a name to search for."
 Input searchName
 Set index = binarySearch(names, searchName, SIZE)

 If index != -1 Then
 Display searchName, " was found."
 Else
 Display searchName, " was NOT found."
 End If
End Module
```

## Programming Exercises



### 1. Sorted Golf Scores

Design a program that asks the user to enter 10 golf scores. The scores should be stored in an `Integer` array. Sort the array in ascending order and display its contents.

### 2. Sorted Names

Design a program that allows the user to enter 20 names into a `String` array. Sort the array in ascending (alphabetical) order and display its contents.

### 3. Rainfall Program Modification

Recall that Programming Exercise 3 in Chapter 8 asked you to design a program that lets the user enter the total rainfall for each of 12 months into an array. The program should calculate and display the total rainfall for the year, the average monthly rainfall, and the months with the highest and lowest amounts. Enhance the program so it sorts the array in ascending order and displays the values it contains.

### 4. Name Search

Modify the *Sorted Names* program that you wrote for exercise #2 so it allows you to search the array for a specific name.

### 5. Charge Account Validation

Recall that Programming Exercise 5 in Chapter 8 asked you to design a program that asks the user to enter a charge account number. The program should determine whether the number is valid by comparing it to a list of valid charge account numbers. Modify the program so it uses the binary search algorithm instead of the sequential search algorithm.

### 6. Phone Number Lookup

Recall that Programming Exercise 7 in Chapter 8 asked you to design a program with two parallel arrays: a `String` array named `people` and a `String` array named `phoneNumbers`. The program allows you to search for a person's name in the `people` array. If the name is found, it displays that person's phone number. Modify the program so it uses the binary search algorithm instead of the sequential search algorithm.

### 7. Search Benchmarks

Design an application that has an array of at least 20 integers. It should call a module that uses the sequential search algorithm to locate one of the values. The module should keep a count of the number of comparisons it makes until it finds the value. Then the program should call another module that uses the binary search algorithm to locate the same value. It should also keep a count of the number of comparisons it makes. Display these values on the screen.

### 8. Sorting Benchmarks

Modify the modules presented in this chapter that perform the bubble sort, selection sort, and insertion sort algorithms on an `Integer` array, such that each module keeps a count of the number of swaps it makes.

Then, design an application that uses three identical arrays of at least 20 integers. It should call each module on a different array, and display the number of swaps made by each algorithm.

## TOPICS

- |                                            |                                                |
|--------------------------------------------|------------------------------------------------|
| 10.1 Introduction to File Input and Output | 10.4 Processing Records                        |
| 10.2 Using Loops to Process Files          | 10.5 Control Break Logic                       |
| 10.3 Using Files and Arrays                | 10.6 Focus on Languages: Java, Python, and C++ |

### 10.1

## Introduction to File Input and Output

**CONCEPT:** When a program needs to save data for later use, it writes the data in a file. The data can be read from the file at a later time.

The programs you have designed so far require the user to reenter data each time the program runs, because data that is stored in variables in RAM disappears once the program stops running. If a program is to retain data between the times it runs, it must have a way of saving it. Data is saved in a file, which is usually stored on a computer's disk. Once the data is saved in a file, it will remain there after the program stops running. Data that is stored in a file can be retrieved and used at a later time.

Most of the commercial software packages that you use on a day-to-day basis store data in files. The following are a few examples:

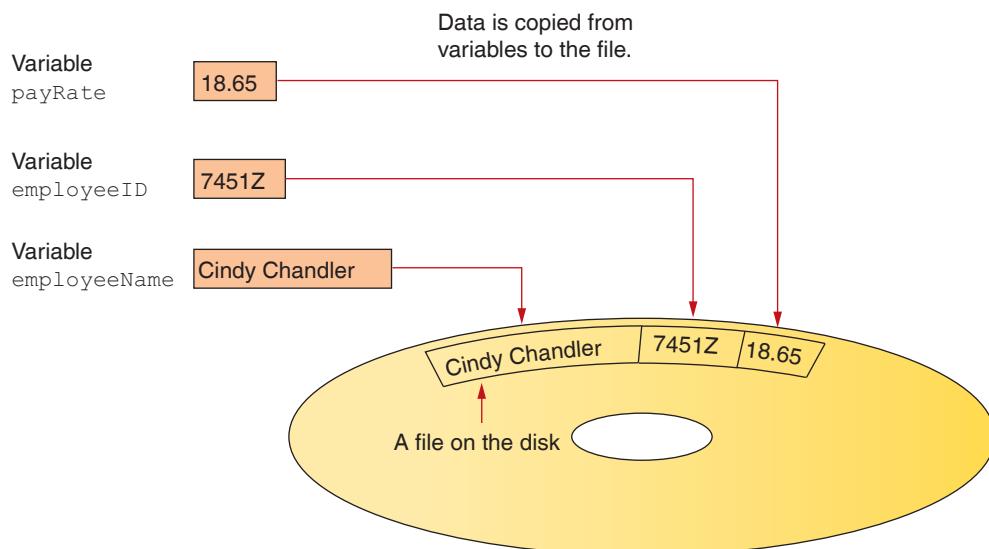
- **Word processors:** Word processing programs are used to write letters, memos, reports, and other documents. The documents are then saved in files so they can be edited and printed.
- **Image editors:** Image editing programs are used to draw graphics and edit images such as the ones that you take with a digital camera. The images that you create or edit with an image editor are saved in files.
- **Spreadsheets:** Spreadsheet programs are used to work with numerical data. Numbers and mathematical formulas can be inserted into the rows and columns of the spreadsheet. The spreadsheet can then be saved in a file for use later.

- **Games:** Many computer games keep data stored in files. For example, some games keep a list of player names with their scores stored in a file. These games typically display the players' names in order of their scores, from highest to lowest. Some games also allow you to save your current game status in a file so you can quit the game and then resume playing it later without having to start from the beginning.
- **Web browsers:** Sometimes when you visit a Web page, the browser stores a small file known as a *cookie* on your computer. Cookies typically contain information about the browsing session, such as the contents of a shopping cart.

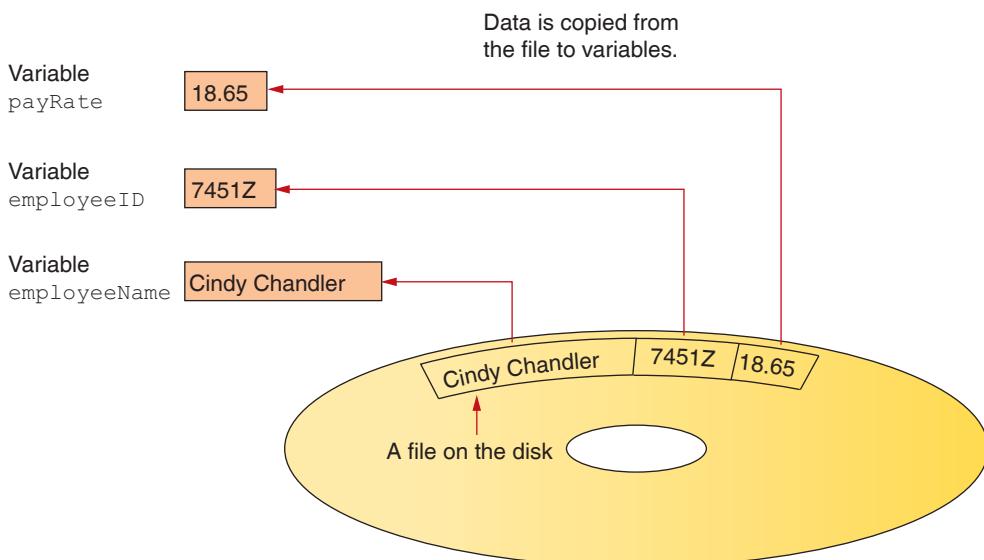
Programs that are used in daily business operations rely extensively on files. Payroll programs keep employee data in files, inventory programs keep data about a company's products in files, accounting systems keep data about a company's financial operations in files, and so on.

Programmers usually refer to the process of saving data in a file as "writing data to" the file. When a piece of data is written to a file, it is copied from a variable in RAM to the file. This is illustrated in Figure 10-1. The term *output file* is used to describe a file that data is written to. It is called an output file because the program stores output in it.

**Figure 10-1** Writing data to a file



The process of retrieving data from a file is known as "reading data from" the file. When a piece of data is read from a file, it is copied from the file into a variable in RAM. Figure 10-2 illustrates this. The term *input file* is used to describe a file that data is read from. It is called an input file because the program gets input from the file.

**Figure 10-2** Reading data from a file

This chapter discusses how to design programs that write data to files and read data from files. There are always three steps that must be taken when a file is used by a program.

1. **Open the file:** Opening a file creates a connection between the file and the program. Opening an output file usually creates the file on the disk and allows the program to write data to it. Opening an input file allows the program to read data from the file.
2. **Process the file:** In this step data is either written to the file (if it is an output file) or read from the file (if it is an input file).
3. **Close the file:** When the program is finished using the file, the file must be closed. Closing a file disconnects the file from the program.

## Types of Files

In general, there are two types of files: text and binary. A *text file* contains data that has been encoded as text, using a scheme such as ASCII or Unicode. Even if the file contains numbers, those numbers are stored in the file as a series of characters. As a result, the file may be opened and viewed in a text editor such as Notepad. A *binary file* contains data that has not been converted to text. As a consequence, you cannot view the contents of a binary file with a text editor.

## File Access Methods

Most programming languages provide two different ways to access data stored in a file: sequential access and direct access. When you work with a *sequential access file*, you

access data from the beginning of the file to the end of the file. If you want to read a piece of data that is stored at the very end of the file, you have to read all of the data that comes before it—you cannot jump directly to the desired data. This is similar to the way cassette tape players work. If you want to listen to the last song on a cassette tape, you have to either fast-forward over all of the songs that come before it or listen to them. There is no way to jump directly to a specific song.

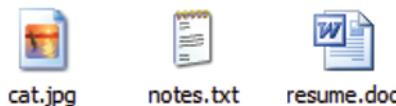
When you work with a *direct access file* (which is also known as a *random access file*), you can jump directly to any piece of data in the file without reading the data that comes before it. This is similar to the way a CD player or an MP3 player works. You can jump directly to any song that you want to listen to.

This chapter focuses on sequential access files. Sequential access files are easy to work with, and you can use them to gain an understanding of basic file operations.

## Creating a File and Writing Data to It

Most computer users are accustomed to the fact that files are identified by a filename. For example, when you create a document with a word processor and then save the document in a file, you have to specify a filename. When you use a utility such as Windows Explorer to examine the contents of your disk, you see a list of filenames. Figure 10-3 shows how three files named `cat.jpg`, `notes.txt`, and `resume.doc` might be represented in Windows Explorer.

**Figure 10-3** Three files (courtesy of Microsoft Corporation)



Each operating system has its own rules for naming files. Many systems support the use of *filename extensions*, which are short sequences of characters that appear at the end of a filename preceded by a period (which is known as a “dot”). For example, the files depicted in Figure 10-3 have the extensions `.jpg`, `.txt`, and `.doc`. The extension usually indicates the type of data stored in the file. For example, the `.jpg` extension usually indicates that the file contains a graphic image that is compressed according to the JPEG image standard. The `.txt` extension usually indicates that the file contains text. The `.doc` extension usually indicates that the file contains a Microsoft Word document. (In this book we will use the `.dat` extension with all of the files we create in our programs. The `.dat` extension simply stands for “data.”)

When writing a program that performs an operation on a file, there are two names that you have to work with in the program’s code. The first of these is the filename that identifies the file on the computer’s disk. The second is an internal name that is similar to a variable name. In fact, you usually declare a file’s internal name in a manner that is similar to declaring a variable. The following example shows how we declare a name for an output file in our pseudocode:

```
Declare outputFile customerFile
```

This statement declares two things.

- The word `OutputFile` indicates the *mode* in which we will use the file. In our pseudocode, `OutputFile` indicates that we will be writing data to the file.
- The name `customerFile` is the internal name we will use to work with the output file in our code.

Although the syntax for making this declaration varies greatly among programming languages, you typically have to declare both the mode in which you will use a file and the file's internal name before you can work with the file.

The next step is to open the file. In our pseudocode we will use the `Open` statement. Here is an example:

```
Open customerFile "customers.dat"
```

The word `Open` is followed by an internal name that was previously declared, and then a string that contains a filename. After this statement executes, a file named `customers.dat` will be created on the disk, and we will be able to use the internal name `customerFile` to write data to the file.



**WARNING!** Remember, when you open an output file you are creating the file on the disk. In most languages, if a file with the specified external name already exists when the file is opened, the contents of the existing file will be erased.

## Writing Data to a File

Once you have opened an output file you can write data to it. In our pseudocode we will use the `Write` statement to write data to a file. For example,

```
Write customerFile "Charles Pace"
```

writes the string `"Charles Pace"` to the file that is associated with `customerFile`. You can also write the contents of a variable to a file, as shown in the following pseudocode:

```
Declare String name = "Charles Pace"
Write customerFile name
```

The second statement in this pseudocode writes the contents of the `name` variable to the file associated with `customerFile`. (These examples show a string being written to a file, but you can also write numeric values.)

## Closing an Output File

Once a program is finished working with a file, it should close the file. Closing a file disconnects the program from the file. In some systems, failure to close an output file can cause a loss of data. This happens because the data that is written to a file is first written to a *buffer*, which is a small “holding section” in memory. When the buffer is full, the computer’s operating system writes the buffer’s contents to the file. This technique increases the system’s performance, because writing data to memory is faster than writing it to a disk. The process of closing an output file forces any unsaved data that remains in the buffer to be written to the file.

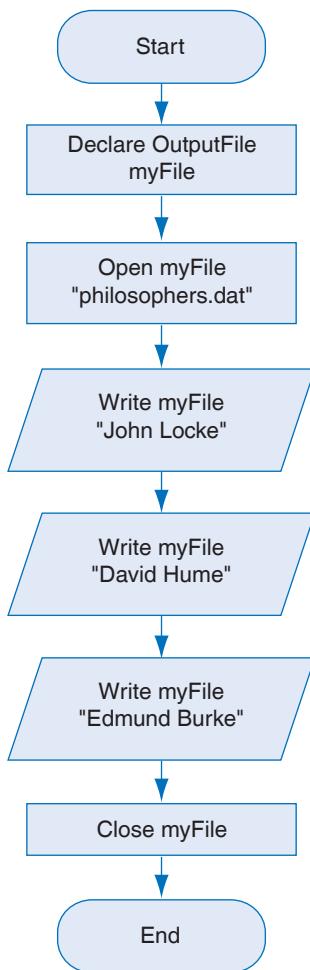
In our pseudocode, we will use the `Close` statement to close a file. For example,

```
Close customerFile
```

closes the file that is associated with the name `customerFile`.

Program 10-1 shows the pseudocode for a sample program that opens an output file, writes data to it, and then closes it. Figure 10-4 shows a flowchart for the program. Because the `Write` statements are output operations, they are shown in parallelograms.

**Figure 10-4** Flowchart for Program 10-1



### Program 10-1



```
1 // Declare an internal name for an output file.
2 Declare outputFile myFile
3
4 // Open a file named philosophers.dat on
5 // the disk.
```

```
6 Open myFile "philosophers.dat"
7
8 // Write the names of three philosophers
9 // to the file.
10 Write myFile "John Locke"
11 Write myFile "David Hume"
12 Write myFile "Edmund Burke"
13
14 // Close the file.
15 Close myFile
```

The statement in line 2 declares the name `myFile` as the internal name for an output file. Line 6 opens the file `philosophers.dat` on the disk and creates an association between the file and the internal name `myFile`. This will allow us to use the name `myFile` to work with the file `philosophers.dat`.

The statements in lines 10 through 12 write three items to the file. Line 10 writes the string `"John Locke"`, line 11 writes the string `"David Hume"`, and line 12 writes the string `"Edmund Burke"`. Line 15 closes the file. If this were an actual program and were executed, the three items shown in Figure 10-5 would be written to the `philosophers.dat` file.

**Figure 10-5** Contents of the file `philosophers.dat`



Notice that the items in the file appear in the same order that they were written by the program. "John Locke" is the first item, "David Hume" is the second item, and "Edmund Burke" is the third item. You will see the significance of this when we read data from the file momentarily.

## Delimiters and the EOF Marker

Figure 10-5 shows that three items were written to the `philosophers.dat` file. In most programming languages, the actual contents of the file would be more complex than the figure shows. In many languages, a special character known as a delimiter is written to a file after each item. A *delimiter* is simply a predefined character or set of characters that marks the end of each piece of data. The delimiter's purpose is to separate the different items that are stored in a file. The exact character or set of characters that are used as delimiters varies from system to system.

In addition to delimiters, many systems write a special character or set of characters, known as an *end-of-file (EOF) marker*, at the end of a file. The purpose of the EOF marker is to indicate where the file's contents end. The character that is used as the EOF marker also varies among different systems. Figure 10-6 shows the layout of the `philosophers.dat` file, with delimiters and an EOF marker.

**Figure 10-6** Contents of the file `philosophers.dat` with delimiters and the EOF marker

## Reading Data from a File

To read data from an input file, you first declare an internal name that you will use to reference the file. In pseudocode we will use a `Declare` statement such as this:

```
Declare InputFile inventoryFile
```

This statement declares two things.

- The word `InputFile` indicates the mode in which we will use the file. In our pseudocode, `InputFile` indicates that we will be reading data from the file.
- The name `inventoryFile` is the internal name we will use to work with the output file in our code.

As previously mentioned, the actual syntax for declaring a file mode and internal name varies greatly among programming languages.

The next step is to open the file. In our pseudocode we will use the `Open` statement. For example, in

```
Open inventoryFile "inventory.dat"
```

the word `Open` is followed by an internal name that was previously declared, and then a string that contains a filename. After this statement executes, the file named `inventory.dat` will be opened, and we will be able to use the internal name `inventoryFile` to read data from the file.

Because we are opening the file for input, it makes sense that the file should already exist. In most systems, an error will occur if you try to open an input file but the file does not exist.

## Reading Data

Once you have opened an input file you can read data from it. In our pseudocode we will use the `Read` statement to read a piece of data from a file. The following is an example (assume `itemName` is a variable that has already been declared):

```
Read inventoryFile itemName
```

This statement reads a piece of data from the file that is associated with `inventoryFile`. The piece of data that is read from the file will be stored in the `itemName` variable.

### Closing an Input File

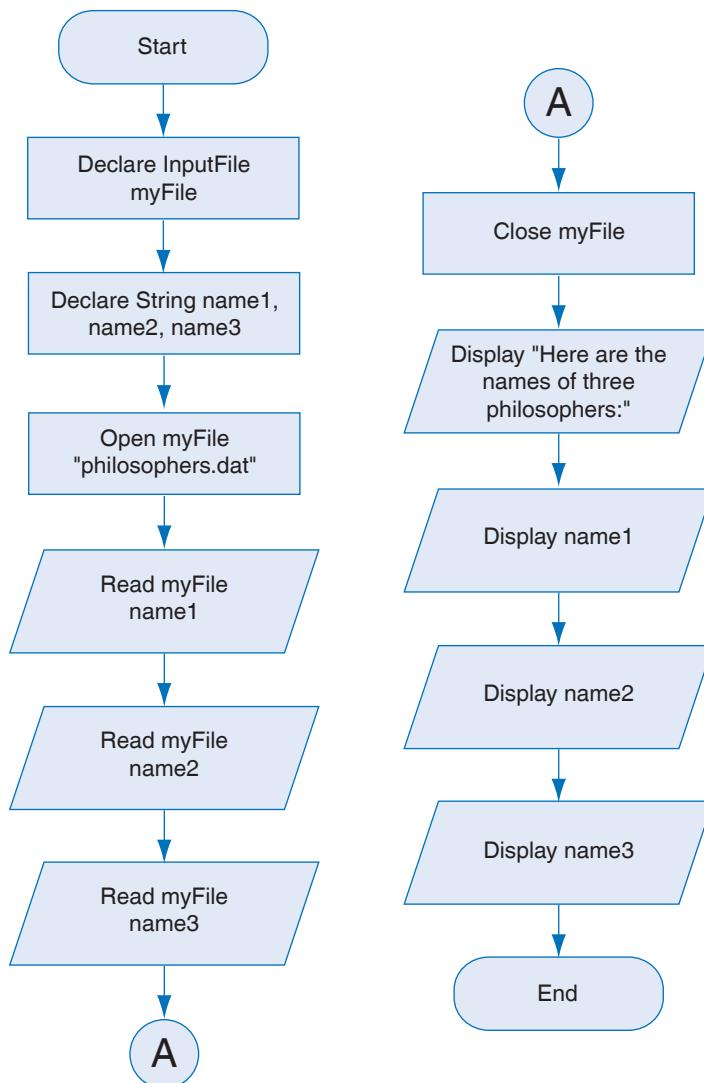
As previously mentioned, a program should close a file when it is finished working with it. In our pseudocode, we will use the `Close` statement to close input files, in the same way that we close output files. For example,

```
Close inventoryFile
```

closes the file that is associated with the name `inventoryFile`.

Program 10-2 shows the pseudocode for a program that opens the `philosophers.dat` file that would be created by Program 10-1, reads the three names from the file, closes the file, and then displays the names that were read. Figure 10-7 shows a flowchart for the program. Notice that the `Read` statements are shown in parallelograms.

**Figure 10-7** Flowchart for Program 10-2



**Program 10-2**

```

1 // Declare an internal name for an input file.
2 Declare InputFile myFile
3
4 // Declare three variables to hold values
5 // that will be read from the file.
6 Declare String name1, name2, name3
7
8 // Open a file named philosophers.dat on
9 // the disk.
10 Open myFile "philosophers.dat"
11
12 // Read the names of three philosophers
13 // from the file into the variables.
14 Read myFile name1
15 Read myFile name2
16 Read myFile name3
17
18 // Close the file.
19 Close myFile
20
21 // Display the names that were read.
22 Display "Here are the names of three philosophers:"
23 Display name1
24 Display name2
25 Display name3

```

**Program Output**

Here are the names of three philosophers:

John Locke  
David Hume  
Edmund Burke

The statement in line 2 declares the name `myFile` as the internal name for an input file. Line 6 declares three `String` variables: `name1`, `name2`, and `name3`. We will use these variables to hold the values read from the file. Line 10 opens the file `philosophers.dat` on the disk and creates an association between the file and the internal name `myFile`. This will allow us to use the name `myFile` to work with the file `philosophers.dat`.

When a program works with an input file, a special value known as a *read position* is internally maintained for that file. A file's read position marks the location of the next item that will be read from the file. When an input file is opened, its read position is initially set to the first item in the file. After the statement in line 10 executes, the read position for the `philosophers.dat` file will be positioned as shown in Figure 10-8.

**Figure 10-8** Initial read position

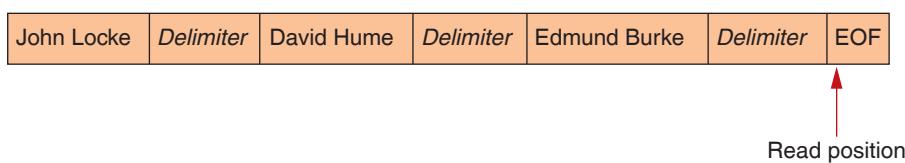
The Read statement in line 14 reads an item from the file's current read position and stores that item in the name1 variable. Once this statement executes, the name1 variable will contain the string "John Locke". In addition, the file's read position will be advanced to the next item in the file, as shown in Figure 10-9.

**Figure 10-9** Read position after the first Read statement

Another Read statement appears in line 15. This reads an item from the file's current read position and stores that value in the name2 variable. Once this statement executes, the name2 variable will contain the string "David Hume". The file's read position will be advanced to the next item, as shown in Figure 10-10.

**Figure 10-10** Read position after the second Read statement

Another Read statement appears in line 16. This reads the next item from the file's current read position and stores that value in the name3 variable. Once this statement executes, the name3 variable will contain the string "Edmund Burke". The file's read position will be advanced to the EOF marker, as shown in Figure 10-11.

**Figure 10-11** Read position after the third Read statement

The statement in line 19 closes the file. The Display statements in lines 23 through 25 display the contents of the name1, name2, and name3 variables.



**NOTE:** Did you notice that Program 10-2 reads the items in the philosophers.dat file in sequence, from the beginning of the file to the end of the file? Recall from our discussion at the beginning of the chapter that this is the nature of a sequential access file.

## Appending Data to an Existing File

In most programming languages, when you open an output file and a file with the specified external name already exists on the disk, the existing file will be erased and a new empty file with the same name will be created. Sometimes you want to preserve an existing file and append new data to its current contents. Appending data to a file means writing new data to the end of the data that already exists in the file.

Most programming languages allow you to open an output file in *append mode*, which means the following:

- If the file already exists, it will not be erased. If the file does not exist, it will be created.
- When data is written to the file, it will be written at the end of the file's current contents.

The syntax for opening an output file in append mode varies greatly from one language to another. In pseudocode we will simply add the word **AppendMode** to the **Declare** statement, as shown here:

```
Declare OutputFile AppendMode myFile
```

This statement declares that we will use the internal name **myFile** to open an output file in append mode. For example, assume the file **friends.dat** exists and contains the following names:

```
Joe
Rose
Greg
Geri
Renee
```

The following pseudocode opens the file and appends additional data to its existing contents.

```
Declare OutputFile AppendMode myFile
Open myFile "friends.dat"
Write myFile "Matt"
Write myFile "Chris"
Write myFile "Suze"
Close myFile
```

After this program runs, the file **friends.dat** will contain the following data:

```
Joe
Rose
Greg
Geri
Renee
```

Matt  
Chris  
Suze



## Checkpoint

- 10.1 Where are files normally stored?
- 10.2 What is an output file?
- 10.3 What is an input file?
- 10.4 What three steps must be taken by a program when it uses a file?
- 10.5 In general, what are the two types of files? What is the difference between these two types of files?
- 10.6 What are the two types of file access? What is the difference between these two?
- 10.7 When writing a program that performs an operation on a file, what two file-associated names do you have to work with in your code?
- 10.8 In most programming languages, if a file already exists what happens to it if you try to open it as an output file?
- 10.9 What is the purpose of opening a file?
- 10.10 What is the purpose of closing a file?
- 10.11 Generally speaking, what is a delimiter? How are delimiters typically used in files?
- 10.12 In many systems, what is written at the end of a file?
- 10.13 What is a file's read position? Initially, where is the read position when an input file is opened?
- 10.14 In what mode do you open a file if you want to write data to it, but you do not want to erase the file's existing contents? When you write data to such a file, to what part of the file is the data written?

## 10.2

## Using Loops to Process Files

**CONCEPT:** Files usually hold large amounts of data, and programs typically use a loop to process the data in a file.



VideoNote  
Using Loops to  
Process Files

Although some programs use files to store only small amounts of data, files are typically used to hold large collections of data. When a program uses a file to write or read a large amount of data, a loop is typically involved. For example, look at the pseudocode in Program 10-3. This program gets sales amounts for a series of days from the user and stores those amounts in a file named `sales.dat`. The user specifies the number of days of sales data that will be entered. In the sample run of the program, the user enters sales amounts for five days. Figure 10-12 shows the contents of the `sales.dat`

file containing the data entered by the user in the sample run. Figure 10-13 shows a flowchart for the program.

**Program 10-3**

```
1 // Variable to hold the number of days
2 Declare Integer numDays
3
4 // Counter variable for the loop
5 Declare Integer counter
6
7 // Variable to hold an amount of sales
8 Declare Real sales
9
10 // Declare an output file.
11 Declare OutputFile salesFile
12
13 // Get the number of days.
14 Display "For how many days do you have sales?"
15 Input numDays
16
17 // Open a file named sales.dat.
18 Open salesFile "sales.dat"
19
20 // Get the amount of sales for each day and write
21 // it to the file.
22 For counter = 1 To numDays
23 // Get the sales for a day.
24 Display "Enter the sales for day #", counter
25 Input sales
26
27 // Write the amount to the file.
28 Write salesFile sales
29 End For
30
31 // Close the file.
32 Close salesFile
33 Display "Data written to sales.dat."
```

**Program Output (with Input Shown in Bold)**

For how many days do you have sales?

5 [Enter]

Enter the sales for day #1

1000.00 [Enter]

Enter the sales for day #2

2000.00 [Enter]

Enter the sales for day #3

3000.00 [Enter]

Enter the sales for day #4

4000.00 [Enter]

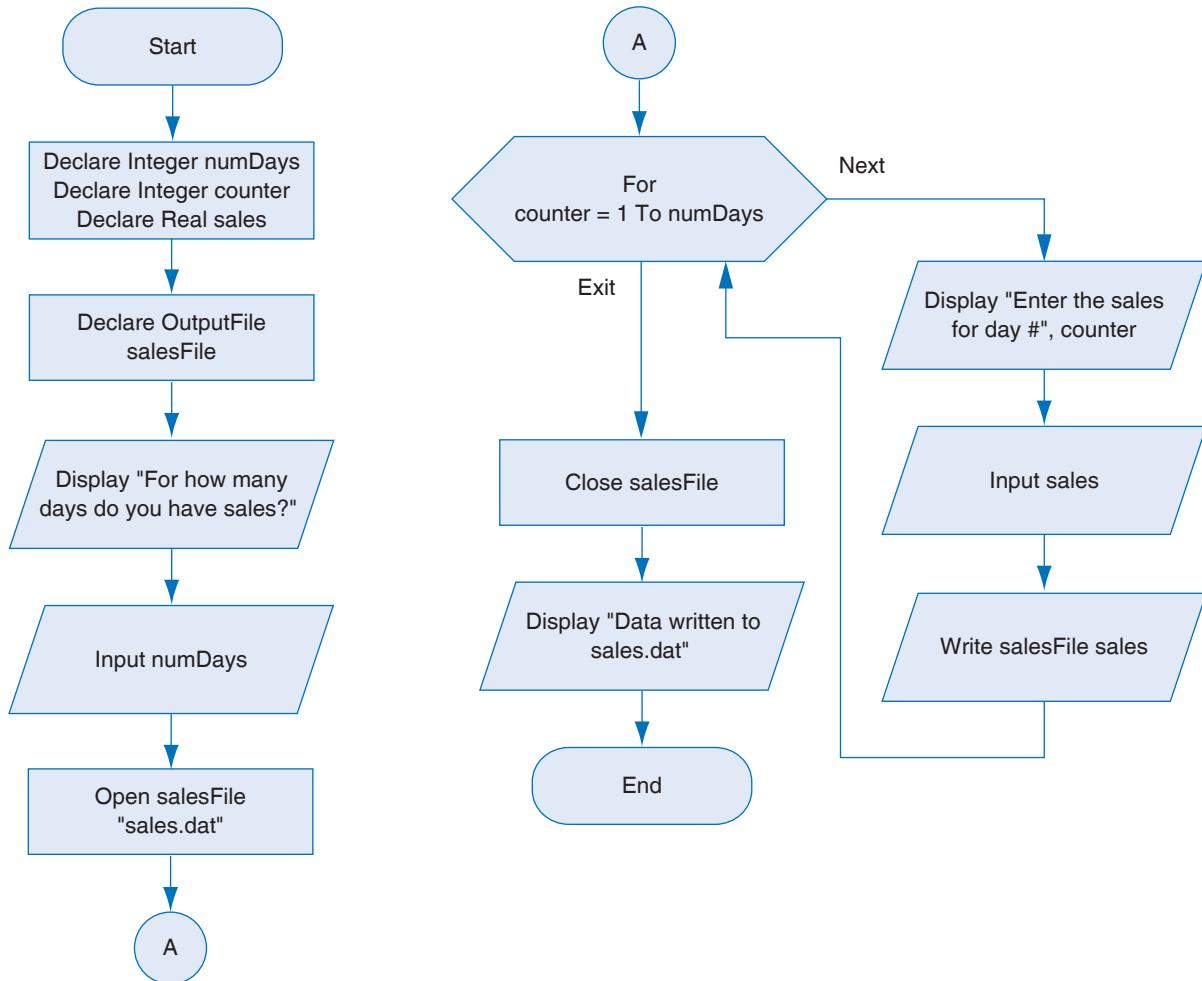
Enter the sales for day #5

5000.00 [Enter]

Data written to sales.dat.

**Figure 10-12** Contents of the sales.dat file

|         |           |         |           |         |           |         |           |         |           |     |
|---------|-----------|---------|-----------|---------|-----------|---------|-----------|---------|-----------|-----|
| 1000.00 | Delimiter | 2000.00 | Delimiter | 3000.00 | Delimiter | 4000.00 | Delimiter | 5000.00 | Delimiter | EOF |
|---------|-----------|---------|-----------|---------|-----------|---------|-----------|---------|-----------|-----|

**Figure 10-13** Flowchart for Program 10-3

## Reading a File with a Loop and Detecting the End of the File

Quite often a program must read the contents of a file without knowing the number of items that are stored in the file. For example, the `sales.dat` file that would be created by Program 10-3 can have any number of items stored in it, because the program asks the user for the number of days that they have sales amounts for. If the user enters 5 as the number of days, the program gets 5 sales amounts and stores them in the file. If the

user enters 100 as the number of days, the program gets 100 sales amounts and stores them in the file.

This presents a problem if you want to write a program that processes all of the items in the file, regardless of how many there are. For example, suppose you need to write a program that reads all of the amounts in the file and calculates their total. You can use a loop to read the items in the file, but an error will occur if the program tries to read beyond the end of the file. The program needs some way of knowing when the end of the file has been reached so it will not try to read beyond it.

Most programming languages provide a library function for this purpose. In our pseudocode we will use the `eof` function. Here is the function's general format:

```
eof(internalFileName)
```

The `eof` function accepts a file's internal name as an argument, and returns `True` if the end of the file has been reached or `False` if the end of the file has not been reached. The pseudocode in Program 10-4 shows an example of how to use the `eof` function. This program displays all of the sales amounts in the `sales.dat` file.

#### Program 10-4



```
1 // Declare an input file.
2 Declare InputFile salesFile
3
4 // Declare a variable to hold a sales amount
5 // that is read from the file.
6 Declare Real sales
7
8 // Open the sales.dat file.
9 Open salesFile "sales.dat"
10
11 Display "Here are the sales amounts:"
12
13 // Read all of the items in the file
14 // and display them.
15 While NOT eof(salesFile)
16 Read salesFile sales
17 Display currencyFormat(sales)
18 End While
19
20 // Close the file.
21 Close salesFile
```

#### Program Output

Here are the sales amounts:

```
$1,000.00
$2,000.00
$3,000.00
$4,000.00
$5,000.00
```

Take a closer look at line 15:

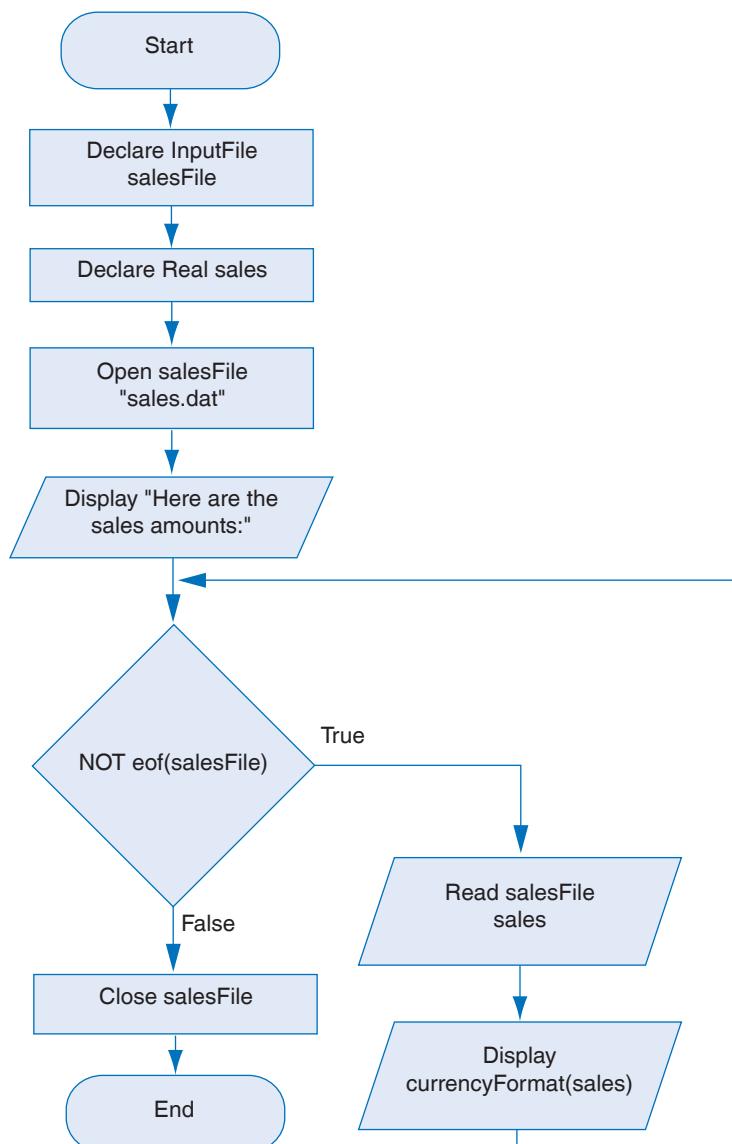
```
While NOT eof(salesFile)
```

When you read this pseudocode, you naturally think: *While not at the end of the file . . .* This statement could have been written as:

```
While eof(salesFile) == False
```

Although this is logically equivalent, most programmers will prefer to use the NOT operator as shown in line 15 because it more clearly states the condition that is being tested. Figure 10-14 shows a flowchart for the program.

**Figure 10-14** Flowchart for Program 10-4



## In the Spotlight: Working with Files



Kevin is a freelance video producer who makes TV commercials for local businesses. When he makes a commercial, he usually films several short videos. Later, he puts these short videos together to make the final commercial. He has asked you to design the following two programs:

1. A program that allows him to enter the running time (in seconds) of each short video in a project. The running times are saved to a file.
2. A program that reads the contents of the file, displays the running times, and then displays the total running time of all the segments.

Here is the general algorithm for the first program:

1. Get the number of videos in the project.
2. Open an output file.
3. For each video in the project:
  - Get the video's running time.
  - Write the running time to the file.
4. Close the file.

Program 10-5 shows the pseudocode for the first program. Figure 10-15 shows a flowchart.

### Program 10-5

```

1 // Declare an output file.
2 Declare outputFile videoFile
3
4 // A variable to hold the number of videos.
5 Declare Integer numVideos
6
7 // A variable to hold a video's running time.
8 Declare Real runningTime
9
10 // Counter variable for the loop
11 Declare Integer counter
12
13 // Get the number of videos.
14 Display "Enter the number of videos in the project."
15 Input numVideos
16
17 // Open an output file to save the running times.
18 Open videoFile "video_times.dat"
19
20 // Write each video's running times to the file.
21 For counter = 1 To numVideos
22 // Get the running time.
23 Display "Enter the running time for video #", counter
24 Input runningTime
25
26 // Write the running time to the file.

```

```

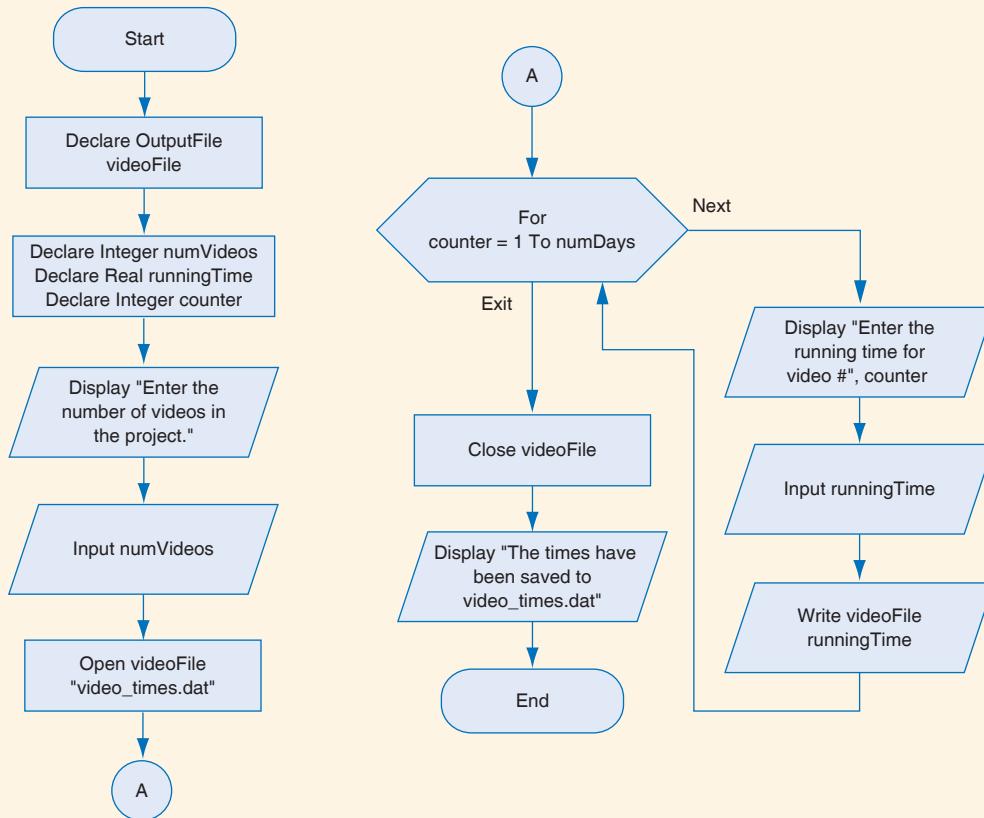
27 Write videoFile runningTime
28 End For
29
30 // Close the file.
31 Close videoFile
32 Display "The times have been saved to video_times.dat."

```

### Program Output (with Input Shown in Bold)

Enter the number of videos in the project.  
**6** [Enter]  
 Enter the running time for video #1  
**24.5** [Enter]  
 Enter the running time for video #2  
**12.2** [Enter]  
 Enter the running time for video #3  
**14.6** [Enter]  
 Enter the running time for video #4  
**20.4** [Enter]  
 Enter the running time for video #5  
**22.5** [Enter]  
 Enter the running time for video #6  
**19.3** [Enter]  
 The times have been saved to video\_times.dat.

**Figure 10-15** Flowchart for Program 10-5



Here is the general algorithm for the second program:

1. Initialize an accumulator to 0.
2. Open the input file.
3. While not at the end of the file:
  - Read a value from the file.
  - Add the value to the accumulator.
4. Close the file.
5. Display the contents of the accumulator as the total running time.

Program 10-6 shows the pseudocode for the second program. Figure 10-16 shows a flowchart.

### Program 10-6

```
1 // Declare an input file.
2 Declare InputFile videoFile
3
4 // A variable to hold a time
5 // that is read from the file.
6 Declare Real runningTime
7
8 // Accumulator to hold the total time,
9 // initialized to 0.
10 Declare Real total = 0
11
12 // Open the video_times.dat file.
13 Open videoFile "video_times.dat"
14
15 Display "Here are the running times, in seconds, of ",
16 "each video in the project:"
17
18 // Read all of the times in the file,
19 // display them, and calculate their total.
20 While NOT eof(videoFile)
21 // Read a time.
22 Read videoFile runningTime
23
24 // Display the time for this video.
25 Display runningTime
26
27 // Add runningTime to total.
28 Set total = total + runningTime
29 End While
30
31 // Close the file.
32 Close videoFile
33
34 // Display the total running time.
35 Display "The total running time of the videos is ",
 total, " seconds."
36
```

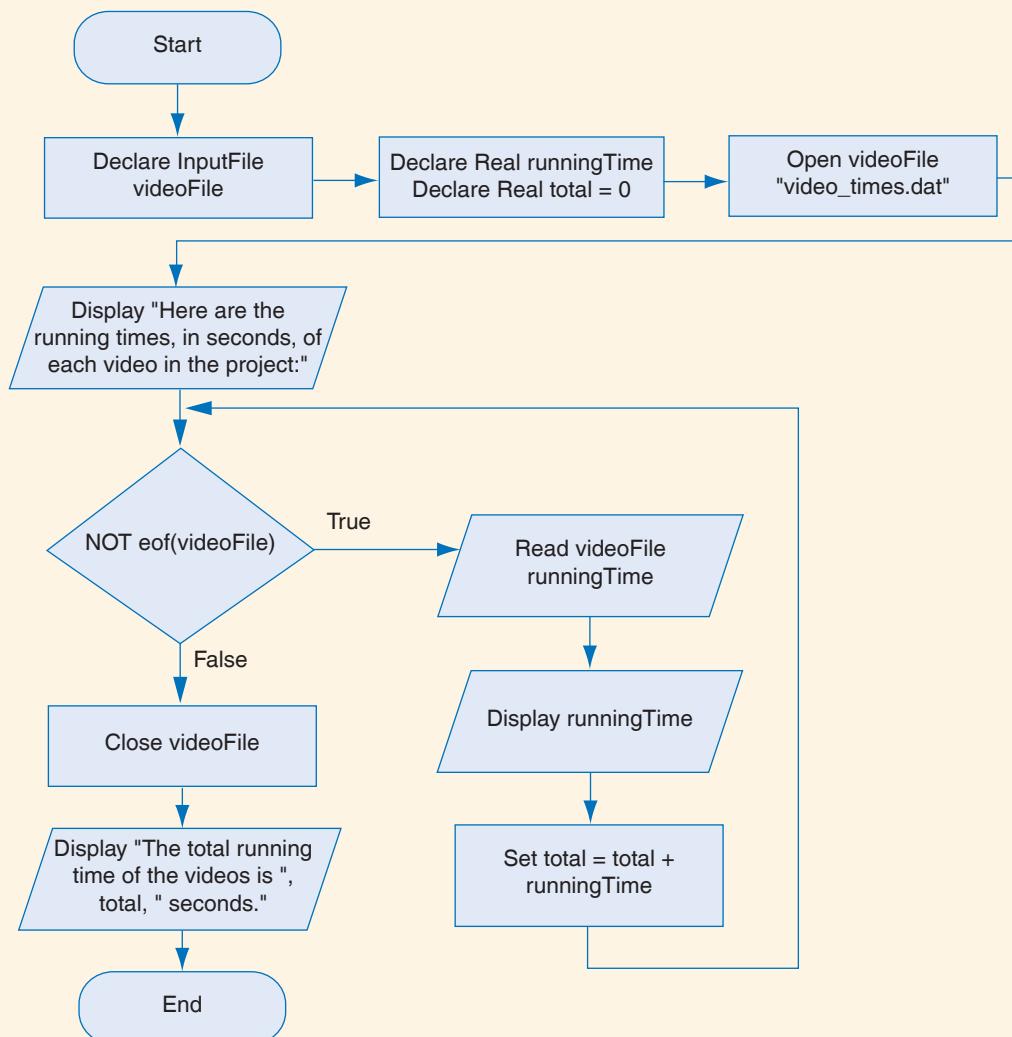
**Program Output**

Here are the running times, in seconds, of each video in the project:

24.5  
12.2  
14.6  
20.4  
22.5  
19.3

The total running time of the videos is 113.5 seconds.

**Figure 10-16** Flowchart for Program 10-6



**Checkpoint**

- 10.15 Design an algorithm that uses a For loop to write the numbers 1 through 10 to a file.
- 10.16 What is the purpose of the eof function?
- 10.17 Is it acceptable for a program to attempt to read beyond the end of a file?
- 10.18 What would it mean if the expression eof(myFile) were to return True?
- 10.19 Which of the following loops would you use to read all of the items from the file associated with myFile?
- While eof(myFile)  
    Read myFile item  
End While
  - While NOT eof(myFile)  
    Read myFile item  
End While

**10.3****Using Files and Arrays**

**CONCEPT:** For some algorithms, files and arrays can be used together effectively. You can easily write a loop that saves the contents of an array to a file, and vice versa.

Some tasks may require you to save the contents of an array to a file so the data can be used at a later time. Likewise, some situations may require you to read the data from a file into an array. For example, suppose you have a file that contains a set of values that appear in random order and you want to sort the values. One technique for sorting the values in the file would be to read them into an array, perform a sorting algorithm on the array, and then write the values in the array back to the file.

Saving the contents of an array to a file is a straightforward procedure: Open the file and use a loop to step through each element of the array, writing its contents to the file. For example, assume a program declares an array as:

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE] = 10, 20, 30, 40, 50
```

The following pseudocode opens a file named `values.dat` and writes the contents of each element of the `numbers` array to the file:

```
// Counter variable to use in the loop.
Declare Integer index
// Declare an output file.
Declare OutputFile numberFile
// Open the values.dat file.
Open numberFile "values.dat"
// Write each array element to the file.
```

```
For index = 0 To SIZE - 1
 Write numberFile numbers[index]
End For
// Close the file.
Close numberFile
```

Reading the contents of a file into an array is also straightforward: Open the file and use a loop to read each item from the file, storing each item in an array element. The loop should iterate until either the array is filled or the end of the file is reached. For example, assume a program declares an array as:

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE]
```

The following pseudocode opens a file named `values.dat` and reads its contents into the `numbers` array:

```
// Counter variable to use in the loop, initialized
// with 0.
Declare Integer index = 0
// Declare an input file.
Declare InputFile numberFile
// Open the values.dat file.
Open numberFile "values.dat"
// Read the contents of the file into the array.
While (index <= SIZE - 1) AND (NOT eof(numberFile))
 Write numberFile numbers[index]
 Set index = index + 1
End While
// Close the file.
Close numberFile
```

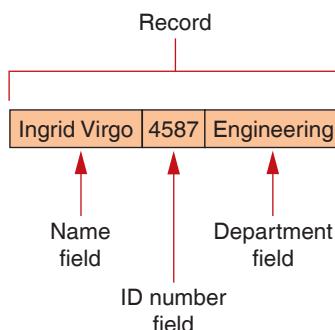
Notice that the `While` loop tests two conditions. The first condition is `index <= SIZE - 1`. The purpose of this condition is to prevent the loop from writing beyond the end of the array. When the array is full, the loop will stop. The second condition is `NOT eof(numberFile)`. The purpose of this condition is to prevent the loop from reading beyond the end of the file. When there are no more values to read from the file, the loop will stop.

## 10.4

## Processing Records

**CONCEPT:** The data that is stored in a file is frequently organized in records. A record is a complete set of data about an item, and a field is an individual piece of data within a record.

When data is written to a file, it is often organized into records and fields. A *record* is a complete set of data that describes one item, and a *field* is a single piece of data within a record. For example, suppose we want to store data about employees in a file. The file will contain a record for each employee. Each record will be a collection of fields, such as name, ID number, and department. This is illustrated in Figure 10-17.

**Figure 10-17** Fields in a record

## Writing Records

In pseudocode, we will write an entire record using a single `Write` statement. For example, assume the variables `name`, `idNumber`, and `department` contain data about an employee, and `employeeFile` is the file we will write the data to. We can write the contents of these variables to the file with the following statement:

```
Write employeeFile name, idNumber, department
```

In the statement we have simply listed the variables, separated by commas, after the file's internal name. The pseudocode in Program 10-7 shows how this statement might be used in a complete program.

### Program 10-7

```

1 // Variables for the fields
2 Declare String name
3 Declare Integer idNumber
4 Declare String department
5
6 // A variable for the number of employee records.
7 Declare Integer numEmployees
8
9 // A counter variable for the loop
10 Declare Integer counter
11
12 // Declare an output file.
13 Declare OutputFile employeeFile
14
15 // Get the number of employees.
16 Display "How many employee records do ",
17 "you want to create?"
18 Input numEmployees
19
20 // Open a file named employees.dat.
21 Open employeeFile "employees.dat"
22
23 // Get each employee's data and write it
24 // to the file.

```

```
25 For counter = 1 To numEmployees
26 // Get the employee name.
27 Display "Enter the name of employee #", counter
28 Input name
29
30 // Get the employee ID number.
31 Display "Enter the employee's ID number."
32 Input idNumber
33
34 // Get the employee's department.
35 Display "Enter the employee's department."
36 Input department
37
38 // Write the record to the file.
39 Write employeeFile name, idNumber, department
40
41 // Display a blank line.
42 Display
43 End For
44
45 // Close the file.
46 Close employeeFile
47 Display "Employee records written to employees.dat."
```

### Program Output (with Input Shown in Bold)

```
How many employee records do you want to create?
3 [Enter]
Enter the name of employee #1
Colleen Pickett [Enter]
Enter the employee's ID number.
7311 [Enter]
Enter the employee's department.
Accounting [Enter]

Enter the name of employee #2
Ryan Pryce [Enter]
Enter the employee's ID number.
8996 [Enter]
Enter the employee's department.
Security [Enter]

Enter the name of employee #3
Bonnie Dundee [Enter]
Enter the employee's ID number.
2301 [Enter]
Enter the employee's department.
Marketing [Enter]

Employee records written to employees.dat.
```

Lines 16 through 18 prompt the user to enter the number of employee records they want to create. Inside the loop, the program gets an employee's name, ID number, and department. This data is written to the file in line 39. The loop iterates once for each employee record.

In the sample run of the program, the user enters data for three employees. The table shown in Figure 10-18 shows how you can think of the resulting records that will be written to the file. The file contains three records, one for each employee, and each record has three fields.

**Figure 10-18** Records written to the employees.dat file

| Name            | ID Number | Department |
|-----------------|-----------|------------|
| Colleen Pickett | 7311      | Accounting |
| Ryan Pryce      | 8996      | Security   |
| Bonnie Dundee   | 2301      | Marketing  |

The way that fields and records are actually organized inside the file, however, varies slightly from language to language. Earlier we mentioned that many systems write a delimiter after each item in a file. Figure 10-19 shows how part of the file's contents might appear with a delimiter after each field.

**Figure 10-19** File contents with a delimiter after each field

Colleen Pickett|Delimiter|7311|Delimiter|Accounting|Delimiter|Ryan Pryce|Delimiter|8996|... and so forth



**NOTE:** When records are created in a file, some systems write one type of delimiter after each field and another type of delimiter after each record.

## Reading Records

In pseudocode we will read an entire record from a file using a single Read statement. The following statement shows how we can read three values from employeeFile into the name, idNumber, and department variables:

```
Read employeeFile name, idNumber, department
```

The pseudocode in Program 10-8 shows a program that reads the records written to the employees.dat file by Program 10-7.

### Program 10-8

```

1 // Variables for the fields
2 Declare String name
3 Declare Integer idNumber
4 Declare String department
5
6 // Declare an input file.
7 Declare InputFile employeeFile
8
9 // Open a file named employees.dat.
10 Open employeeFile "employees.dat"
11

```

```
12 Display "Here are the employee records."
13
14 // Display the records in the file.
15 While NOT eof(employeeFile)
16 // Read a record from the file.
17 Read employeeFile name, idNumber, department
18
19 // Display the record.
20 Display "Name: ", name
21 Display "ID Number: ", idNumber
22 Display "Department: ", department
23
24 // Display a blank line.
25 Display
26 End For
27
28 // Close the file.
29 Close employeeFile
```

### Program Output

Here are the employee records.

Name: Colleen Pickett

ID Number: 7311

Department: Accounting

Name: Ryan Pryce

ID Number: 8996

Department: Security

Name: Bonnie Dundee

ID Number: 2301

Department: Marketing

## The File Specification Document

If you are a programmer for a company or an organization, you will most likely have to write programs that read data from files that already exist. The files will probably be stored on the company's servers, or on some other computer that is part of the company's information system. When this is the case, you will not know how the data is organized inside the files. For that reason, companies and organizations usually have a *file specification document* for each data file. A file specification document describes the fields that are stored in a particular file, including their data types. A programmer who has never previously worked with a particular file can consult that file's specification document to learn how data is organized inside the file.

A company or organization might keep file specification documents stored as word processing documents, PDF documents, or plain text documents. (In some cases, they might be printed on paper.) The contents of a file specification document will look different from one organization to another, but in each case, it will provide the information

that a programmer needs to work with a particular file. Figure 10-20 shows an example of a file specification document for the `employees.dat` file that was used in Programs 10-7 and 10-8.

**Figure 10-20** Example file specification document

|                          |                                              |
|--------------------------|----------------------------------------------|
| <b>Filename:</b>         | employees.dat                                |
| <b>Description:</b>      | Each record contains data about an employee. |
| <b>Field Description</b> | <b>Data Type</b>                             |
| Employee Name            | String                                       |
| ID Number                | Integer                                      |
| Department               | String                                       |

In this example, the file specification document shows the filename, a brief description of the file's contents, and a list of fields in each record. Each field's data type is also listed. In addition, the fields are listed in the order that they appear in each record. In this case, the first field in a record holds the employee name, the second field holds the ID number, and the third field holds the department name.

## Managing Records

Applications that store records in a file typically require more capabilities than simply writing and reading records. In the following *In the Spotlight* sections we will examine algorithms for adding records to a file, searching a file for specific records, modifying a record, and deleting a record.

### In the Spotlight: Adding and Displaying Records

Midnight Coffee Roasters, Inc. is a small company that imports raw coffee beans from around the world and roasts them to create a variety of gourmet coffees. Julie, the owner of the company, has asked you to design a series of programs that she can use to manage her inventory. After speaking with her, you have determined that a file is needed to keep inventory records. Each record should have two fields to hold the following data:

- Description: a string containing the name of the coffee
- Quantity in inventory: the number of pounds in inventory, as a real number



Your first job is to design a program that can be used to add records to the file. Program 10-9 shows the pseudocode, and Figure 10-21 shows a flowchart. Note that the output file is opened in append mode. Each time the program is executed, the new records will be added to the file's existing contents.

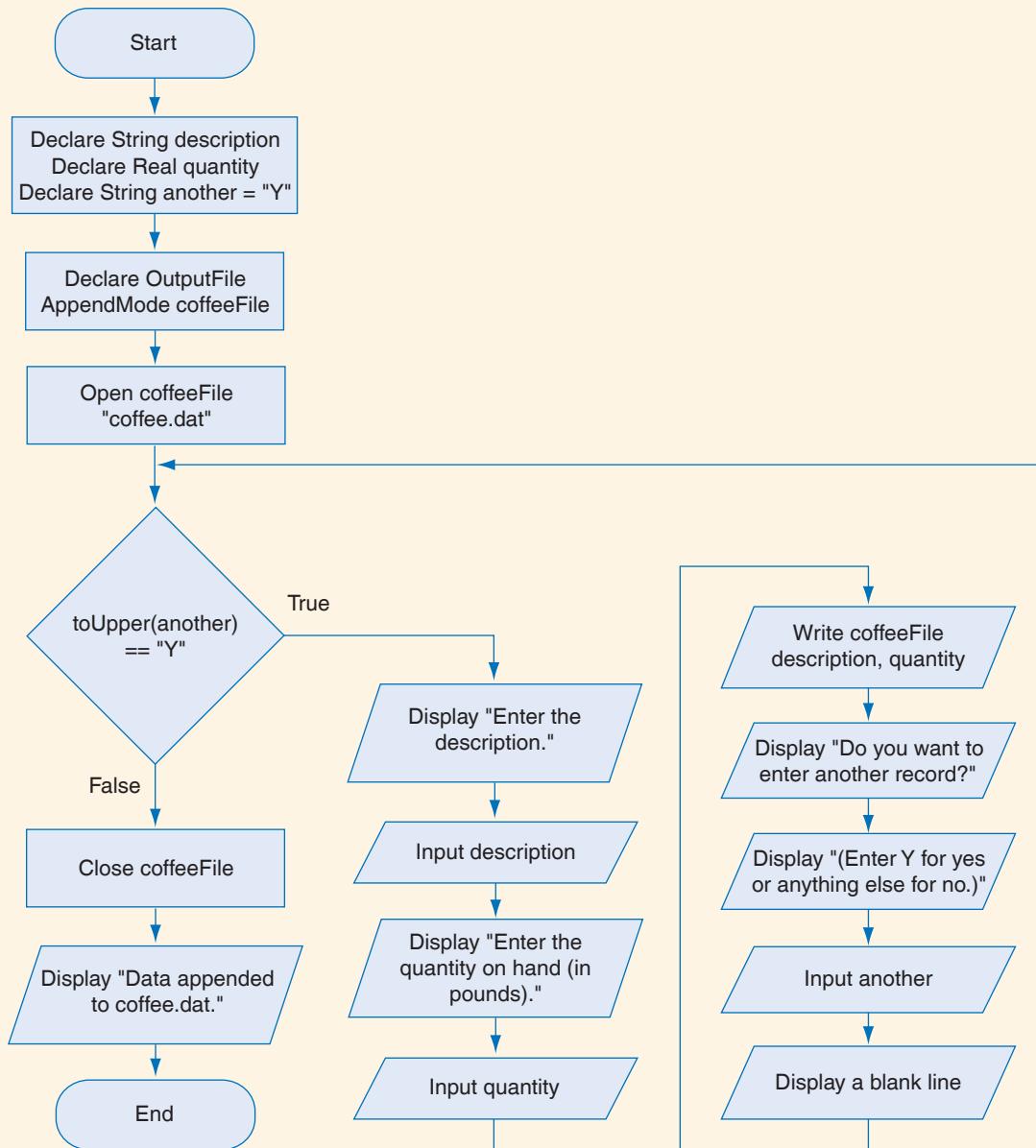
### Program 10-9

```
1 // Variables for the fields
2 Declare String description
3 Declare Real quantity
4
5 // A variable to control the loop.
6 Declare String another = "Y"
7
8 // Declare an output file in append mode.
9 Declare OutputFile AppendMode coffeeFile
10
11 // Open the file.
12 Open coffeeFile "coffee.dat"
13
14 While toUpper(another) == "Y"
15 // Get the description.
16 Display "Enter the description."
17 Input description
18
19 // Get the quantity on hand.
20 Display "Enter the quantity on hand ",
21 "(in pounds)."
22 Input quantity
23
24 // Append the record to the file.
25 Write coffeeFile description, quantity
26
27 // Determine whether the user wants to enter
28 // another record.
29 Display "Do you want to enter another record?"
30 Display "(Enter Y for yes, or anything else for no.)"
31 Input another
32
33 // Display a blank line.
34 Display
35 End While
36
37 // Close the file.
38 Close coffeeFile
39 Display "Data appended to coffee.dat."
```

### Program Output (with Input Shown in Bold)

```
Enter the description.
Brazilian Dark Roast [Enter]
Enter the quantity on hand (in pounds).
18 [Enter]
Do you want to enter another record?
```

```
(Enter Y for yes, or anything else for no.)
y [Enter]
Enter the description.
Sumatra Medium Roast [Enter]
Enter the quantity on hand (in pounds).
25 [Enter]
Do you want to enter another record?
(Enter Y for yes, or anything else for no.)
n [Enter]
Data appended to coffee.dat.
```

**Figure 10-21** Flowchart for Program 10-9

Your next job is to design a program that displays all of the records in the inventory file. Program 10-10 shows the pseudocode, and Figure 10-22 shows a flowchart.

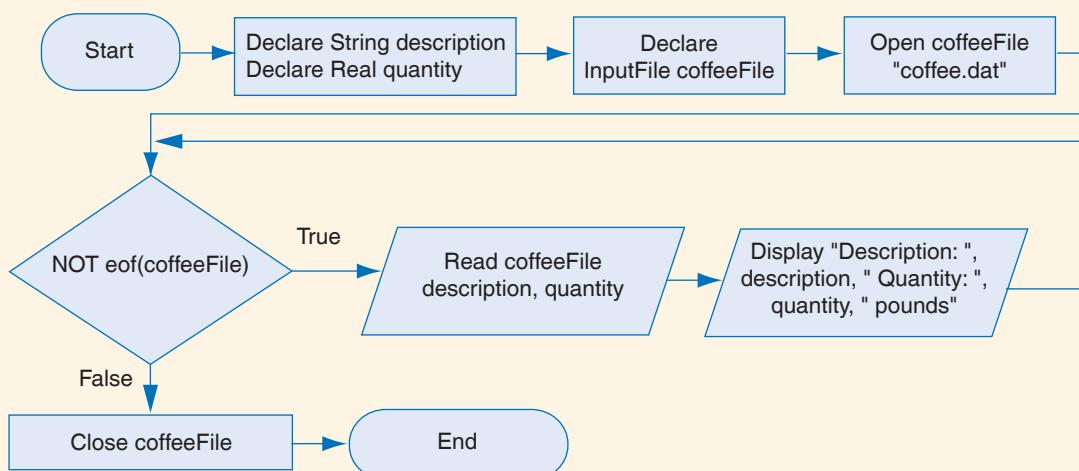
### Program 10-10

```
1 // Variables for the fields
2 Declare String description
3 Declare Real quantity
4
5 // Declare an input file.
6 Declare InputFile coffeeFile
7
8 // Open the file.
9 Open coffeeFile "coffee.dat"
10
11 While NOT eof(coffeeFile)
12 // Read a record from the file.
13 Read coffeeFile description, quantity
14
15 // Display the record.
16 Display "Description: ", description,
17 "Quantity: ", quantity, " pounds"
18 End While
19
20 // Close the file.
21 Close coffeeFile
```

### Program Output

```
Description: Brazilian Dark Roast Quantity: 18 pounds
Description: Sumatra Medium Roast Quantity: 25 pounds
```

**Figure 10-22** Flowchart for Program 10-10



## In the Spotlight: Searching for a Record



Julie has been using the first two programs that you designed for her. She now has several records stored in the `coffee.dat` file, and has asked you to design another program that she can use to search for records. She wants to be able to enter a string and see a list of all the records containing that string in the description field. For example, suppose the file contains the following records:

| Description                  | Quantity |
|------------------------------|----------|
| Sumatra Dark Roast           | 12       |
| Sumatra Medium Roast         | 30       |
| Sumatra Decaf                | 20       |
| Sumatra Organic Medium Roast | 15       |

If she enters “Sumatra” as the value to search for, the program should display all of these records. Program 10-11 shows the pseudocode, and Figure 10-23 shows the flowchart for the program.

Notice that line 27 of the pseudocode uses the `contains` function. Recall from Chapter 6 that the `contains` function returns True if the first argument, a string, contains the second argument, also a string.

### Program 10-11

```

1 // Variables for the fields
2 Declare String description
3 Declare Real quantity
4
5 // A variable to hold the search value.
6 Declare String searchValue
7
8 // A Flag to indicate whether the value was found.
9 Declare Boolean found = False
10
11 // Declare an input file.
12 Declare InputFile coffeeFile
13
14 // Get the value to search for.
15 Display "Enter a value to search for."
16 Input searchValue
17
18 // Open the file.
19 Open coffeeFile "coffee.dat"
20
21 While NOT eof(coffeeFile)
22 // Read a record from the file.
23 Read coffeeFile description, quantity
24
25 // If the record contains the search value,
26 // then display it.
27 If contains(description, searchValue) Then

```

```

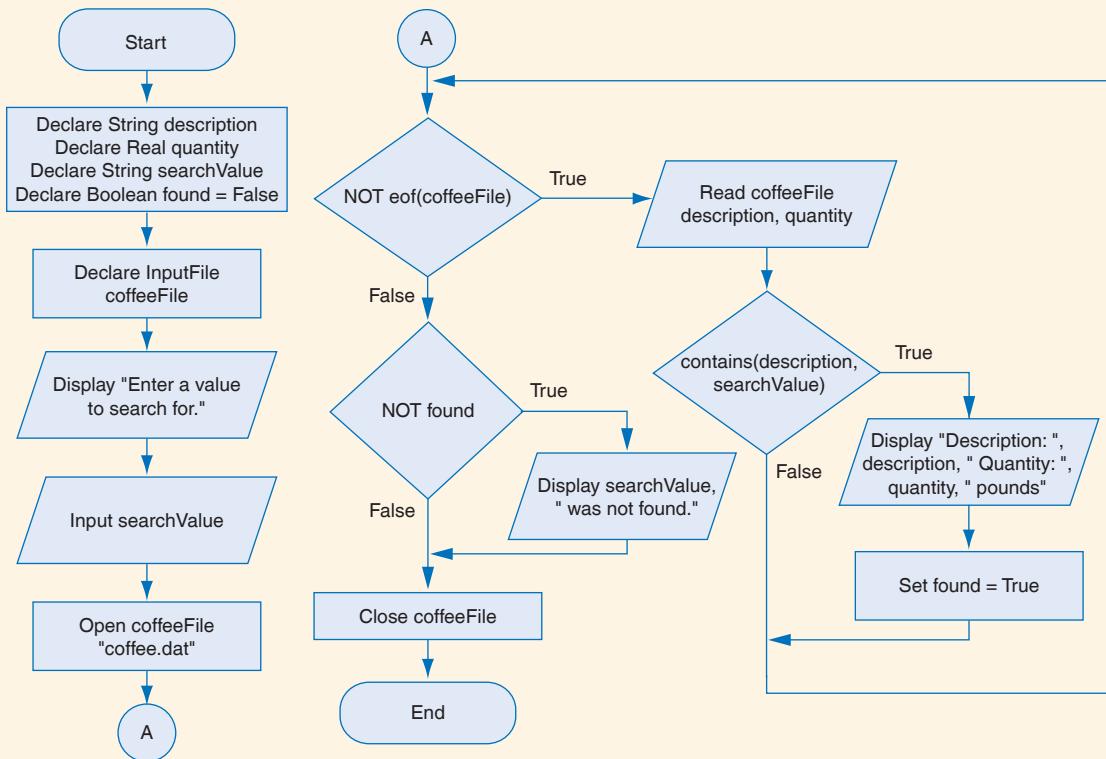
28 // Display the record.
29 Display "Description: ", description,
30 "Quantity: ", quantity, " pounds"
31
32 // Set the found flag to true.
33 Set found = True
34 End If
35 End While
36
37 // If the value was not found in the file,
38 // display a message indicating so.
39 If NOT found Then
40 Display searchValue, " was not found."
41 End If
42
43 // Close the file.
44 Close coffeeFile

```

### Program Output (with Input Shown in Bold)

Enter a value to search for.  
**Sumatra [Enter]**  
 Description: Sumatra Dark Roast Quantity: 12 pounds  
 Description: Sumatra Medium Roast Quantity: 30 pounds  
 Description: Sumatra Decaf Quantity: 20 pounds  
 Description: Sumatra Organic Medium Roast Quantity: 15 pounds

**Figure 10-23** Flowchart for Program 10-11



## In the Spotlight: Modifying Records



Julie is very happy with the programs that you have designed so far. Your next job is to design a program that she can use to modify the quantity field in an existing record. This will allow her to keep the records up to date as coffee is sold or more coffee is added to inventory.

To modify a record in a sequential file, you must create a second temporary file. You copy all of the original file's records to the temporary file, but when you get to the record that is to be modified, you do not write its old contents to the temporary file. Instead, you write its new modified values to the temporary file. Then, you finish copying any remaining records from the original file to the temporary file.

The temporary file then takes the place of the original file. You delete the original file and rename the temporary file, giving it the name that the original file had on the computer's disk. Here is the general algorithm for your program:

1. Open the original file for input and create a temporary file for output.
2. Get the description field of the record to be modified and the new value for the quantity field.
3. While not at the end of the original file:
  - Read a record.  
If this record's description field matches the description entered, then:  
    Write the new data to the temporary file.  
    Else write the existing record to the temporary file.
4. Close the original file and the temporary file.
5. Delete the original file.
6. Rename the temporary file, giving it the name of the original file.

Notice that at the end of the algorithm you delete the original file and then rename the temporary file. Most programming languages provide a way to perform these operations. In pseudocode we will use the **Delete** statement to delete a file on the disk. You simply provide a string containing the name of the file that you wish to delete, such as:

```
Delete "coffee.dat"
```

To change the name of a file, we will use the **Rename** statement. For example,

```
Rename "temp.dat", "coffee.dat"
```

indicates that we are changing the name of the file `temp.dat` to `coffee.dat`.

Program 10-12 shows the pseudocode for the program, and Figures 10-24 and 10-25 show the flowchart.

### Program 10-12

```
1 // Variables for the fields
2 Declare String description
3 Declare Real quantity
4
```

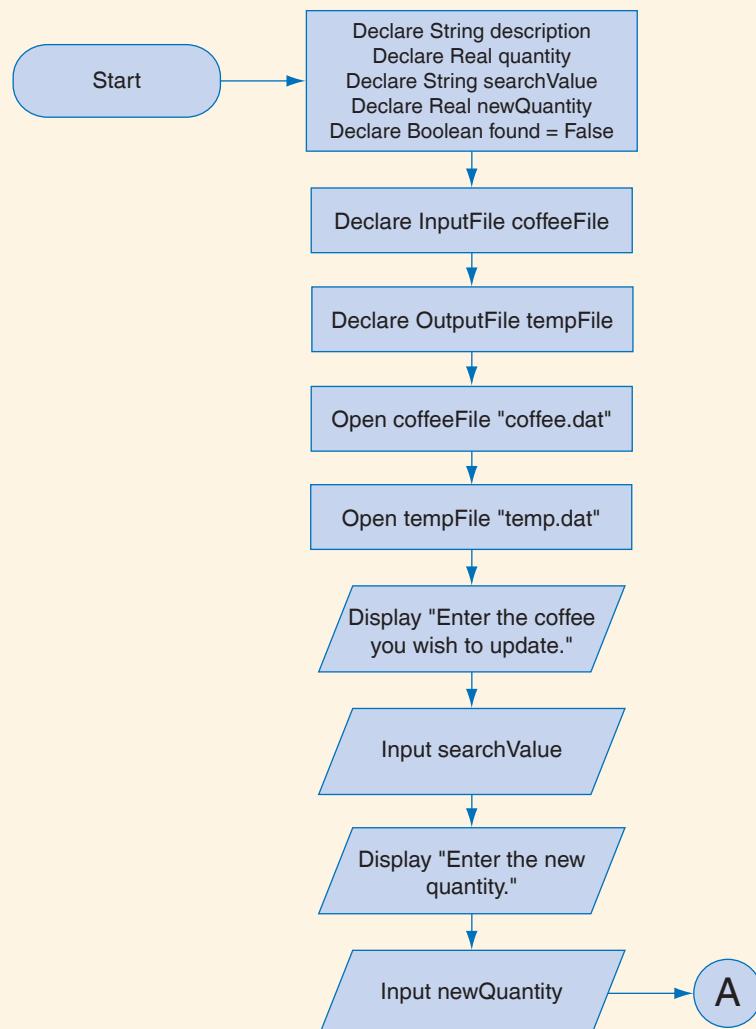
```
5 // A variable to hold the search value.
6 Declare String searchValue
7
8 // A variable to hold the new quantity.
9 Declare Real newQuantity
10
11 // A Flag to indicate whether the value was found.
12 Declare Boolean found = False
13
14 // Declare an input file.
15 Declare InputFile coffeeFile
16
17 // Declare an output file to copy the original
18 // file to.
19 Declare OutputFile tempFile
20
21 // Open the original file.
22 Open coffeeFile "coffee.dat"
23
24 // Open the temporary file.
25 Open tempFile "temp.dat"
26
27 // Get the value to search for.
28 Display "Enter the coffee you wish to update."
29 Input searchValue
30
31 // Get the new quantity.
32 Display "Enter the new quantity."
33 Input newQuantity
34
35 While NOT eof(coffeeFile)
36 // Read a record from the file.
37 Read coffeeFile description, quantity
38
39 // Write either this record to the temporary
40 // file, or the new record if this is the
41 // one that is to be changed.
42 If description == searchValue Then
43 Write tempFile description, newQuantity
44 Set found = True
45 Else
46 Write tempFile description, quantity
47 End If
48 End While
49
50 // Close the original file.
51 Close coffeeFile
52
53 // Close the temporary file.
54 Close tempFile
55
56 // Delete the original file.
57 Delete "coffee.dat"
58
59 // Rename the temporary file.
```

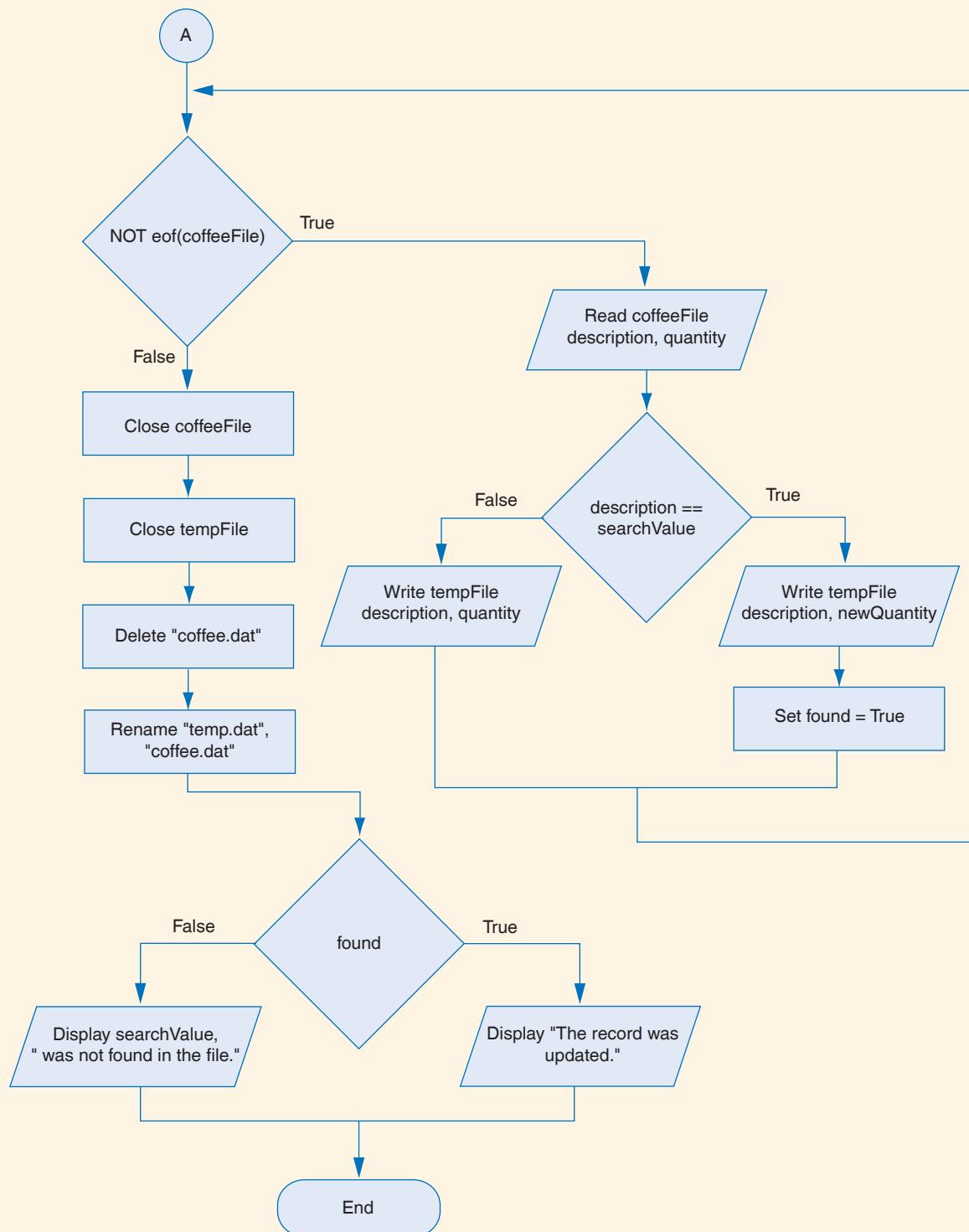
```
60 Rename "temp.dat", "coffee.dat"
61
62 // Indicate whether the operation was successful.
63 If found Then
64 Display "The record was updated."
65 Else
66 Display searchValue, " was not found in the file."
67 End If
```

### Program Output (with Input Shown in Bold)

Enter the coffee you wish to update.  
**Sumatra Medium Roast [Enter]**  
Enter the new quantity.  
**18 [Enter]**  
The record was updated.

**Figure 10-24** Flowchart for Program 10-12, part 1



**Figure 10-25** Flowchart for Program 10-12, part 2



**TIP:** If you are using a language that does not have built-in statements for deleting and renaming files, you can perform the following steps after closing the original file and the temporary files:

1. Open the original file for output. (This will erase the contents of the original file.)
2. Open the temporary file for input.
3. Read each record in the temporary file and then write it to the original file. (This copies all of the records from the temporary file to the original file.)
4. Close the original and temporary files.

A disadvantage to using this approach is that the additional steps of copying the temporary file to the original file will slow the program down. Another disadvantage is that the temporary file will remain on the disk. If the temporary file contains a large amount of data, you might need to open it for output once again and then immediately close it. This erases the file's contents.

## In the Spotlight: Deleting Records



Your last task is to write a program that Julie can use to delete records from the `coffee.dat` file. Like the process of modifying a record, the process of deleting a record from a sequential access file requires that you create a second temporary file. You copy all of the original file's records to the temporary file, except for the record that is to be deleted. The temporary file then takes the place of the original file. You delete the original file and rename the temporary file, giving it the name that the original file had on the computer's disk. Here is the general algorithm for your program:

1. Open the original file for input and create a temporary file for output.
2. Get the description field of the record to be deleted.
3. While not at the end of the original file:
  - Read a record.
  - If this record's description field does not match the description entered, then:
    - Write the record to the temporary file.
4. Close the original file and the temporary file.
5. Delete the original file.
6. Rename the temporary file, giving it the name of the original file.

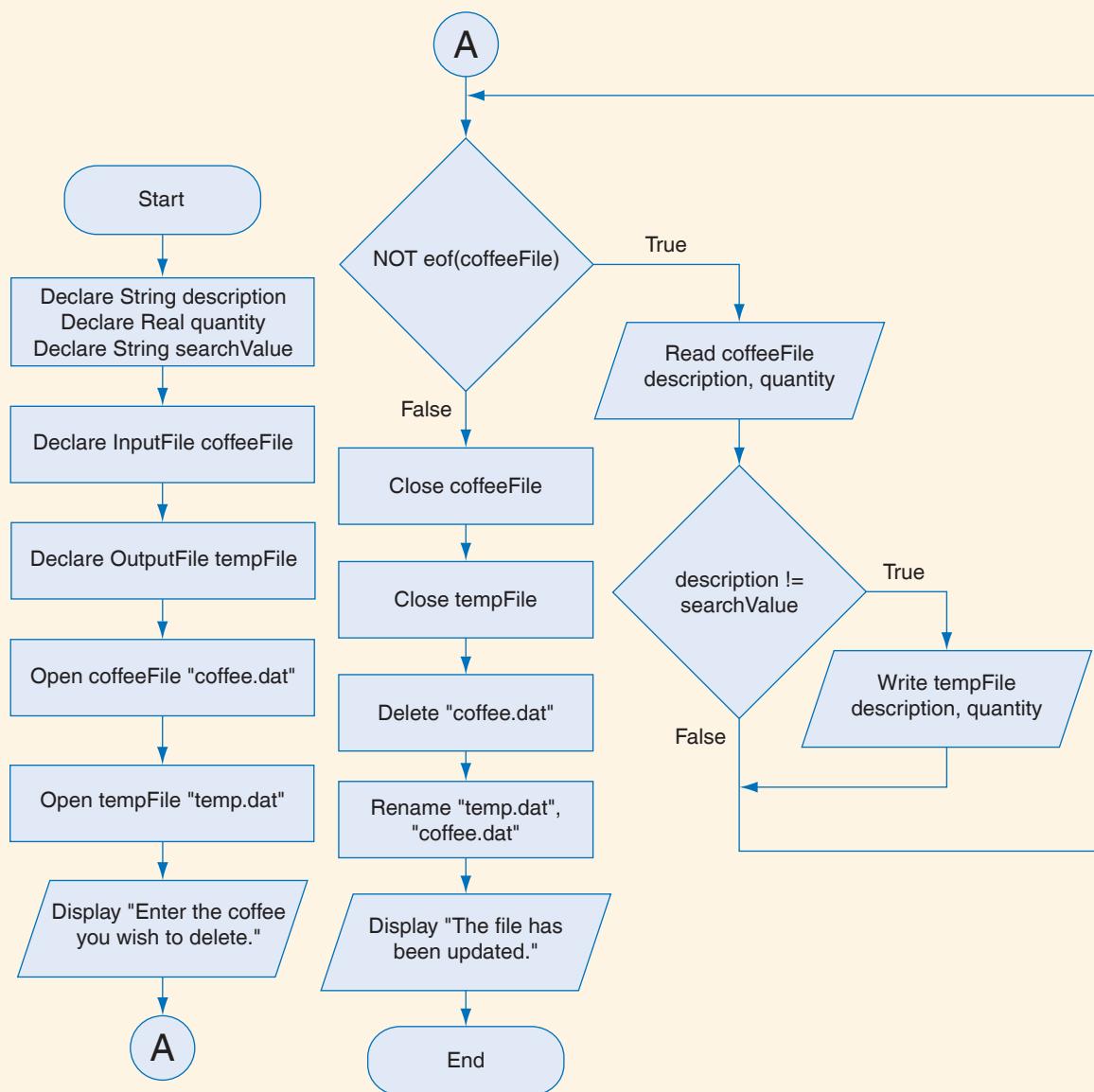
Program 10-13 shows the pseudocode for the program, and Figure 10-26 shows a flowchart.

**Program 10-13**

```
1 // Variables for the fields
2 Declare String description
3 Declare Real quantity
4
5 // A variable to hold the search value.
6 Declare String searchValue
7
8 // Declare an input file.
9 Declare InputFile coffeeFile
10
11 // Declare an output file to copy the original
12 // file to.
13 Declare OutputFile tempFile
14
15 // Open the files.
16 Open coffeeFile "coffee.dat"
17 Open tempFile "temp.dat"
18
19 // Get the value to search for.
20 Display "Enter the coffee you wish to delete."
21 Input searchValue
22
23 While NOT eof(coffeeFile)
24 // Read a record from the file.
25 Read coffeeFile description, quantity
26
27 // If this is not the record to delete, then
28 // write it to the temporary file.
29 If description != searchValue Then
30 Write tempFile description, quantity
31 End If
32 End While
33
34 // Close the two files.
35 Close coffeeFile
36 Close tempFile
37
38 // Delete the original file.
39 Delete "coffee.dat"
40
41 // Rename the temporary file.
42 Rename "temp.dat", "coffee.dat"
43
44 Display "The file has been updated."
```

**Program Output (with Input Shown in Bold)**

Enter the coffee you wish to delete.  
**Sumatra Organic Medium Roast [Enter]**  
The file has been updated.

**Figure 10-26** Flowchart for Program 10-13

### Checkpoint

10.20 What is a record? What is a field?

10.21 Describe the way that you use a temporary file in a program that modifies a record in a sequential access file.

10.22 Describe the way that you use a temporary file in a program that deletes a record from a sequential file.

**10.5**

## Control Break Logic

**CONCEPT:** Control break logic interrupts (breaks) a program's regular processing to perform a different action when a control variable's value changes or the variable acquires a specific value. After the action is complete, the program's regular processing resumes.

Suppose a business has nine retail locations: three in North Carolina, three in Georgia, and three in Florida. The business' accounting system has a file named `sales.dat` that contains the sales for each store, listed by state. Each record in the file has the following fields:

- Store Number: an Integer
- State: a String
- Sales: a Real

Here is an example of the data stored in the file:

| Store Number | State | Sales    |
|--------------|-------|----------|
| 101          | NC    | 10000.00 |
| 102          | NC    | 11000.00 |
| 103          | NC    | 12000.00 |
| 201          | GA    | 7000.00  |
| 202          | GA    | 8000.00  |
| 203          | GA    | 9000.00  |
| 301          | FL    | 12000.00 |
| 302          | FL    | 13000.00 |
| 303          | FL    | 14000.00 |

We want to write a program that prints a sales report showing the total sales for each state. The report should look like this:

### Sales Report by State

| Store Number        | State | Sales       |
|---------------------|-------|-------------|
| <hr/>               |       |             |
| 101                 | NC    | \$10,000.00 |
| 102                 | NC    | \$11,000.00 |
| 103                 | NC    | \$12,000.00 |
| Total Sales for NC: |       | \$33,000.00 |
| 201                 | GA    | \$7,000.00  |
| 202                 | GA    | \$8,000.00  |
| 203                 | GA    | \$9,000.00  |
| Total Sales for GA: |       | \$24,000.00 |

|                            |    |                    |
|----------------------------|----|--------------------|
| 301                        | FL | \$12,000.00        |
| 302                        | FL | \$13,000.00        |
| 303                        | FL | \$14,000.00        |
| <b>Total Sales for FL:</b> |    | <b>\$39,000.00</b> |

To accomplish this, we will use a technique known as *control-break processing*. In a nutshell, control-break processing means that the program performs some ongoing task (such as reading items from a file), but temporarily interrupts the task when a *control variable* changes its value. When this happens, some other action is performed and then the program resumes its ongoing task.

In our example, the program will read the records from the `sales.dat` file, keeping a total of the sales amounts. When the program notices that the state has changed, it will print the total, and then reset the total to 0. The program will then continue this process until there are no more records left to read.

Control break logic is used often in programs that print reports where data is organized into categories. The following *In the Spotlight* section shows an example of this, and also introduces a new pseudocode statement: `Print`. We will use the `Print` statement exactly like we use the `Display` statement, except the `Print` statement sends its output to the printer. (The actual process of sending data to a printer varies greatly among systems.)

## In the Spotlight: Using Control Break Logic

Dr. Shephard, the headmaster at Pinebrook Academy, has organized a fundraiser where each student has an opportunity to collect donations. She has asked you to design a program that prints a donation report. The report should show the amounts that each student has collected, the total collected by each student, and the total of all donations.

Dr. Shephard has provided a file, `donations.dat`, that has all of the data that you will need to generate the report. Figure 10-27 shows the file specification document for the file.

**Figure 10-27** File specification document for `donations.dat`

|                                                                                                       |                            |
|-------------------------------------------------------------------------------------------------------|----------------------------|
| <b>Filename:</b>                                                                                      | <code>donations.dat</code> |
| <b>Description:</b> Contains the amounts of donations collected by each student, sorted by student ID |                            |
| <b>Field Description</b>                                                                              | <b>Data Type</b>           |
| Student ID Number                                                                                     | Integer                    |
| Donation Amount                                                                                       | Real                       |

The file contains a record for each donation. Each record has two fields: one containing the ID number of the student who collected the donation (an `Integer`), and another containing the amount of the donation (a `Real`). The records in the file are already sorted in order of student ID numbers.

Here is an example of how the report should appear:

| Pinebrook Academy Fundraiser Report     |                 |
|-----------------------------------------|-----------------|
| Student ID                              | Donation Amount |
| 104                                     | \$250.00        |
| 104                                     | \$100.00        |
| 104                                     | \$500.00        |
| Total donations for student: \$850.00   |                 |
| 105                                     | \$100.00        |
| 105                                     | \$800.00        |
| 105                                     | \$400.00        |
| Total donations for student: \$1,300.00 |                 |
| 106                                     | \$350.00        |
| 106                                     | \$450.00        |
| 106                                     | \$200.00        |
| Total donations for student: \$1,000.00 |                 |
| Total of all donations: \$3,150.00      |                 |

Program 10-14 shows the pseudocode for the program. Let's first look at the `main` module and the `printHeader` module:

**Program 10-14****Fundraiser report program:  
main and printHeader modules**

```
1 Module main()
2 // Print the report header.
3 Call printHeader()
4
5 // Print the details of the report.
6 Call printDetails()
7 End Module
8
9 // The printHeader module prints the report header.
10 Module printHeader()
11 Print "Pinebrook Academy Fundraiser Report"
12 Print
13 Print "Student ID Donation Amount"
14 Print "===="
15 End Module
16
```

In the `main` module, line 3 calls the `printHeader` module, which prints the report header. Then, line 6 calls the `printDetails` module, which prints the body of the report. The pseudocode for the `printDetails` module follows.

**Program 10-14****Fundraiser report program (continued):  
printDetails module**

```
17 // The printDetails module prints the report details.
18 Module printDetails()
19 // Variables for the fields
20 Declare Integer studentID
21 Declare Real donation
22
23 // Accumulator variables
24 Declare Real studentTotal = 0
25 Declare Real total = 0
26
27 // A variable to use in the control
28 // break logic.
29 Declare Integer currentID
30
31 // Declare an input file and open it.
32 Declare InputFile donationsFile
33 Open donationsFile "donations.dat"
34
35 // Read the first record.
36 Read donationsFile studentID, donation
37
38 // Save the student ID number.
39 Set currentID = studentID
40
41 // Print the report details.
42 While NOT eof(donationsFile)
43 // Check the student ID field to see if
44 // it has changed.
45 If studentID != currentID Then
46 // Print the total for the student,
47 // followed by a blank line.
48 Print "Total donations for student: ",
49 currencyFormat(studentTotal)
50 Print
51
52 // Save the next student's ID number.
53 Set currentID = studentID
54
55 // Reset the student accumulator.
56 Set studentTotal = 0
57 End If
58
59 // Print the data for the donation.
60 Print studentID, Tab, currencyFormat(donation)
61
62 // Update the accumulators.
63 Set studentTotal = studentTotal + donation
64 Set total = total + donation
65
66 // Read the next record.
67 Read donationsFile studentID, donation
68 End While
```

```
69
70 // Print the total for the last student.
71 Print "Total donations for student: ",
72 currencyFormat(studentTotal)
73
74 // Print the total of all donations.
75 Print "Total of all donations: ",
76 currencyFormat(total)
77
78 // Close the file.
79 Close donationsFile
80 End Module
```

Let's take a closer look at the `printDetails` module. Here is a summary of the variable declarations:

- Lines 20 and 21 declare the `studentID` and `donation` variables, which will hold the field values for each record read from the file.
- Lines 24 and 25 declare the `studentTotal` and `total` variables. The `studentTotal` is an accumulator that the program will use to calculate the total donations that each student collects. The `total` variable is an accumulator that will calculate the total of all donations.
- Line 29 declares the `currentID` variable. This will store the ID number of the student whose donation total is currently being calculated.
- Line 32 declares `donationsFile` as an internal name associates with the `donations.dat` file.

Line 33 opens the `donations.dat` file, and line 36 reads the first record. The values that are read are stored in the `studentID` and `donation` variables.

Line 39 assigns the student ID that was read from the file to the `currentID` variable. The `currentID` variable will hold the ID of the student whose records are currently being processed.

Line 42 is the beginning of the loop that processes the file. The `If` statement that appears in lines 45 through 57 contains the control break logic. It tests the control variable, `studentID`, to determine whether it is *not* equal to `currentID`. If the two are not equal, then the program has read a record with a student ID that is different from the value stored in `currentID`. This means it has read the last record for the student whose ID is stored in `currentID`, so the program momentarily breaks out of the process to display the student's total donations (lines 48 and 49), save the new student ID in `currentID` (line 53), and reset the `studentTotal` accumulator (line 56).

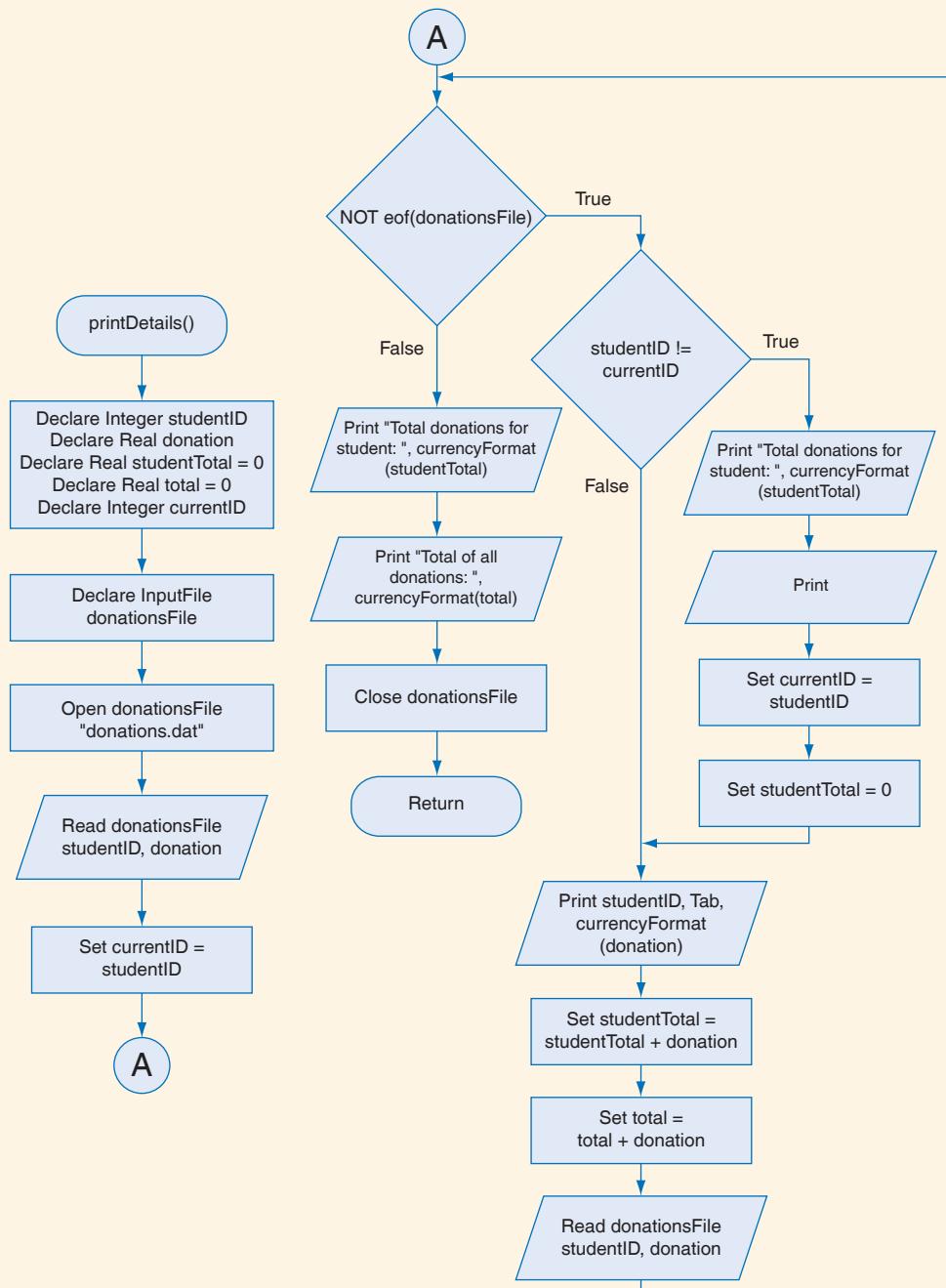
Line 60 prints the contents of the current record. Lines 63 and 64 update the accumulator variables. Line 67 reads the next record from the file. Once all the records have been processed, lines 71 and 72 display the total donations for the last student, lines 75 and 76 display the total of all donations, and line 79 closes the file. The report that is printed by the program will appear similar to the sample report previously shown.



**NOTE:** The logic of this program assumes that the records in the `donations.dat` file are already sorted by student ID. If the records are not sorted by student ID, the sales report will not list all of the donations for each student together.

Figure 10-28 shows a flowchart for the `printDetails` module.

**Figure 10-28** Flowchart for the `printDetails` module



# Print Spacing Charts

When writing programs that print reports on paper, it is sometimes helpful to use a *print spacing chart* to design the appearance of the printed report. A print spacing chart is a sheet of paper that has a grid, similar to graph paper. Figure 10-29 shows an example. Each box in the grid represents a space on the paper, and it can hold one character. Numbers that are printed along the top and side of the chart allow you to identify any space on the page. You simply fill in the report headers and other text in the desired locations. Then, when writing code, you can use the chart to determine where the report items should be located, how many blank spaces to print between items, etc.

**Figure 10-29** A print spacing chart

Figure 10-29 is an example of a print spacing chart for the donations program that you saw in Program 10-14. Notice that the report header and other unchanging text is written in the chart exactly as it is to appear in the report. Where the student ID numbers and donation amounts are to be printed, we have written 9s to indicate the positions of numeric digits.



**NOTE:** You can also write Xs instead of 9s to represent variable data in the report; however, it is a common practice to use 9s to represent digits, and Xs to represent characters.

**10.6**

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

#### Files

##### Opening a File and Writing Data to It in Java

To work with files in a Java program you first write the following statement at the top of your program:

```
import java.io.*;
```

Then, in the method where you wish to open a file and write data to it you will create a `PrintWriter` object. Here is an example of a statement that creates a `PrintWriter` object:

```
PrintWriter outputFile = new PrintWriter("StudentData.txt");
```

This statement does the following:

- It creates a `PrintWriter` object in memory. The `PrintWriter` object's name is `outputFile`. You will use this `PrintWriter` object in your program to manage the file.
- It opens a file on the disk named `StudentData.txt`.

(Note that if the `StudentData.txt` file does not exist, this statement will create the file. If the file already exists, its contents will be erased. Either way, after this statement executes an empty file named `StudentData.txt` will exist on the disk.)

Once you have created `PrintWriter` object and opened a file, you can write data to the file using the `println` method. You already know how to use `println` with `System.out` to display data on the screen. It is used the same way with a `PrintWriter` object to write data to a file. For example, assuming that `outputFile` is a `PrintWriter` object, the following statement writes the string "Jim" to the file:

```
outputFile.println("Jim");
```

Assuming that `payRate` is a variable, the following statement writes the value of the `payRate` variable to the file:

```
outputFile.println(payRate);
```

##### Closing a File in Java

Assuming that `outputFile` is the name of a `PrintWriter` object, here is an example of how to call the `close` method to close the file:

```
outputFile.close();
```

Once a file is closed, the connection between it and the `PrintWriter` object is removed. In order to perform further operations on the file, it must be opened again.

Program 10-15 demonstrates how to create a `PrintWriter` object (and open a file for output), write some data to the file, and close the file. This is the Java version of pseudocode Program 10-1 shown earlier in this chapter.

### Program 10-15 (FileWriteDemo.java)

```
1 import java.io.*;
2
3 public class FileWriteDemo
4 {
5 public static void main(String[] args) throws IOException
6 {
7 // Declare a PrintWriter variable named myFile and open a
8 // file named philosophers.dat.
9 PrintWriter myFile = new PrintWriter("philosophers.dat");
10
11 // Write the names of three philosophers to the file.
12 myFile.println("John Locke");
13 myFile.println("David Hume");
14 myFile.println("Edmund Burke");
15
16 // Close the file.
17 myFile.close();
18 }
19 }
```

Notice in line 5, the header for the `main` method ends with the clause `throws IOException`. This is required because of Java's advanced error handling mechanism. You do not need to be concerned about the details of the clause, but you do need to remember that it is required for any method that uses the file techniques shown in this section.

When this program executes, line 9 creates a file named `philosophers.dat` on the disk, and lines 12 through 14 write the strings "John Locke," "David Hume," and "Edmund Burke" to the file. Line 17 closes the file.

### Opening a File and Reading Data From It in Java

In addition to reading keyboard input, you can also use a `Scanner` object to read data from a file. First, you need this statement at the top of your program:

```
import java.util.Scanner;
```

Then, inside the method that needs to read data from a file you create a `Scanner` object and connect it to that file. Here is an example:

```
Scanner inputFile = new Scanner(new File("StudentData.txt"));
```

This statement creates a `Scanner` object in memory. The name of the `Scanner` object is `inputFile`. The file `StudentData.txt` is opened for reading, and the `Scanner` object is connected to it. After this statement executes, you will be able to use the `Scanner` object to read data from the file.

Once you've connected a `Scanner` object to a file, you can use the `nextLine` method to read a string from the file, the `nextInt` method to read an integer, or the `nextDouble` method to read a `double`.

Program 10-16 shows an example that reads strings from a file. This program opens the `philosophers.dat` file that was created by Program 10-1. This is the Java version of pseudocode Program 10-2. Here are some specific points about the program:

- Line 14 creates a `Scanner` object named `myFile`, opens a file on the disk named `philosophers.dat`, and connects the `Scanner` object to the file.
- Line 18 reads a line of text from the file and assigns it to the `name1` variable.
- Line 19 reads the next line of text from the file and assigns it to the `name2` variable.
- Line 20 reads the next line of text from the file and assigns it to the `name3` variable.
- Line 29 closes the file.

### Program 10-16

```
1 import java.io.*;
2 import java.util.Scanner;
3
4 public class FileReadDemo
5 {
6 public static void main(String[] args) throws IOException
7 {
8 // Declare three variables that will hold the values
9 // read from the file.
10 String name1, name2, name3;
11
12 // Declare a Scanner variable named myFile and open a
13 // file named philosophers.dat.
14 Scanner myFile = new Scanner(new File("philosophers.dat"));
15
16 // Read the names of three philosophers from the file
17 // into the variables.
18 name1 = myFile.nextLine();
19 name2 = myFile.nextLine();
20 name3 = myFile.nextLine();
21
22 // Display the names that were read.
23 System.out.println("Here are the names of three philosophers:");
24 System.out.println(name1);
25 System.out.println(name2);
26 System.out.println(name3);
27
28 // Close the file.
29 myFile.close();
30 }
31 }
```

### Program Output

Here are the names of three philosophers:  
John Locke  
David Hume  
Edmund Burke

### Appending Data to an Existing File in Java

Sometimes you want to open an existing file for writing and preserve its contents so new data can be appended to the existing contents. When this is the case, you create a `PrintWriter` object with a statement like this:

```
PrintWriter outputFile =
 new PrintWriter(new FileWriter("MyFriends.txt", true));
```

This statement opens an existing file named `MyFriends.txt`. The contents of the file are not erased, and when we use the `println` method to write data to the file, the data will be appended to the end of the file.

### Detecting the End of a File in Java

Sometimes you need to read a file's contents, and you do not know the number of items that are stored in the file. When this is the case, you can use the `Scanner` method `hasNext` to determine whether the file contains another item before you attempt to read an item from it. If there is more data that can be read from the file, the `hasNext` method returns `true`. If the end of the file has been reached and there is no more data to read, the `hasNext` method returns `false`.

For example, the following code snippet opens a file named `sales.txt`. It then reads each line of the file and displays it.

```
Scanner salesFile = new Scanner(new File("sales.dat"));

while (salesFile.hasNext())
{
 sales = salesFile.nextDouble();
 System.out.println(sales);
}

salesFile.close();
```

## Python

### Files

#### Opening a File in Python

You use the `open` function in Python to open a file. The `open` function creates a file object and associates it with a file on the disk. Here is the general format of how the `open` function is used:

```
file_variable = open(filename, mode)
```

In the general format:

- `file_variable` is the name of the variable that will reference the file object.
- `filename` is a string specifying the name of the file.
- `mode` is a string specifying the mode (reading, writing, etc.) in which the file will be opened. Table 10-1 shows three of the strings that you can use to specify a mode. (There are other, more complex modes. The modes shown in Table 10-1 are the ones we will use in this book.)

**Table 10-1** Some of the Python file modes

| Mode | Description                                                                                                                    |
|------|--------------------------------------------------------------------------------------------------------------------------------|
| 'r'  | Open a file for reading only. The file cannot be changed or written to.                                                        |
| 'w'  | Open a file for writing. If the file already exists, erase its contents. If it does not exist, create it.                      |
| 'a'  | Open a file to be written to. All data written to the file will be appended to its end. If the file does not exist, create it. |

For example, suppose the file `customers.txt` contains customer data, and we want to open for reading. Here is an example of how we would call the `open` function:

```
customer_file = open('customers.txt', 'r')
```

After this statement executes, the file named `customers.txt` will be opened, and the variable `customer_file` will reference a file object that we can use to read data from the file.

Suppose we want to create a file named `sales.txt` and write data to it. Here is an example of how we would call the `open` function:

```
sales_file = open('sales.txt', 'w')
```

After this statement executes, the file named `sales.txt` will be created, and the variable `sales_file` will reference a file object that we can use to write data to the file. (Remember, when you use the 'w' mode you are creating the file on the disk. If a file with the specified name already exists when the file is opened, the contents of the existing file will be erased.)

### Writing Data to a File in Python

Once you have opened a file for writing, you use the file object's `write` method to write data to a file. Here is the general format of how you call the `write` method:

```
file_variable.write(string)
```

In the format, `file_variable` is a variable that references a file object, and `string` is a string that will be written to the file. The file must be opened for writing (using the 'w' or 'a' mode) or an error will occur.

Let's assume that `customer_file` references a file object, and the file was opened for writing with the 'w' mode. Here is an example of how we would write the string 'Charles Pace' to the file:

```
customer_file.write('Charles Pace')
```

The following code shows another example:

```
name = 'Charles Pace'
customer_file.write(name)
```

The second statement writes the value referenced by the `name` variable to the file associated with `customer_file`. In this case, it would write the string 'Charles Pace' to the file. (These examples show a string being written to a file, but you can also write numeric values.)

### Closing a File in Python

In Python, you use the file object's `close` method to close a file. For example, the following statement closes the file that is associated with `customer_file`:

```
customer_file.close()
```

Once a file is closed, the connection between it and the file object is removed. To perform further operations on the file, it must be opened again.

Program 10-17 shows a complete Python program that opens an output file, writes data to it, and then closes it. This is the Python version of pseudocode Program 10-1.

#### Program 10-17 (`file_write_demo.py`)

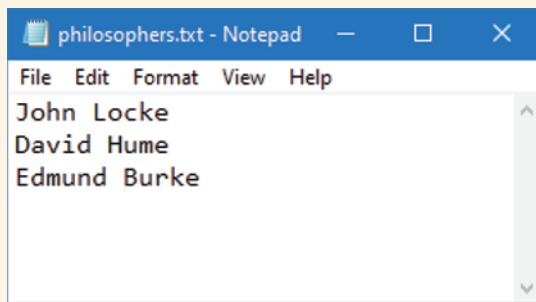
```
1 # This program writes three lines of data
2 # to a file.
3 def main():
4 # Open a file named philosophers.txt.
5 outfile = open('philosophers.txt', 'w')
6
7 # Write the names of three philosophers to the file.
8 outfile.write('John Locke\n')
9 outfile.write('David Hume\n')
10 outfile.write('Edmund Burke\n')
11
12 # Close the file.
13 outfile.close()
14
15 # Call the main function.
16 main()
```

When this program executes, line 5 creates a file named `philosophers.dat` on the disk, and lines 8 through 10 write the strings ‘John Locke\n’, ‘David Hume\n’, and ‘Edmund Burke\n’ to the file. Line 13 closes the file.

### Writing Newlines at the End of Each Line in a File in Python

Notice the use of the `\n` that appears inside the strings that are written to the file in lines 8, 9, and 10. The `\n` sequence is known as an escape character. An *escape character* is a special character that is preceded with a backslash (\), appearing inside a string literal. When a string literal that contains escape characters is printed on the screen or written to a file, the escape characters are treated as special commands that are embedded in the string.

The `\n` sequence is the *newline escape character*. It is used to mark the location where a new line begins in the file. We can see how this works if we open the file in a text editor. For example, Figure 10-30 shows the `philosophers.txt` file as it appears in Notepad.

**Figure 10-30** Contents of philosophers.txt in Notepad (courtesy of Microsoft Corporation)

### Opening a File and Reading Data in Python

If a file has been opened for reading (using the ‘r’ mode) you can use the file object’s `readline` method to read a line from the file. The method returns the line as a string, including the `\n` that is stored at the end of the line. Program 10-18 shows how we can use the `readline` method to read the contents of the `philosophers.txt` file, one line at a time. (This is the Python version of pseudocode Program 10-2.)

#### Program 10-18 (`file_read_demo.py`)

```
1 # This program reads the contents of the
2 # philosophers.txt file one line at a time.
3 def main():
4 # Open a file named philosophers.txt.
5 infile = open('philosophers.txt', 'r')
6
7 # Read three lines from the file
8 line1 = infile.readline()
9 line2 = infile.readline()
10 line3 = infile.readline()
11
12 # Close the file.
13 infile.close()
14
15 # Print the names that were read.
16 print('Here are the names of three philosophers:')
17 print(line1)
18 print(line2)
19 print(line3)
20
21 # Call the main function.
22 main()
```

#### Program Output

Here are the names of three philosophers:  
John Locke

David Hume

Edmund Burke

The statement in line 5 opens the `philosophers.txt` file for reading, using the ‘r’ mode. It also creates a file object and assigns the object to the `infile` variable. When a file is opened for reading, a special value known as a *read position* is internally maintained for that file. A file’s read position marks the location of the next item that will be read from the file. Initially, the read position is set to the beginning of the file.

The statement in line 8 calls the `infile.readline` method to read the first line from the file. The line, which is returned as a string, is assigned to the `line1` variable. After this statement executes the `line1` variable will be assigned the string `'John Locke\n'`. In addition, the file’s read position will be advanced to the next line in the file.

Then the statement in line 9 reads a line of text from the file, beginning at the current read position. The line of text is assigned to the `line2` variable. After this statement executes the `line2` variable will be assigned the string `'David Hume\n'`. The file’s read position will also be advanced to the next line in the file.

Then the statement in line 10 reads a line of text from the file, beginning at the current read position. The line of text is assigned to the `line3` variable. After this statement executes, the `line3` variable will be assigned the string `'Edmund Burke\n'`. The file’s read position will be advanced to the end of the file.

The statement in line 13 closes the file. The statements in lines 17 through 19 display the contents of the `line1`, `line2`, and `line3` variables.



**NOTE:** If the last line in a file is not terminated with a `\n`, the `readline` method will return the line without a `\n`.

### Reading a String and Stripping the Newline From It in Python

Sometimes complications are caused by the `\n` that appears at the end of the strings that are returned from the `readline` method. For example, did you notice in the sample output of Program 10-18 that a blank line is printed after each line of output? This is because each of the strings that are printed in lines 17 through 19 end with a `\n` escape sequence. When the strings are printed, the `\n` causes an extra blank line to appear.

The `\n` serves a necessary purpose inside a file: it separates the items that are stored in the file. However, in most cases, you want to remove the `\n` from a string after it is read from a file. Each string in Python has a method named `rstrip` that removes, or “strips,” specific characters from the end of a string. The following code shows an example of how the `rstrip` method can be used.

```
name = 'Joanne Manchester\n'
name = name.rstrip('\n')
```

The first statement assigns the string `'Joanne Manchester\n'` to the `name` variable. (Notice that the string ends with the `\n` escape sequence.) The second statement calls the `name.rstrip('\n')` method. The method returns a copy of the `name` string without the trailing `\n`. This string is assigned back to the `name` variable. The result is that the trailing `\n` is stripped away from the `name` string.

Program 10-19 is another program that reads and displays the contents of the `philosophers.txt` file. This program uses the `rstrip` method to strip the `\n` from the strings that are read from the file before they are displayed on the screen. As a result, the extra blank lines do not appear in the output.

**Program 10-19 (*strip\_newline.py*)**

```

1 # This program reads the contents of the
2 # philosophers.txt file one line at a time.
3 def main():
4 # Open a file named philosophers.txt.
5 infile = open('philosophers.txt', 'r')
6
7 # Read three lines from the file
8 line1 = infile.readline()
9 line2 = infile.readline()
10 line3 = infile.readline()
11
12 # Strip the \n from each string.
13 line1 = line1.rstrip('\n')
14 line2 = line2.rstrip('\n')
15 line3 = line3.rstrip('\n')
16
17 # Close the file.
18 infile.close()
19
20 # Print the names that were read.
21 print('Here are the names of three philosophers:')
22 print(line1)
23 print(line2)
24 print(line3)
25
26 # Call the main function.
27 main()

```

**Program Output**

Here are the names of three philosophers:  
 John Locke  
 David Hume  
 Edmund Burke

**Concatenating a Newline to a String in Python**

Program 10-17 wrote three string literals to a file, and each string literal ended with a `\n` escape sequence. In most cases, the data items that are written to a file are not string literals, but values in memory that are referenced by variables. This would be the case in a program that prompts the user to enter data, and then writes that data to a file.

When a program writes data that has been entered by the user to a file, it is usually necessary to concatenate a `\n` escape sequence to the data before writing it. This ensures that each piece of data is written to a separate line in the file. Program 10-20 demonstrates how this is done.

**Program 10-20 (write\_names.py)**

```
1 # This program gets three names from the user
2 # and writes them to a file.
3
4 def main():
5 # Get three names.
6 print('Enter the names of three friends.')
7 name1 = input('Friend #1: ')
8 name2 = input('Friend #2: ')
9 name3 = input('Friend #3: ')
10
11 # Open a file named friends.txt.
12 myfile = open('friends.txt', 'w')
13
14 # Write the names to the file.
15 myfile.write(name1 + '\n')
16 myfile.write(name2 + '\n')
17 myfile.write(name3 + '\n')
18
19 # Close the file.
20 myfile.close()
21 print('The names were written to friends.txt.')
22
23 # Call the main function.
24 main()
```

**Program Output (with Input Shown in Bold)**

```
Enter the names of three friends.
Friend #1: Joe [Enter]
Friend #2: Rose [Enter]
Friend #3: Geri [Enter]
The names were written to friends.txt.
```

Lines 7 through 9 prompt the user to enter three names, and those names are assigned to the variables name1, name2, and name3. Line 12 opens a file named friends.txt for writing. Then, lines 15 through 17 write the names entered by the user, each with '\n' concatenated to it. As a result, each name will have the \n escape sequence added to it when written to the file.

**Writing Numeric Data to a Text File in Python**

Strings can be written directly to a file with the `write` method, but numbers must be converted to strings before they can be written. Python has a built-in function named `str` that converts a value to a string. For example, assuming the variable `num` is assigned the value 99, the expression `str(num)` will return the string '99'.

Program 10-21 shows an example of how you can use the `str` function to convert a number to a string, and write the resulting string to a file.

**Program 10-21 (*write\_numbers.py*)**

```

1 # This program demonstrates how numbers
2 # must be converted to strings before they
3 # are written to a text file.
4
5 def main():
6 # Open a file for writing.
7 outfile = open('numbers.txt', 'w')
8
9 # Get three numbers from the user.
10 num1 = int(input('Enter a number: '))
11 num2 = int(input('Enter another number: '))
12 num3 = int(input('Enter another number: '))
13
14 # Write the numbers to the file.
15 outfile.write(str(num1) + '\n')
16 outfile.write(str(num2) + '\n')
17 outfile.write(str(num3) + '\n')
18
19 # Close the file.
20 outfile.close()
21 print('Data written to numbers.txt')
22
23 # Call the main function.
24 main()

```

**Program Output (with Input Shown in Bold)**

```

Enter a number: 22 [Enter]
Enter another number: 14 [Enter]
Enter another number: -99 [Enter]
Data written to numbers.txt

```

The statement in line 7 opens the file `numbers.txt` for writing. Then the statements in lines 10 through 12 prompt the user to enter three numbers, which are assigned to the variables `num1`, `num2`, and `num3`.

Take a closer look at the statement in line 15, which writes the value referenced by `num1` to the file:

```
outfile.write(str(num1) + '\n')
```

The expression `str(num1) + '\n'` converts the value referenced by `num1` to a string and concatenates the `\n` escape sequence to the string. In the program's sample run, the user entered 22 as the first number, so this expression produces the string '`22\n`'. As a result, the string '`22\n`' is written to the file. Lines 16 and 17 perform the similar operations, writing the values referenced by `num2` and `num3` to the file.

### Reading Numeric Data From a Text File in Python

When you read numbers from a text file, they are always read as strings. For example, suppose a program uses the following code to read the first line from the numbers.txt file that was created by Program 10-5:

```
1 infile = open('numbers.txt', 'r')
2 value = infile.readline()
3 infile.close()
```

The statement in line 2 uses the `readline` method to read a line from the file. After this statement executes, the `value` variable will reference the string '22\n'. This can cause a problem if we intend to perform math with the `value` variable, because you cannot perform math on strings. In such a case, you must convert the string to a numeric type.

Python provides the built-in function `int` to convert a string to an integer, and the built-in function `float` to convert a string to a floating-point number. For example, we could modify the code previously shown as follows:

```
1 infile = open('numbers.txt', 'r')
2 string_input = infile.readline()
3 value = int(string_input)
4 infile.close()
```

The statement in line 2 reads a line from the file and assigns it to the `string_input` variable. As a result, `string_input` will reference the string '22\n'. Then the statement in line 3 uses the `int` function to convert `string_input` to an integer, and assigns the result to `value`. After this statement executes, the `value` variable will reference the integer 22. (Both the `int` and `float` functions ignore the \n that appears at the end of the string that is passed as an argument.)

This code demonstrates the steps involved in reading a string from a file with the `readline` method, and then converting that string to an integer with the `int` function. In many situations, however, the code can be simplified. A better way is to read the string from the file and convert it in one statement, as shown here:

```
1 infile = open('numbers.txt', 'r')
2 value = int(infile.readline())
3 infile.close()
```

Notice in line 2 that a call to the `readline` method is used as the argument to the `int` function. Here's how the code works: the `readline` method is called, and it returns a string. That string is passed to the `int` function, which converts it to an integer. The result is assigned to the `value` variable.

### Detecting the End of a File in Python

In Python, the `readline` method returns an empty string (' ') when it has attempted to read beyond the end of a file. This makes it possible to write a `while` loop that determines when the end of a file has been reached. Program 10-22 demonstrates how this can be done in code. The program reads and displays all of the values in the sales.txt file. (This is the Python version of pseudocode Program 10-3.)

**Program 10-22 (*read\_sales.py*)**

```
1 # This program reads all of the values in
2 # the sales.txt file.
3
4 def main():
5 # Open the sales.txt file for reading.
6 sales_file = open('sales.txt', 'r')
7
8 # Read the first line from the file, but
9 # don't convert to a number yet. We still
10 # need to test for an empty string.
11 line = sales_file.readline()
12
13 print('Here are the sales amounts:')
14
15 # As long as an empty string is not returned
16 # from readline, continue processing.
17 while line != '':
18 # Convert line to a float.
19 amount = float(line)
20
21 # Format and display the amount.
22 print('$', format(amount, '.2f'))
23
24 # Read the next line.
25 line = sales_file.readline()
26
27 # Close the file.
28 sales_file.close()
29
30 # Call the main function.
31 main()
```

**Program Output (with Input Shown in Bold)**

Here are the sales amounts:

```
$ 1000.00
$ 2000.00
$ 3000.00
$ 4000.00
$ 5000.00
```

**Using Python's for Loop to Read Lines**

In the previous example, you saw how the `readline` method returns an empty string when the end of the file has been reached. The Python language also allows you to write a `for` loop that automatically reads line in a file without testing for any special condition that signals the end of the file. The loop does not require a priming read operation, and it automatically stops when the end of the file has been reached. When you simply

want to read the lines in a file, one after the other, this technique is simpler and more elegant than writing a `while` loop that explicitly tests for an end of the file condition. Here is the general format of the loop:

```
for variable in file_object:
 statement
 statement
 etc.
```

In the general format, *variable* is the name of a variable and *file\_object* is a variable that references a file object. The loop will iterate once for each line in the file. The first time the loop iterates, *variable* will reference the first line in the file (as a string), the second time the loop iterates, *variable* will reference the second line, and so forth. Program 10-23 provides a demonstration. It reads and displays all the items in the sales.txt file.

### Program 10-23 (*read\_sales2.py*)

```
1 # This program uses the for loop to read
2 # all of the values in the sales.txt file.
3
4 def main():
5 # Open the sales.txt file for reading.
6 sales_file = open('sales.txt', 'r')
7
8 # Read all the lines from the file.
9 for line in sales_file:
10 # Convert line to a float.
11 amount = float(line)
12 # Format and display the amount.
13 print('$', format(amount, '.2f'))
14
15 # Close the file.
16 sales_file.close()
17
18 # Call the main function.
19 main()
```

### Program Output

```
$ 1000.00
$ 2000.00
$ 3000.00
$ 4000.00
$ 5000.00
```

## C++

### Files

#### Opening a File and Writing Data to It in C++

To work with files in a C++ program you first write the following `#include` directive at the top of your program:

```
#include <fstream>
```

Then, in the function where you wish to open a file and write data to it you will declare an `ofstream` object. Here is an example of a statement that declares an `ofstream` object:

```
ofstream outputFile;
```

This statement declares an `ofstream` object named `outputFile`. Next, you use the `ofstream` object to open a file. Here is an example:

```
outputFile.open("StudentData.txt");
```

After this statement has executed, we will be able to use the `ofstream` object that is named `outputFile` to write data to the `StudentData.txt` file. You can think of it this way: In memory, we have an `ofstream` object that we refer to in our code as `outputFile`. That object is connected to a file on the disk named `StudentData.txt`. If we want to write data to the `StudentData.txt` file, we will use the `ofstream` object. (Note that if the `StudentData.txt` file does not exist, this statement will create the file. If the file already exists, its contents will be erased. Either way, after this statement executes an empty file named `StudentData.txt` will exist on the disk.)

Once you have created an `ofstream` object and opened a file, you can write data to the file using the stream insertion operator (`<<`). You already know how to use the `<<` operator with `cout` to display data on the screen. It is used the same way with an `ofstream` object to write data to a file. For example, assuming that `outputFile` is an `ofstream` object, the following statement writes the string "Jim" to the file:

```
outputFile << "Jim" << endl;
```

Assuming that `payRate` is a variable, the following statement writes the value of the `payRate` variable to the file:

```
outputFile << payRate << endl;
```

#### Closing a File in C++

When the program is finished writing data to the file, it must close the file. Assuming that `outputFile` is the name of an `ofstream` object, here is an example of how to call the `close` function to close the file:

```
outputFile.close();
```

Once a file is closed, the connection between it and the `ofstream` object is removed. In order to perform further operations on the file, it must be opened again.

Program 10-1 demonstrates how to create an `ofstream` object (and open a file for output), write some data to the file, and close the file. This is the C++ version of pseudocode Program 10-1.

**Program 10-24 (WriteNames.cpp)**

```
1 #include <iostream>
2 #include <fstream>
3 using namespace std;
4
5 int main()
6 {
7 // Declare an ofstream object named myFile and open a
8 // file named philosophers.txt.
9 ofstream myFile;
10 myFile.open("philosophers.txt");
11
12 // Write the names of three philosophers to the file.
13 myFile << "John Locke" << endl;
14 myFile << "David Hume" << endl;
15 myFile << "Edmund Burke" << endl;
16
17 // Close the file.
18 myFile.close();
19 return 0;
20 }
```

When this program executes, line 9 declares an `ofstream` object named `myFile`, and line 10 uses that object to open a file named `philosophers.txt` on the disk. Lines 13 through 15 write the strings “John Locke,” “David Hume,” and “Edmund Burke” to the file. Line 18 closes the file.

Program 10-25 shows another example. This program opens a file named `numbers.txt`, and uses a loop to write the numbers 1 through 5 to the file.

**Program 10-25 (WriteNumbers.cpp)**

```
1 #include <iostream>
2 #include <fstream>
3 using namespace std;
4
5 int main()
6 {
7 // Constant for the maximum number of numbers.
8 const int MAX_NUMS = 5;
9
10 // Variable
11 int counter;
12
13 // Declare an ofstream object named myFile and open a
14 // file named numbers.txt.
15 ofstream myFile;
16 myFile.open("numbers.txt");
17
18 // Write the numbers 1-5 to the file.
```

```

19 for (counter = 1; counter <= MAX_NUMS; counter++)
20 {
21 // Write the number to the file.
22 myFile << counter << endl;
23 }
24
25 // Close the file.
26 myFile.close();
27 return 0;
28 }
```

### Opening a File and Reading Data From It in C++

Now we will discuss how you can read data from a file in C++. The following `#include` directive is needed in your program:

```
#include <iostream>
```

Then, in the function where you wish to open a file and read data from it, you will declare an `ifstream` object. Here is an example of a statement that declares an `ifstream` object:

```
ifstream inputFile;
```

This statement declares an `ifstream` object named `inputFile`. Next, you use the `ifstream` object to open a file. Here is an example:

```
inputFile.open("numbers.txt");
```

After this statement has executed, we will be able to use the `ifstream` object that is named `inputFile` to read data from the `numbers.txt` file. You can think of it this way: In memory, we have an `ifstream` object that we refer to in our code as `inputFile`. That object is connected to a file on the disk named `numbers.txt`. If we want to read data from the `numbers.txt` file, we will use the `ifstream` object.

Once you have created an `ifstream` object and opened a file, you can read an item of data from the file using the stream extraction operator (`>>`). You already know how to use the `>>` operator with `cin` to read input from the keyboard. It is used the same way with an `ifstream` object to read data from a file. For example, assuming that `inputFile` is an `ifstream` object, the following statement reads a piece of data from the file, and stores that piece of data in the `value` variable:

```
inputFile >> value;
```

### Closing the File in C++

Assuming that `inputFile` is the name of an `ifstream` object, here is an example of how to call the `close` function to close the file:

```
inputFile.close();
```

Once a file is closed, the connection between it and the `ifstream` object is removed. In order to perform further operations on the file, it must be opened again.

Previously, in Program 10-25, you saw an example that created a file and wrote the numbers 1-5 to the file. Program 10-26 demonstrates how to read the list of numbers from the file and display them on the screen.

**Program 10-26 (ReadNumbers.cpp)**

```
1 #include <iostream>
2 #include <fstream>
3 using namespace std;
4
5 int main()
6 {
7 // Constant for the maximum number of numbers.
8 const int MAX_NUMS = 5;
9
10 // Variables
11 int counter, number;
12
13 // Declare an ifstream object named myFile and open a
14 // file named numbers.txt, for reading.
15 ifstream myFile;
16 myFile.open("numbers.txt");
17
18 // The following loop reads 5 numbers from the file
19 // and displays them.
20 for (counter = 1; counter <= MAX_NUMS; counter++)
21 {
22 // Read a number from the file.
23 myFile >> number;
24
25 // Display the number.
26 cout << number << endl;
27 }
28
29 // Close the file.
30 myFile.close();
31 return 0;
32 }
```

**Program Output**

```
1
2
3
4
5
```

**Using `getline` to Read Strings**

You've already learned that when you want to read a string that contains multiple words, separated by spaces, from the keyboard, you must use the `getline` function. The same is true when you want to read a string from a file, and the string contains spaces. The `getline` function can read an entire line of input from a file, including embedded spaces, storing the input in a `string` variable.

Assume that `inputFile` is the name of an `ifstream` object, and that you have opened a file. Also assume that `line` is the name of a `string` variable. The following statement

shows how you can use the `getline` function to read a line of input from the file, storing that line of input in the `line` variable:

```
getline(inputFile, line);
```

Program 10-27 shows an example. This program opens the `philosophers.txt` file that was created by Program 10-24. This is the C++ version of pseudocode Program 10-2.

### Program 10-27

```
1 #include <iostream>
2 #include <fstream>
3 #include <string>
4 using namespace std;
5
6 int main()
7 {
8 // Declare three variables that will hold the values
9 // read from the file.
10 string name1, name2, name3;
11
12 // Declare an ifstream object named myFile and open a
13 // file named philosophers.txt.
14 ifstream myFile;
15 myFile.open("philosophers.txt");
16
17 // Read the names of three philosophers from the file
18 // into the variables.
19 getline(myFile, name1);
20 getline(myFile, name2);
21 getline(myFile, name3);
22
23 // Display the names that were read.
24 cout << "Here are the names of three philosophers:" << endl;
25 cout << name1 << endl;
26 cout << name2 << endl;
27 cout << name3 << endl;
28
29 // Close the file.
30 myFile.close();
31 return 0;
32 }
```

### Program Output

Here are the names of three philosophers:  
John Locke  
David Hume  
Edmund Burke

### Appending Data to an Existing File in C++

When you use an `ofstream` object to open a file, and that file already exists, its contents will be erased. Sometimes you want to open an existing file without erasing its current contents, and write new data to the end of the file. This is called *appending* data to the file.

In C++, you declare an `fstream` object when you want to append data to a file's existing contents. Here is an example of how you would declare an `fstream` object named `myFile`, and then use that object to open a file named `friends.txt`. The file's existing contents will not be erased.

```
fstream myFile;
myFile.open("friends.txt", ios::app);
```

Notice that two arguments are passed to the `open` function:

- The name of the file. In this case, the file's name is `friends.txt`.
- The special value `ios::app`. This specifies that any data that is written to the file should be appended to the file's existing contents.

### Detecting the End of a File in C++

Sometimes you need to read a file's contents, and you do not know the number of items that are stored in the file. You can open the file, and then use a loop to repeatedly read an item from the file and display it. However, an error will occur if the program attempts to read beyond the end of the file. The program needs some way of knowing when the end of the file has been reached so it will not try to read beyond it. Fortunately, the `>>` operator not only reads data from a file, but also returns a true or false value indicating whether the data was successfully read or not. If the operator returns true, then a value was successfully read. If the operator returns false, it means that no value was read from the file.

Program 10-28 demonstrates how to use this technique. The program opens the `numbers.txt` file that was created by Program 10-25, then reads and displays each item of data in the file.

#### Program 10-28

```
1 #include <iostream>
2 #include <fstream>
3 using namespace std;
4
5 int main()
6 {
7 // Declare an input file object.
8 ifstream salesFile;
9
10 // Declare a variable to hold a number.
11 int number;
12
13 // Open the numbers.txt file.
14 salesFile.open("numbers.txt");
15
```

```
16 // Read the items in the file and display them.
17 while (salesFile >> number)
18 {
19 cout << number << endl;
20 }
21
22 // Close the file.
23 salesFile.close();
24 return 0;
25 }
```

### Program Output

```
1
2
3
4
5
```

## Review Questions

### Multiple Choice

1. A file that data is written to is known as a(n)
  - a. input file
  - b. output file
  - c. sequential access file
  - d. binary file
2. A file that data is read from is known as a(n)
  - a. input file
  - b. output file
  - c. sequential access file
  - d. binary file
3. Before a file can be used by a program, it must be
  - a. formatted
  - b. encrypted
  - c. closed
  - d. opened
4. When a program is finished using a file, it should do this.
  - a. erase the file
  - b. open the file
  - c. close the file
  - d. encrypt the file

5. The contents of this type of file can be viewed in an editor such as Notepad.
  - a. text file
  - b. binary file
  - c. English file
  - d. human-readable file
6. This type of file contains data that has not been converted to text.
  - a. text file
  - b. binary file
  - c. Unicode file
  - d. symbolic file
7. When working with this type of file, you access its data from the beginning of the file to the end of the file.
  - a. ordered access
  - b. binary access
  - c. direct access
  - d. sequential access
8. When working with this type of file, you can jump directly to any piece of data in the file without reading the data that comes before it.
  - a. ordered access
  - b. binary access
  - c. direct access
  - d. sequential access
9. This is a small “holding section” in memory that many systems write data to before writing the data to a file.
  - a. buffer
  - b. variable
  - c. virtual file
  - d. temporary file
10. This is a character or set of characters that marks the end of a piece of data.
  - a. median value
  - b. delimiter
  - c. boundary marker
  - d. EOF marker
11. This is a character or set of characters that marks the end of a file.
  - a. median value
  - b. delimiter
  - c. boundary marker
  - d. EOF marker
12. This marks the location of the next item that will be read from a file.
  - a. input position
  - b. delimiter
  - c. pointer
  - d. read position

13. When a file is opened in this mode, data will be written at the end of the file's existing contents.
  - a. output mode
  - b. append mode
  - c. backup mode
  - d. read-only mode
14. The expression NOT eof(myFile) is equivalent to
  - a. eof(myFile) == True
  - b. eof(myFile)
  - c. eof(myFile) == False
  - d. eof(myFile) < 0
15. This is a single piece of data within a record.
  - a. field
  - b. variable
  - c. delimiter
  - d. subrecord

### True or False

1. When working with a sequential access file, you can jump directly to any piece of data in the file without reading the data that comes before it.
2. In most languages, when you open an output file and that file already exists on the disk, the contents of the existing file will be erased.
3. The process of opening a file is only necessary with input files. Output files are automatically opened when data is written to them.
4. The purpose of an EOF marker is to indicate where a field ends. Files typically contain several EOF markers.
5. When an input file is opened, its read position is initially set to the first item in the file.
6. When a file that already exists is opened in append mode, the file's existing contents are erased.
7. In control break logic, the program performs some ongoing task (such as processing the items in a file), but permanently stops the task when a control variable reaches a specific value or changes its value.

### Short Answer

1. Describe the three steps that must be taken when a file is used by a program.
2. Why should a program close a file when it's finished using it?
3. What is a file's read position? Where is the read position when a file is first opened for reading?
4. If an existing file is opened in append mode, what happens to the file's existing contents?
5. In most languages, if a file does not exist and a program attempts to open it in append mode, what happens?

6. What is the purpose of the `eof` function that was discussed in this chapter?
7. What is control break logic?

### Algorithm Workbench

1. Design a program that opens an output file with the external name `my_name.dat`, writes your name to the file, and then closes the file.
2. Design a program that opens the `my_name.dat` file that was created by the algorithm in question 1, reads your name from the file, displays the name on the screen, and then closes the file.
3. Design an algorithm that does the following: opens an output file with the external name `number_list.dat`, uses a loop to write the numbers 1 through 100 to the file, and then closes the file.
4. Design an algorithm that does the following: opens the `number_list.dat` file that was created by the algorithm created in question 3, reads all of the numbers from the file and displays them, and then closes the file.
5. Modify the algorithm that you designed in question 4 so it adds all of the numbers read from the file and displays their total.
6. Write pseudocode that opens an output file with the external name `number_list.dat`, but does not erase the file's contents if it already exists.
7. A file exists on the disk named `students.dat`. The file contains several records, and each record contains two fields: (1) the student's name and (2) the student's score for the final exam. Design an algorithm that deletes the record containing "John Perez" as the student name.
8. A file exists on the disk named `students.dat`. The file contains several records, and each record contains two fields: (1) the student's name and (2) the student's score for the final exam. Design an algorithm that changes Julie Milan's score to 100.

### Debugging Exercises

1. Why doesn't the following pseudocode module work as indicated in the comments?

```
// The readFile method accepts a string containing a filename as
// an argument. It reads and displays all the items in the file.
Module readFile(String filename)
 // Declare an input file.
 Declare InputFile file

 // A variable to hold an item that is read from the file.
 Declare String item

 // Open the file using the filename.
 Open file filename

 // Read all the items in the file and display them.
 While eof(file)
 Read file item
 Display item
 End While
End Module
```

## Programming Exercises

VideoNote  
File Display

### 1. File Display

Assume that a file containing a series of integers is named `numbers.dat` and exists on the computer's disk. Design a program that displays all of the numbers in the file.

### 2. Item Counter

Assume that a file containing a series of names (as strings) is named `names.dat` and exists on the computer's disk. Design a program that displays the number of names that are stored in the file. (*Hint:* Open the file and read every string stored in it. Each time you read a string, increment a counter variable. When you've read all the strings from the file, the counter variable will contain the number of names stored in the file.)

### 3. Sum of Numbers

Assume that a file containing a series of integers is named `numbers.dat` and exists on the computer's disk. Design a program that reads all of the numbers stored in the file and calculates their total.

### 4. Average of Numbers

Assume that a file containing a series of integers is named `numbers.dat` and exists on the computer's disk. Design a program that calculates the average of all the numbers stored in the file.

### 5. Largest Number

Assume that a file containing a series of integers is named `numbers.dat` and exists on the computer's disk. Design a program that determines the largest number stored in the file. (*Hint:* Use a technique similar to the one that was discussed in Chapter 8 for finding the largest value in an array. You do not need to read the file into an array to use this technique, however. It can be adapted for use with a file.)

### 6. Golf Scores

The Springfork Amateur Golf Club has a tournament every weekend. The club president has asked you to design two programs.

- (1) A program that will read each player's name and golf score as keyboard input, and then save these as records in a file named `golf.dat`. (Each record will have a field for the player's name and a field for the player's score.)
- (2) A program that reads the records from the `golf.dat` file and displays them.

### 7. Best Golf Score

Modify program #2 that you wrote for Programming Exercise 6 so it also displays the name of the player with the best (lowest) golf score. (*Hint:* Use a technique similar to the one that was discussed in Chapter 8 for finding the lowest value in an array. You do not need to read the file into an array to use this technique, however. It can be adapted for use with a file.)

## 8. Sales Report

Brewster's Used Cars, Inc. employs several salespeople. Brewster, the owner of the company, has provided a file that contains sales records for each salesperson for the past month. Each record in the file contains the following two fields:

- The salesperson's ID number, as an integer
- The amount of a sale, as a real number

The records are already sorted by salesperson ID. Brewster wants you to design a program that prints a sales report. The report should show each salesperson's sales and the total sales for that salesperson. The report should also show the total sales for all salespeople for the month. Here is an example of how the sales report should appear:

Brewster's Used Cars, Inc.  
Sales Report

| Salesperson ID                                | Sale Amount |
|-----------------------------------------------|-------------|
| 100                                           | \$10,000.00 |
| 100                                           | \$12,000.00 |
| 100                                           | \$5,000.00  |
| Total sales for this salesperson: \$27,000.00 |             |
| 101                                           | \$14,000.00 |
| 101                                           | \$18,000.00 |
| 101                                           | \$12,500.00 |
| Total sales for this salesperson: \$44,500.00 |             |
| 102                                           | \$13,500.00 |
| 102                                           | \$14,500.00 |
| 102                                           | \$20,000.00 |
| Total sales for this salesperson: \$48,000.00 |             |
| Total of all sales: \$119,500.00              |             |

## 9. Lowest and Highest Gas Prices

Assume that you have a file that contains the weekly average prices for a gallon of gas in the United States for the past 3 years. The data is stored in the file as records. Each record contains the average price of a gallon of gas on a specific date. Each record contains the following fields:

- The month, stored as an integer. January = 1, February = 2, etc.
- The day of the month, stored as an integer.
- The year, stored as an integer.
- The average price of a gallon of gas on the specified date, stored as a real number, rounded to 3 decimal places.

Design a program that reads the file and displays the lowest and highest gas prices, as well as the dates for those prices.

### 10. Average Steps Taken

A Personal Fitness Tracker is a wearable device that tracks your physical activity, calories burned, heart rate, sleeping patterns, and so forth. One common physical activity that most of these devices track is the number of steps you take each day.

Assume that you have a file that contains the number of steps a person has taken each day for a year. The data is stored in the file as records. Each record contains the number of steps taken on a specific date. Each record contains the following fields:

- The month, stored as an integer. January = 1, February = 2, etc.
- The day of the month, stored as an integer.
- The year, stored as an integer.
- The number of steps taken on the specified date, stored as an integer.

Furthermore, the records are stored in order of the date. For example, the first record in the file is for January 1st, and the last record in the file is for December 31st. Design a program that reads the file and displays the average number of steps taken for each month.

## TOPICS

- |                                           |                                                   |
|-------------------------------------------|---------------------------------------------------|
| 11.1 Introduction to Menu-Driven Programs | 11.4 Multiple-Level Menus                         |
| 11.2 Modularizing a Menu-Driven Program   | 11.5 Focus on Languages: Java, Python,<br>and C++ |
| 11.3 Using a Loop to Repeat the Menu      |                                                   |

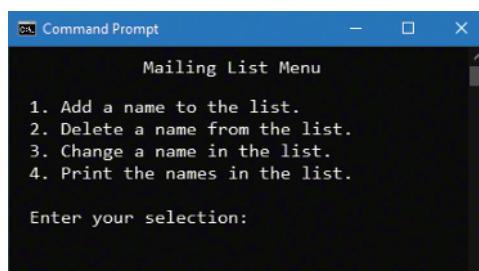
## 11.1

## Introduction to Menu-Driven Programs

**CONCEPT:** A menu is a list of operations that are displayed by a program. The user can select one of the operations and the program will perform it.

A *menu-driven program* displays a list of operations that it can perform on the screen, and allows the user to select one of the operations. The list of operations that is displayed on the screen is called a *menu*. For example, a program that manages a mailing list might display the menu shown in Figure 11-1.

**Figure 11-1** A menu (courtesy of Microsoft Corporation)



Notice that each item in this particular menu is preceded by a number. The user selects one of the operations by entering the number that appears next to it. Entering 1, for example, allows the user to add a name to the mailing list, and entering 4 causes the program to print the mailing list. Menu-driven programs that ask the user to enter a selection on the keyboard typically display a character such as a number or a letter next to each menu item. The user types the character that corresponds to the menu item they want to select.



**NOTE:** In a program that uses a graphical user interface (GUI), the user typically makes menu selections by clicking them with the mouse. You will learn about graphical user interfaces in Chapter 15.

## Using a Decision Structure to Perform Menu Selections

When the user selects an item from a menu, the program must use a decision structure to perform an action based on that selection. In most languages the case structure is a good mechanism for making this happen. Let's look at a simple example. Suppose we need a program that converts the following measurements from English units to metric units:

- Convert inches to centimeters
- Convert feet to meters
- Convert miles to kilometers

Here are the formulas for making these conversions:

$$\text{centimeters} = \text{inches} \times 2.54$$

$$\text{meters} = \text{feet} \times 0.3048$$

$$\text{kilometers} = \text{miles} \times 1.609$$

The program should display a menu, such as the following, that allows the user to select the desired conversion.

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

Program 11-1 shows the pseudocode for the program with four sample executions of the program. The case structure in lines 21 through 48 performs the operation that the user selects from the menu. Notice that a **Default** section appears in lines 45 through 47. The **Default** section validates the user's menu selection. If the user enters any value other than 1, 2, or 3 at the menu prompt, an error message is displayed. The first three sample execution sessions show what happens when the user makes a valid selection from the menu. The last sample session shows what happens when the user makes an invalid menu selection. Figure 11-2 shows a flowchart for the program.

**Program 11-1**

```
1 // Declare a variable to hold the
2 // user's menu selection.
3 Declare Integer menuSelection
4
5 // Declare variables to hold the units
6 // of measurement.
7 Declare Real inches, centimeters, feet, meters,
8 miles, kilometers
9
10 // Display the menu.
11 Display "1. Convert inches to centimeters."
12 Display "2. Convert feet to meters."
13 Display "3. Convert miles to kilometers."
14 Display
15
16 // Prompt the user for a selection
17 Display "Enter your selection."
18 Input menuSelection
19
20 // Perform the selected operation.
21 Select menuSelection
22 Case 1:
23 // Convert inches to centimeters.
24 Display "Enter the number of inches."
25 Input inches
26 Set centimeters = inches * 2.54
27 Display "That is equal to ", centimeters,
28 " centimeters."
29
30 Case 2:
31 // Convert feet to meters.
32 Display "Enter the number of feet."
33 Input feet
34 Set meters = feet * 0.3048
35 Display "That is equal to ", meters, " meters."
36
37 Case 3:
38 // Convert miles to kilometers.
39 Display "Enter the number of miles."
40 Input miles
41 Set kilometers = miles * 1.609
42 Display "That is equal to ", kilometers,
43 " kilometers."
44
45 Default:
46 // Display an error message.
47 Display "That is an invalid selection."
48 End Select
```

This displays the menu and prompts the user to enter a selection. The user's input is stored in the menuSelection variable.

This executes if the user enters 1.

This executes if the user enters 2.

This executes if the user enters 3.

This executes if the user enters anything other than 1, 2, or 3.

**Program Output (with Input Shown in Bold)**

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

**1 [Enter]**

Enter the number of inches.

**10 [Enter]**

That is equal to 25.4 centimeters.

**Program Output (with Input Shown in Bold)**

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

**2 [Enter]**

Enter the number of feet.

**10 [Enter]**

That is equal to 3.048 meters.

**Program Output (with Input Shown in Bold)**

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

**3 [Enter]**

Enter the number of miles.

**10 [Enter]**

That is equal to 16.09 kilometers.

**Program Output (with Input Shown in Bold)**

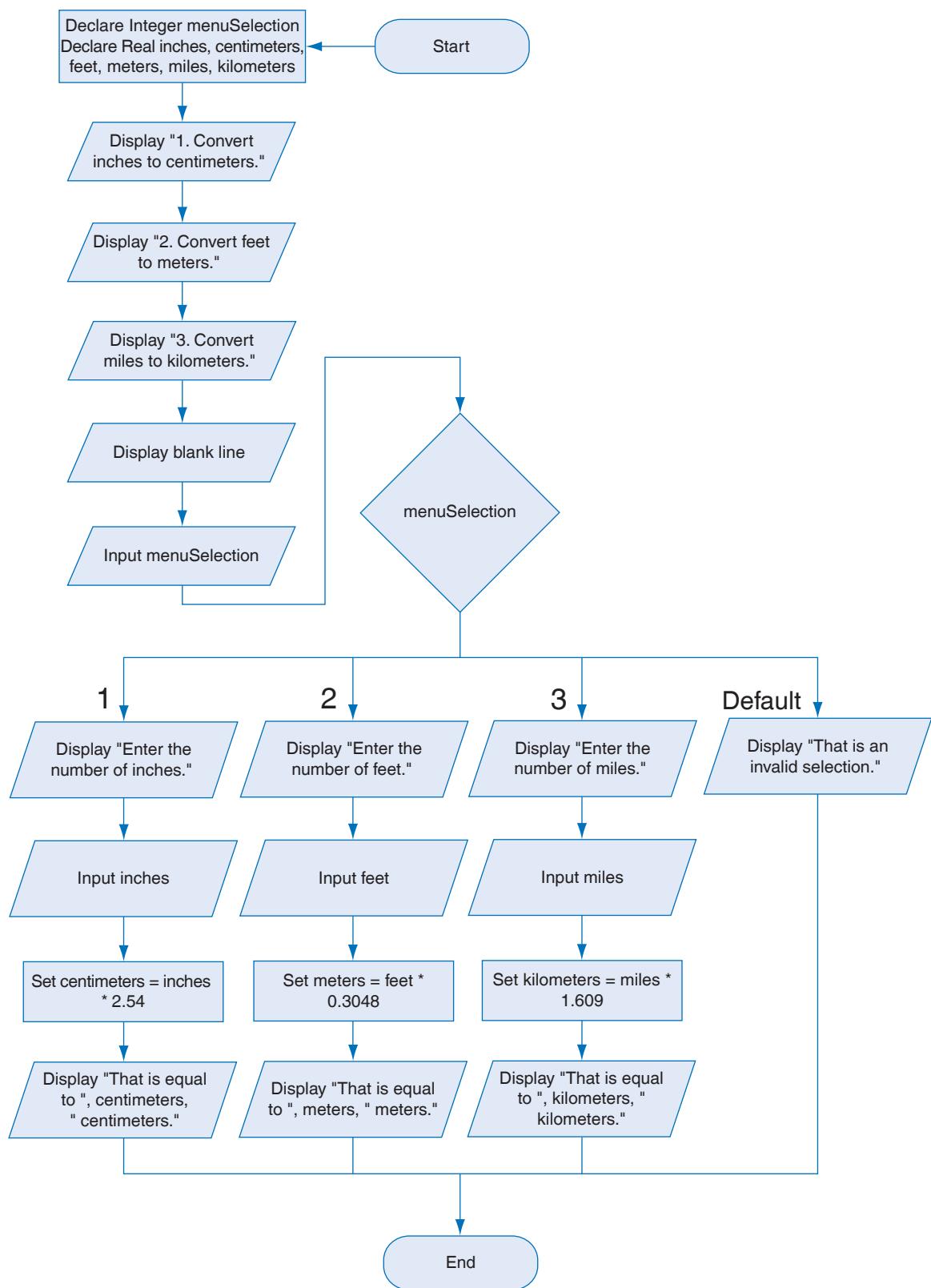
1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

**4 [Enter]**

That is an invalid selection.

Although a case structure is often the easiest and most straightforward decision structure to use in a menu-driven program, other approaches can be taken as an alternative. For example, a series of nested If-Then-Else statements could be used as shown in Program 11-2. Figure 11-3 shows a flowchart for this program.

**Figure 11-2** Flowchart for Program 11-1

**Program 11-2**

```

1 // Declare a variable to hold the
2 // user's menu selection.
3 Declare Integer menuSelection
4
5 // Declare variables to hold the units
6 // of measurement.
7 Declare Real inches, centimeters, feet, meters,
8 miles, kilometers
9
10 // Display the menu.
11 Display "1. Convert inches to centimeters."
12 Display "2. Convert feet to meters."
13 Display "3. Convert miles to kilometers."
14 Display
15
16 // Prompt the user for a selection
17 Display "Enter your selection."
18 Input menuSelection
19
20 // Perform the selected operation.
21 If menuSelection == 1 Then
22 // Convert inches to centimeters.
23 Display "Enter the number of inches."
24 Input inches
25 Set centimeters = inches * 2.54
26 Display "That is equal to ", centimeters,
27 " centimeters."
28 Else
29 If menuSelection == 2 Then
30 // Convert feet to meters.
31 Display "Enter the number of feet."
32 Input feet
33 Set meters = feet * 0.3048
34 Display "That is equal to ", meters, " meters."
35 Else
36 If menuSelection == 3 Then
37 // Convert miles to kilometers.
38 Display "Enter the number of miles."
39 Input miles
40 Set kilometers = miles * 1.609
41 Display "That is equal to ", kilometers,
42 " kilometers."
43 Else
44 // Display an error message.
45 Display "That is an invalid selection."
46 End If
47 End If
48 End If

```

This displays the menu and prompts the user to enter a selection. The user's input is stored in the `menuSelection` variable.

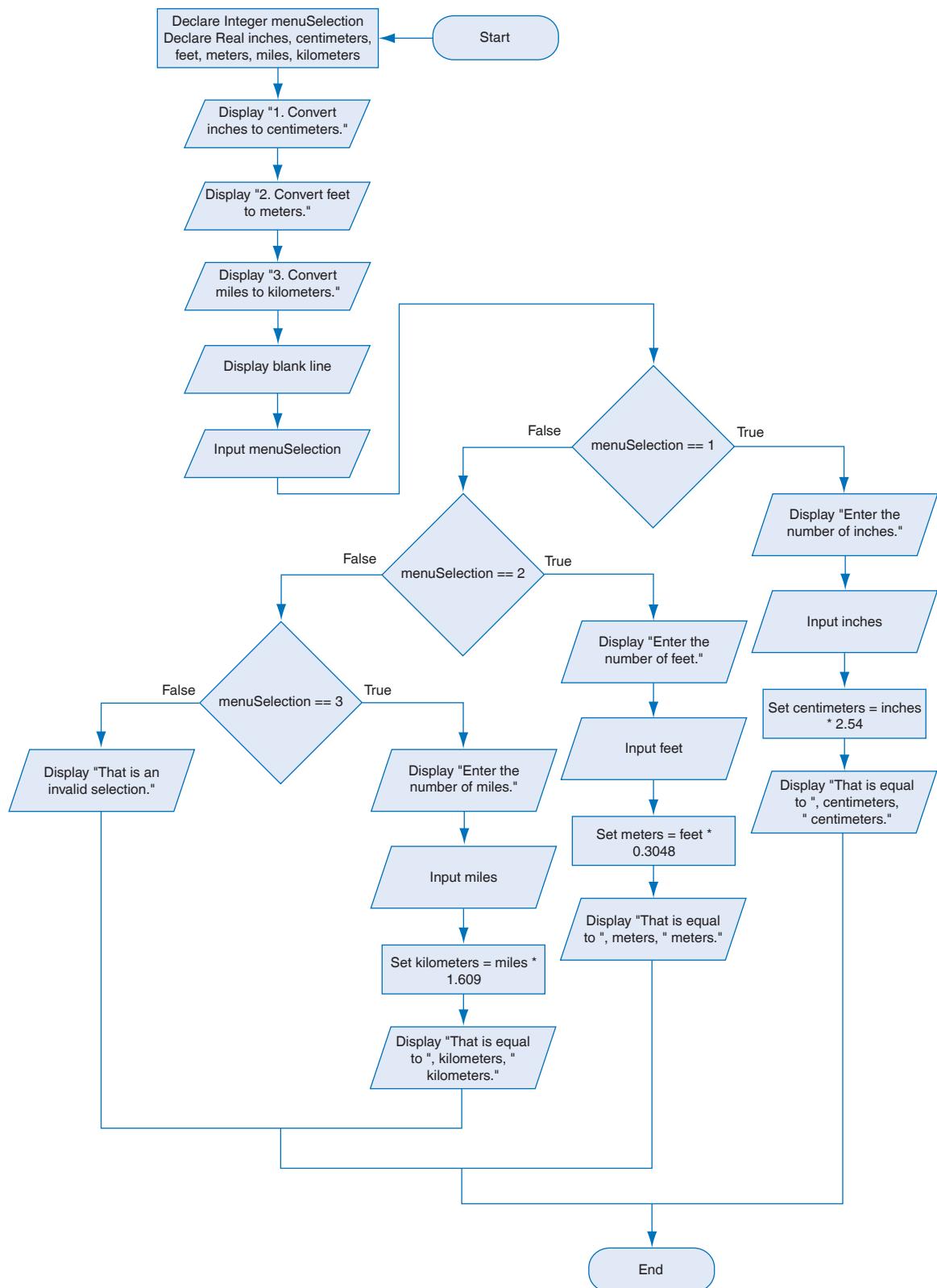
This executes if the user enters 1.

This executes if the user enters 2.

This executes if the user enters 3.

Error message

**(The output is the same as that for Program 11-1.)**

**Figure 11-3** Flowchart for Program 11-2



**NOTE:** As a third alternative, the program could also be modified to use an If-Then-Else If statement.

## Validating the Menu Selection

Any program that allows the user to select an item from a menu should validate the user's selection. Program 11-1 validated the user's menu selection with the `Default` section in the case structure (in lines 45 through 47). Program 11-2 validated the menu selection with the `Else` clause (in lines 43 through 45).

An alternative approach is to use an input validation loop immediately after the `Input` statement that reads the user's menu selection. If the menu selection is invalid, the loop displays an error message and prompts the user to enter it again. The loop repeats as long as the input is invalid.

The pseudocode in Program 11-3 shows how Program 11-1 can be modified to use an input validation loop. The input validation loop appears in lines 20 through 25. Notice that the case structure in this program does not have a `Default` section. The input validation loop makes sure the `menuSelection` variable is set to a value in the range of 1 through 3 before the program enters the case structure. Figure 11-4 shows a flowchart for the program.

### Program 11-3



```

1 // Declare a variable to hold the
2 // user's menu selection.
3 Declare Integer menuSelection
4
5 // Declare variables to hold the units
6 // of measurement.
7 Declare Real inches, centimeters, feet, meters,
8 miles, kilometers
9
10 // Display the menu.
11 Display "1. Convert inches to centimeters."
12 Display "2. Convert feet to meters."
13 Display "3. Convert miles to kilometers."
14 Display
15
16 // Prompt the user for a selection
17 Display "Enter your selection."
18 Input menuSelection
19

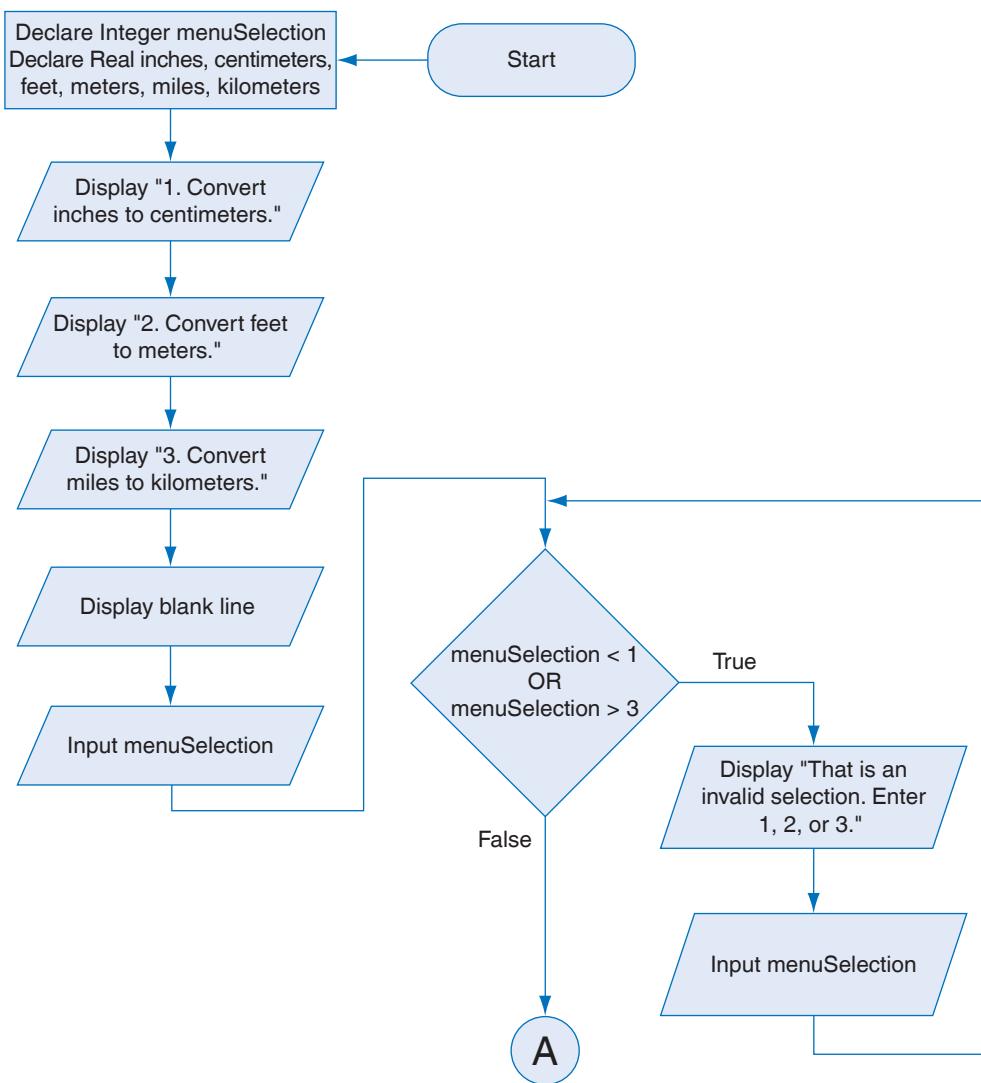
```

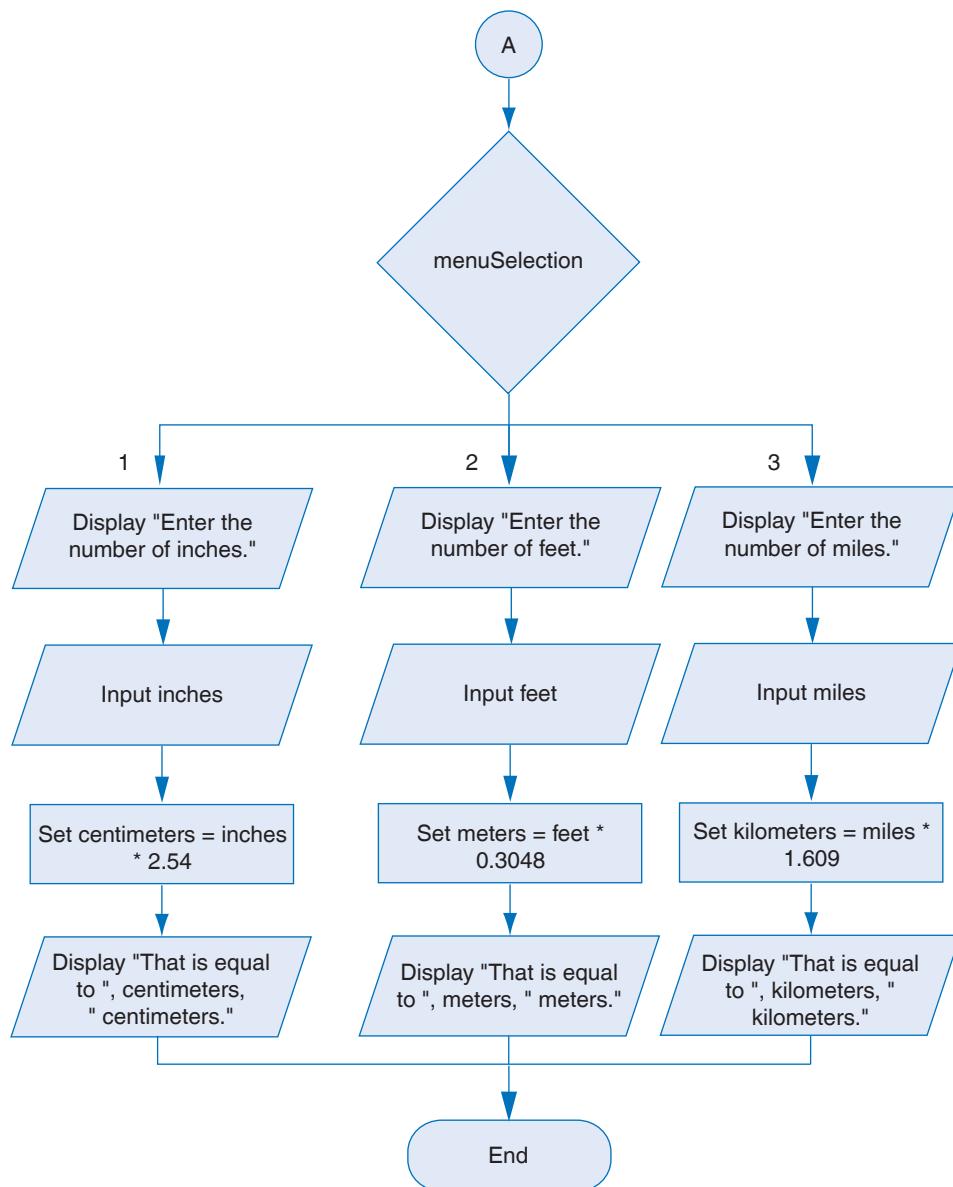
```
20 // Validate the menu selection.
21 While menuSelection < 1 OR menuSelection > 3
22 Display "That is an invalid selection. ",
23 "Enter 1, 2, or 3."
24 Input menuSelection
25 End While
26
27 // Perform the selected operation.
28 Select menuSelection
29 Case 1:
30 // Convert inches to centimeters.
31 Display "Enter the number of inches."
32 Input inches
33 Set centimeters = inches * 2.54
34 Display "That is equal to ", centimeters,
35 " centimeters."
36
37 Case 2:
38 // Convert feet to meters.
39 Display "Enter the number of feet."
40 Input feet
41 Set meters = feet * 0.3048
42 Display "That is equal to ", meters, " meters."
43
44 Case 3:
45 // Convert miles to kilometers.
46 Display "Enter the number of miles."
47 Input miles
48 Set kilometers = miles * 1.609
49 Display "That is equal to ", kilometers,
50 " kilometers."
51 End Select
```

### Program Output (with Input Shown in Bold)

```
1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.
4 [Enter]
That is an invalid selection. Enter 1, 2, or 3.
1 [Enter]
Enter the number of inches.
10 [Enter]
That is equal to 25.4 centimeters.
```

**Figure 11-4** Flowchart for Program 11-3

**Figure 11-4** Flowchart for Program 11-3 (continued)**Checkpoint**

- 11.1 What is a menu-driven program?
- 11.2 The items displayed in a menu are often preceded by a number, letter, or other character. What is the purpose of this character?
- 11.3 What type of structure do you use in a program to perform the action that the user has selected from a menu?

**11.2**

## Modularizing a Menu-Driven Program

**CONCEPT:** Most menu-driven programs should be modularized, with each task written in its own module.

A menu-driven program is typically capable of performing several tasks, and allows the user to select the task they want the program to perform. In most cases, menu-driven programs should be broken down into modules that perform individual tasks. For example, look at the pseudocode in Program 11-4. This is an improved version of Program 11-3, using modules to break the program into small, manageable pieces.

Here are summaries of the modules that are used in Program 11-4:

- **main:** The `main` module is the program's starting point. It calls the other modules.
- **displayMenu:** The `displayMenu` module displays the menu on the screen, gets the user's menu selection, and validates it.
- **inchesToCentimeters:** The `inchesToCentimeters` module prompts the user to enter an amount of inches and displays that amount converted to centimeters. This module is called from the `main` module (in line 13) when the user enters 1 at the menu prompt.
- **feetToMeters:** The `feetToMeters` module prompts the user to enter an amount of feet and displays that amount converted to meters. This module is called from the `main` module (in line 16) when the user enters 2 at the menu prompt.
- **milesToKilometers:** The `milesToKilometers` module prompts the user to enter an amount of miles and displays that amount converted to meters. This module is called from the `main` module (in line 19) when the user enters 3 at the menu prompt.

Figure 11-5 shows a flowchart for the `main` module. Compare this to the flowchart for Program 11-3 (shown in Figure 11-4), and you can see how the modules have simplified the design. Figure 11-6 shows the flowcharts for the other modules.

### Program 11-4

```

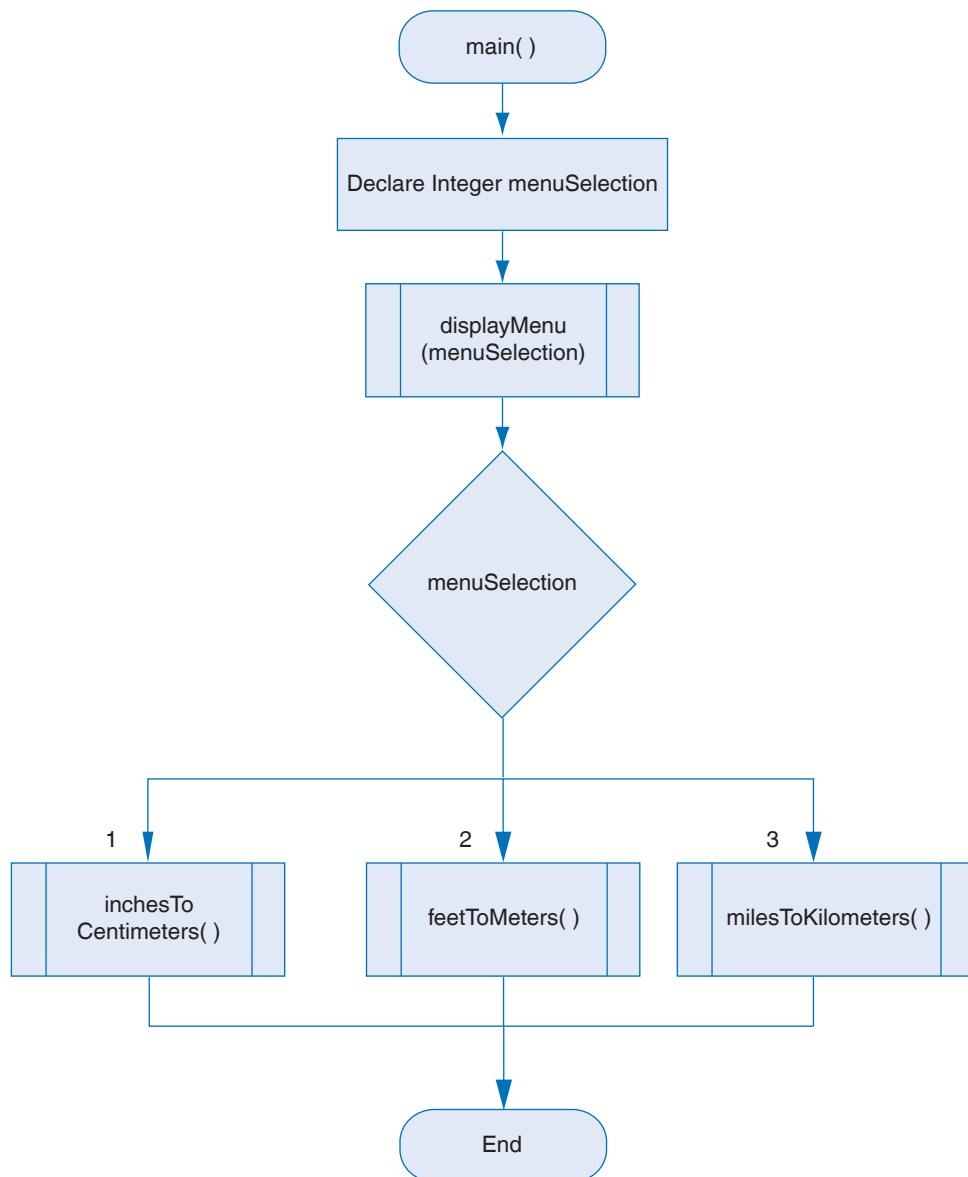
1 Module main()
2 // Declare a variable to hold the
3 // user's menu selection.
4 Declare Integer menuSelection
5
6 // Display the menu and get the
7 // user's selection.
8 Call displayMenu(menuSelection)
9

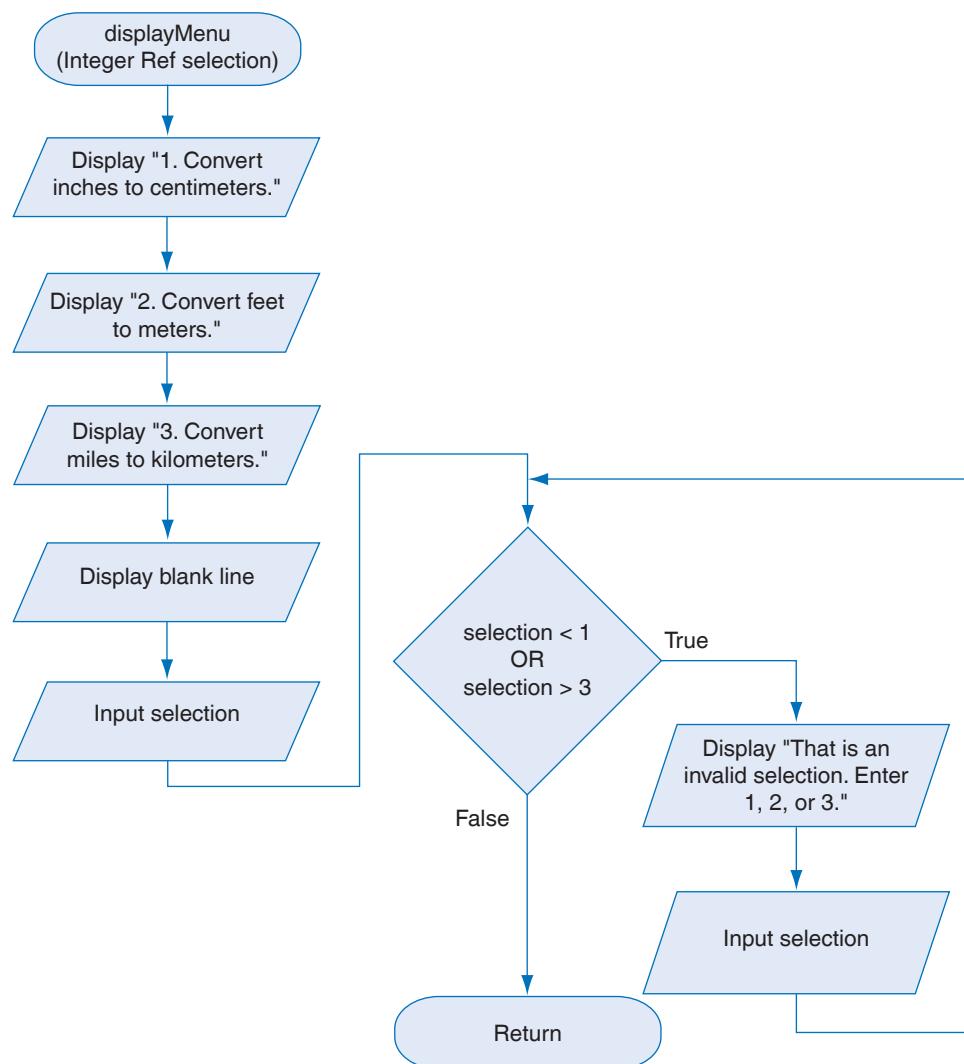
```

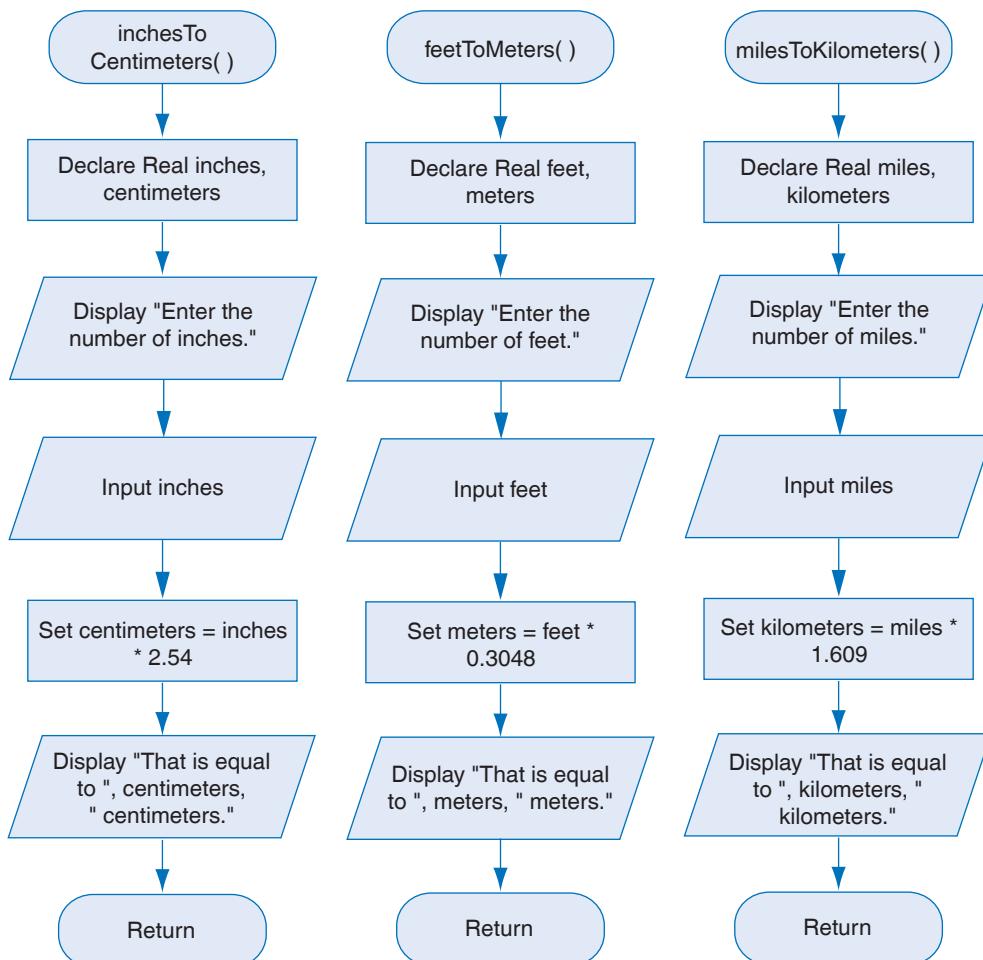
```
10 // Perform the selected operation.
11 Select menuSelection
12 Case 1:
13 Call inchesToCentimeters()
14
15 Case 2:
16 Call feetToMeters()
17
18 Case 3:
19 Call milesToKilometers()
20 End Select
21 End Module
22
23 // The displayMenu module displays the menu and
24 // prompts the user for a selection. The selected
25 // value is validated and stored in the selection
26 // parameter, which is passed by reference.
27 Module displayMenu(Integer Ref selection)
28 // Display the menu.
29 Display "1. Convert inches to centimeters."
30 Display "2. Convert feet to meters."
31 Display "3. Convert miles to kilometers."
32 Display
33
34 // Prompt the user for a selection.
35 Display "Enter your selection."
36 Input selection
37
38 // Validate the menu selection.
39 While selection < 1 OR selection > 3
40 Display "That is an invalid selection. ",
41 "Enter 1, 2, or 3."
42 Input selection
43 End While
44 End Module
45
46 // The inchesToCentimeters module converts a
47 // measurement from inches to centimeters.
48 Module inchesToCentimeters()
49 // Local variables
50 Declare Real inches, centimeters
51
52 // Get the number of inches.
53 Display "Enter the number of inches."
54 Input inches
55
56 // Convert the inches to centimeters.
57 Set centimeters = inches * 2.54
58
59 // Display the result.
60 Display "That is equal to ", centimeters,
61 " centimeters."
62 End Module
```

```
63
64 // The feetToMeters module converts a
65 // measurement from feet to meters.
66 Module feetToMeters()
67 // Local variables
68 Declare Real feet, meters
69
70 // Get the number of feet.
71 Display "Enter the number of feet."
72 Input feet
73
74 // Convert the feet to meters.
75 Set meters = feet * 0.3048
76
77 // Display the result.
78 Display "That is equal to ", meters, " meters."
79 End Module
80
81 // The milesToKilometers module converts a
82 // measurement from miles to kilometers.
83 Module milesToKilometers()
84 // Local variables
85 Declare Real miles, kilometers
86
87 // Get the number of miles.
88 Display "Enter the number of miles."
89 Input miles
90
91 // Convert the miles to kilometers.
92 Set kilometers = miles * 1.609
93
94 // Display the result.
95 Display "That is equal to ", kilometers,
96 " kilometers."
97 End Module
```

(The output is the same as that for Program 11-3.)

**Figure 11-5** Flowchart for the main module in Program 11-4

**Figure 11-6** Flowcharts for the other modules in Program 11-4

**Figure 11-6** Flowcharts for the other modules in Program 11-4 (continued)**11.3**

## Using a Loop to Repeat the Menu

**CONCEPT:** Most menu-driven programs use a loop to repeatedly display the menu after a selected task is performed.

The programs you've seen so far in this chapter end immediately after performing an operation that is selected from the menu. If the user wants to select another operation from the menu, the program must be run again. Having to run a program repeatedly to perform multiple operations can be inconvenient for the user, so most menu-driven programs use a loop that redisplays the menu after the user's selected action has been performed. When the user is ready to end the program, an operation such as "End the program" must be selected from the menu.

Program 11-5 is a modification of Program 11-4. It shows how we can use a Do-While loop in the `main` module to display the menu repeatedly until the user is ready to end the program. Selecting item 4, End the program, causes the loop to stop and ends the program. Figure 11-7 shows a flowchart for the `main` module.

### Program 11-5

```
1 Module main()
2 // Declare a variable to hold the
3 // user's menu selection.
4 Declare Integer menuSelection
5
6 Do
7 // Display the menu and get the
8 // user's selection.
9 Call displayMenu(menuSelection)
10
11 // Perform the selected operation.
12 Select menuSelection
13 Case 1:
14 Call inchesToCentimeters()
15
16 Case 2:
17 Call feetToMeters()
18
19 Case 3:
20 Call milesToKilometers()
21 End Select
22 While menuSelection != 4
23 End Module
24
25 // The displayMenu module displays the menu and
26 // prompts the user for a selection. The selected
27 // value is stored in the selection parameter, which
28 // is passed by reference.
29 Module displayMenu(Integer Ref selection)
30 // Display the menu.
31 Display "1. Convert inches to centimeters."
32 Display "2. Convert feet to meters."
33 Display "3. Convert miles to kilometers."
34 Display "4. End the program."
35 Display
36
37 // Prompt the user for a selection.
38 Display "Enter your selection."
39 Input selection
40
41 // Validate the menu selection.
42 While selection < 1 OR selection > 4
43 Display "That is an invalid selection. ",
44 "Enter 1, 2, 3, or 4."
45 Input selection
46 End While
47 End Module
```

```
48
49 // The inchesToCentimeters module converts a
50 // measurement from inches to centimeters.
51 Module inchesToCentimeters()
52 // Local variables
53 Declare Real inches, centimeters
54
55 // Get the number of inches.
56 Display "Enter the number of inches."
57 Input inches
58
59 // Convert the inches to centimeters.
60 Set centimeters = inches * 2.54
61
62 // Display the result.
63 Display "That is equal to ", centimeters,
64 " centimeters."
65
66 // Display a blank line.
67 Display
68 End Module
69
70 // The feetToMeters module converts a
71 // measurement from feet to meters.
72 Module feetToMeters()
73 // Local variables
74 Declare Real feet, meters
75
76 // Get the number of feet.
77 Display "Enter the number of feet."
78 Input feet
79
80 // Convert the feet to meters.
81 Set meters = feet * 0.3048
82
83 // Display the result.
84 Display "That is equal to ", meters, " meters."
85
86 // Display a blank line.
87 Display
88 End Module
89
90 // The milesToKilometers module converts a
91 // measurement from miles to kilometers.
92 Module milesToKilometers()
93 // Local variables
94 Declare Real miles, kilometers
95
96 // Get the number of miles.
97 Display "Enter the number of miles."
98 Input miles
99
100 // Convert the miles to kilometers.
101 Set kilometers = miles * 1.609
102
```

```
103 // Display the result.
104 Display "That is equal to ", kilometers,
105 " kilometers."
106
107 // Display a blank line.
108 Display
109 End Module
```

### Program Output (with Input Shown in Bold)

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.
4. End the program.

Enter your selection.

**1 [Enter]**

Enter the number of inches.

**10 [Enter]**

That is equal to 25.4 inches.

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.
4. End the program.

Enter your selection.

**2 [Enter]**

Enter the number of feet.

**10 [Enter]**

That is equal to 3.048 meters.

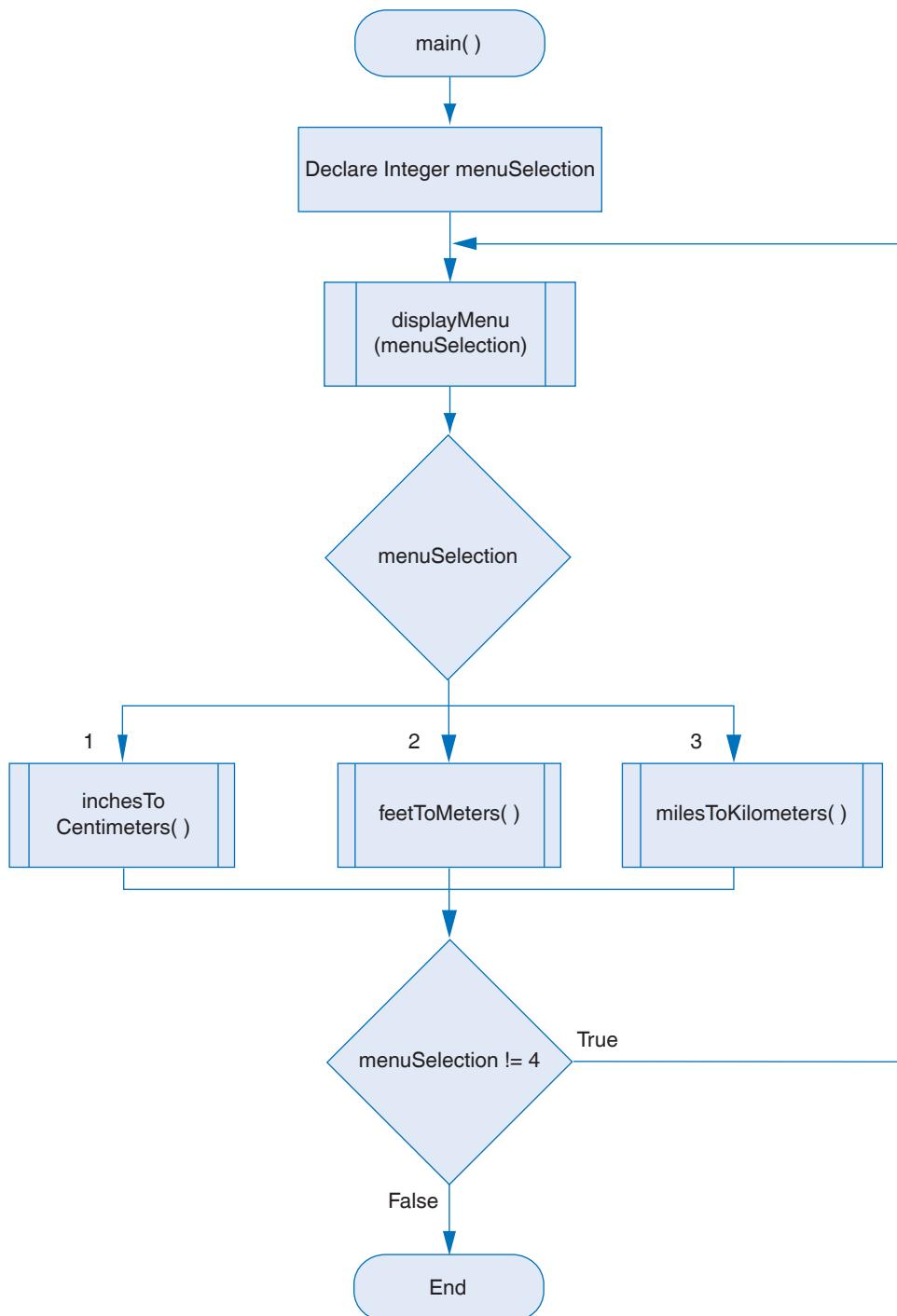
1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.
4. End the program.

Enter your selection.

**4 [Enter]**



**TIP:** A Do-While loop was chosen for Program 11-5 because it is a posttest loop, and it will always display the menu at least one time. A While loop could be used, but remember, the While loop is a pretest loop. Using it would require that the menuSelection variable be initialized with some value other than 4.

**Figure 11-7** Flowchart for the main module in Program 11-5

## In the Spotlight: Designing a Menu-Driven Program

In several of Chapter 10's *In the Spotlight* sections we stepped through the design of a series of programs for Midnight Coffee Roasters, Inc. These programs are used to manage the company's inventory of coffee. Each type of coffee that is in the inventory has a record in a file. Each record has fields indicating the name of the coffee and the quantity in stock. The programs you saw in Chapter 10 allow the user to perform the following operations:

- Add a record to the inventory file
- Search for a record
- Modify the quantity in an existing record in the inventory file
- Delete a record in the inventory file
- Display all of the records in the inventory file

Currently, all of these operations are performed by separate programs. Julie, the owner of Midnight Coffee Roasters, Inc., has asked you to consolidate all of these operations into a single program with a menu.

You decide to design a program with the following modules:

- **main:** This module executes when the program starts. It uses a loop that calls the appropriate modules to display the menu, get the user's selection, and then perform the selected operation.
- **displayMenu:** This module displays the following menu:

Inventory Menu

  1. Add a record.
  2. Search for a record.
  3. Modify a record.
  4. Delete a record.
  5. Display all records.
  6. End the program.
- The **displayMenu** module also gets the user's selection and validates the selection.
- **addRecord:** This module is called when the user selects item #1 from the menu. It allows the user to add a record to the inventory file.
- **searchRecord:** This module is called when the user selects item #2 from the menu. It allows the user to search the inventory file for a specific record.
- **modifyRecord:** This module is called when the user selects item #3 from the menu. It allows the user to modify the quantity that is stored in an existing record in the inventory file.
- **deleteRecord:** This module is called when the user selects item #4 from the menu. It allows the user to delete a record from the inventory file.
- **displayRecords:** This module is called when the user selects item #5 from the menu. It displays all of the records in the inventory file.

The pseudocode for the **main** module is shown in Program 11-6. Figure 11-8 shows a flowchart for the **main** module.



**Program 11-6****Coffee inventory program:  
main module**

```
1 Module main()
2 // Variable to hold the menu selection.
3 Declare Integer menuSelection
4
5 Do
6 // Display the menu.
7 Call displayMenu(menuSelection)
8
9 // Perform the selected operation.
10 Select menuSelection
11 Case 1:
12 Call addRecord()
13
14 Case 2:
15 Call searchRecord()
16
17 Case 3:
18 Call modifyRecord()
19
20 Case 4:
21 Call deleteRecord()
22
23 Case 5:
24 Call displayRecords()
25 End Select
26 While menuSelection != 6
27 End Module
28
```

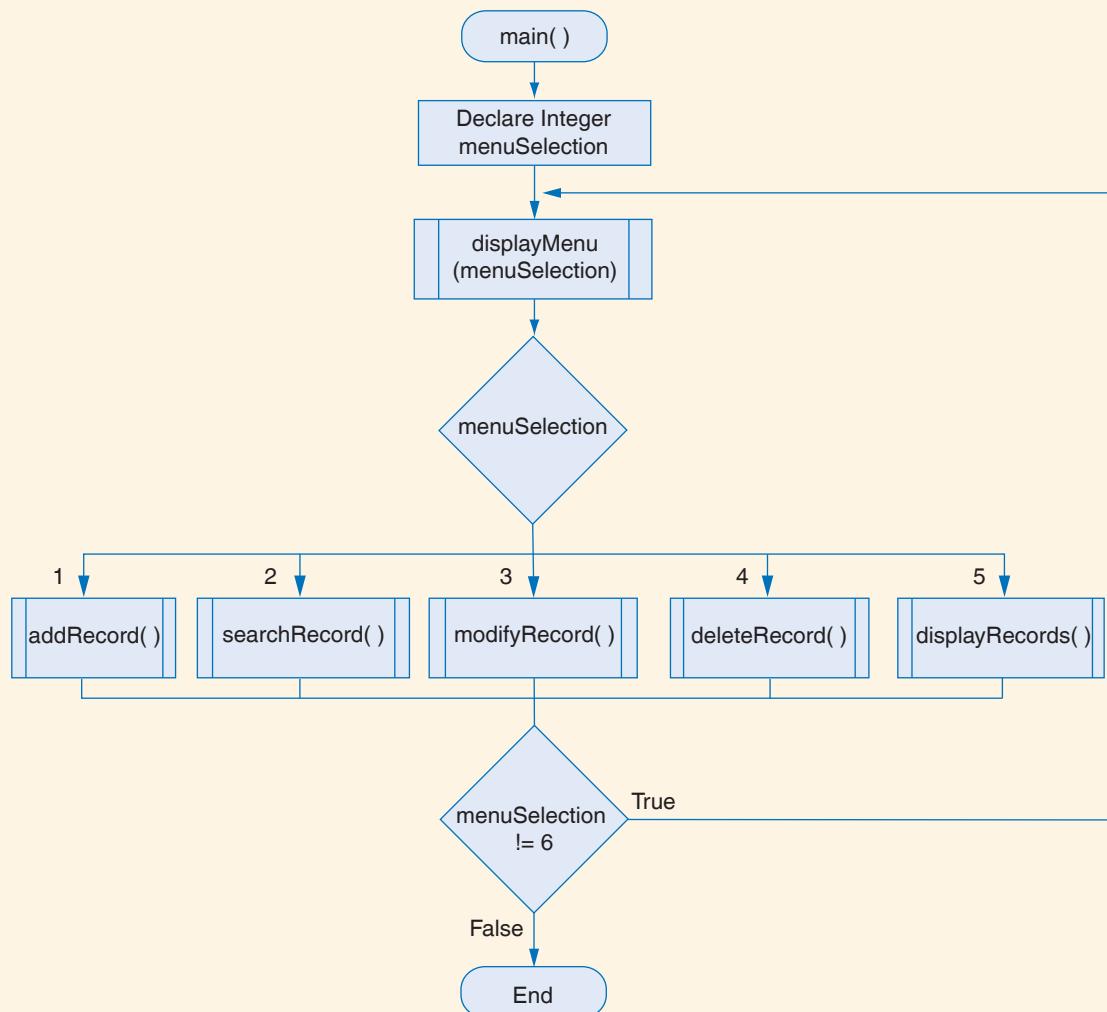
The pseudocode for the `displayMenu` module follows. Figure 11-9 shows a flowchart for the `displayMenu` module.

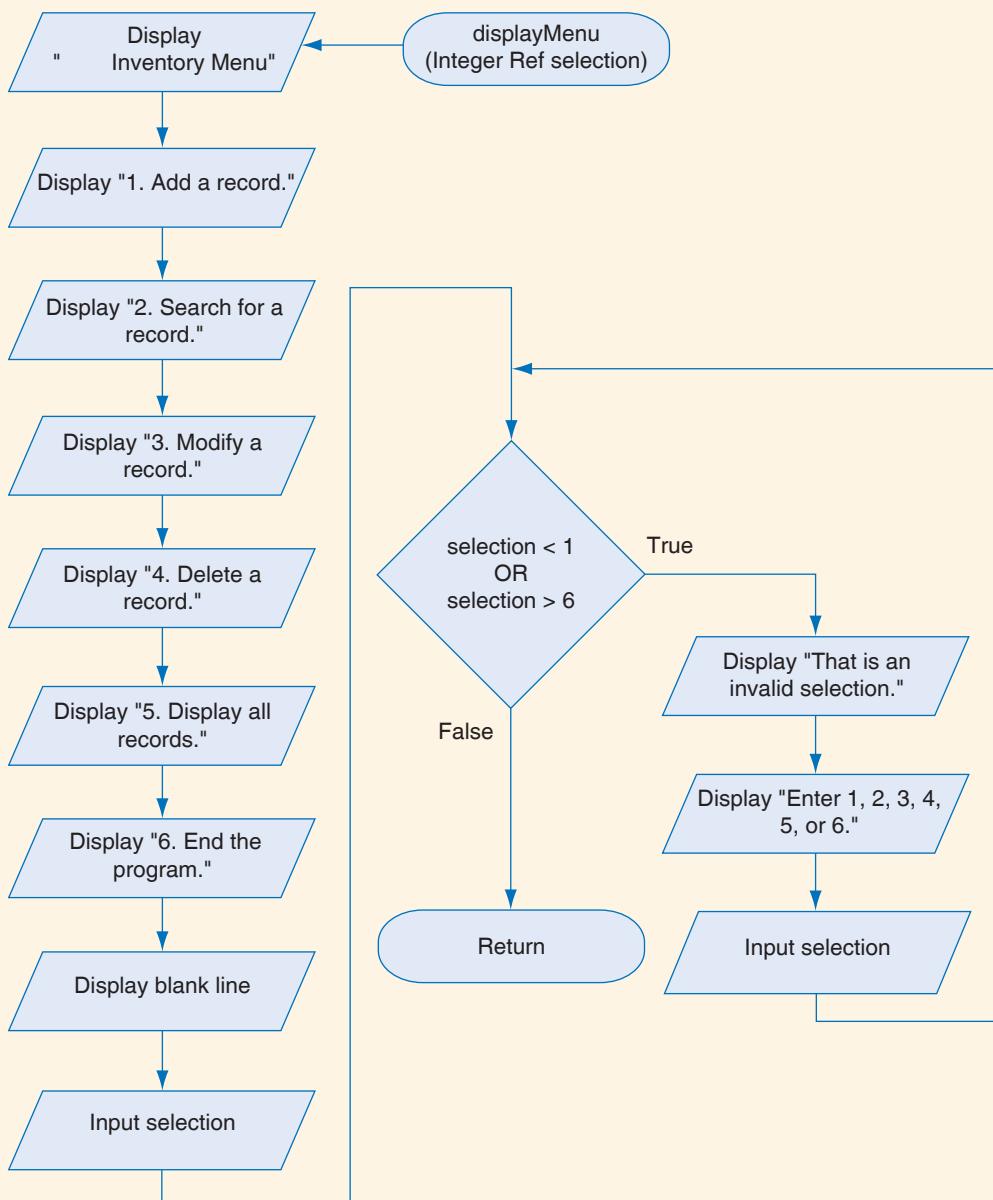
**Program 11-6****Coffee inventory program (continued):  
displayMenu module**

```
29 // The displayMenu module displays the menu, gets
30 // the user's selection, and validates it.
31 Module displayMenu(Integer Ref selection)
32 // Display the menu.
33 Display " Inventory Menu"
34 Display "1. Add a record."
35 Display "2. Search for a record."
36 Display "3. Modify a record."
37 Display "4. Delete a record."
38 Display "5. Display all records."
39 Display "6. End the program."
40 Display
41
```

```
42 // Get the user's selection.
43 Display "Enter your selection."
44 Input selection
45
46 // Validate the selection.
47 While selection < 1 OR selection > 6
48 Display "That is an invalid selection."
49 Display "Enter 1, 2, 3, 4, 5, or 6."
50 Input selection
51 End While
52 End Module
53
```

**Figure 11-8** Flowchart for the `main` module in Program 11-6

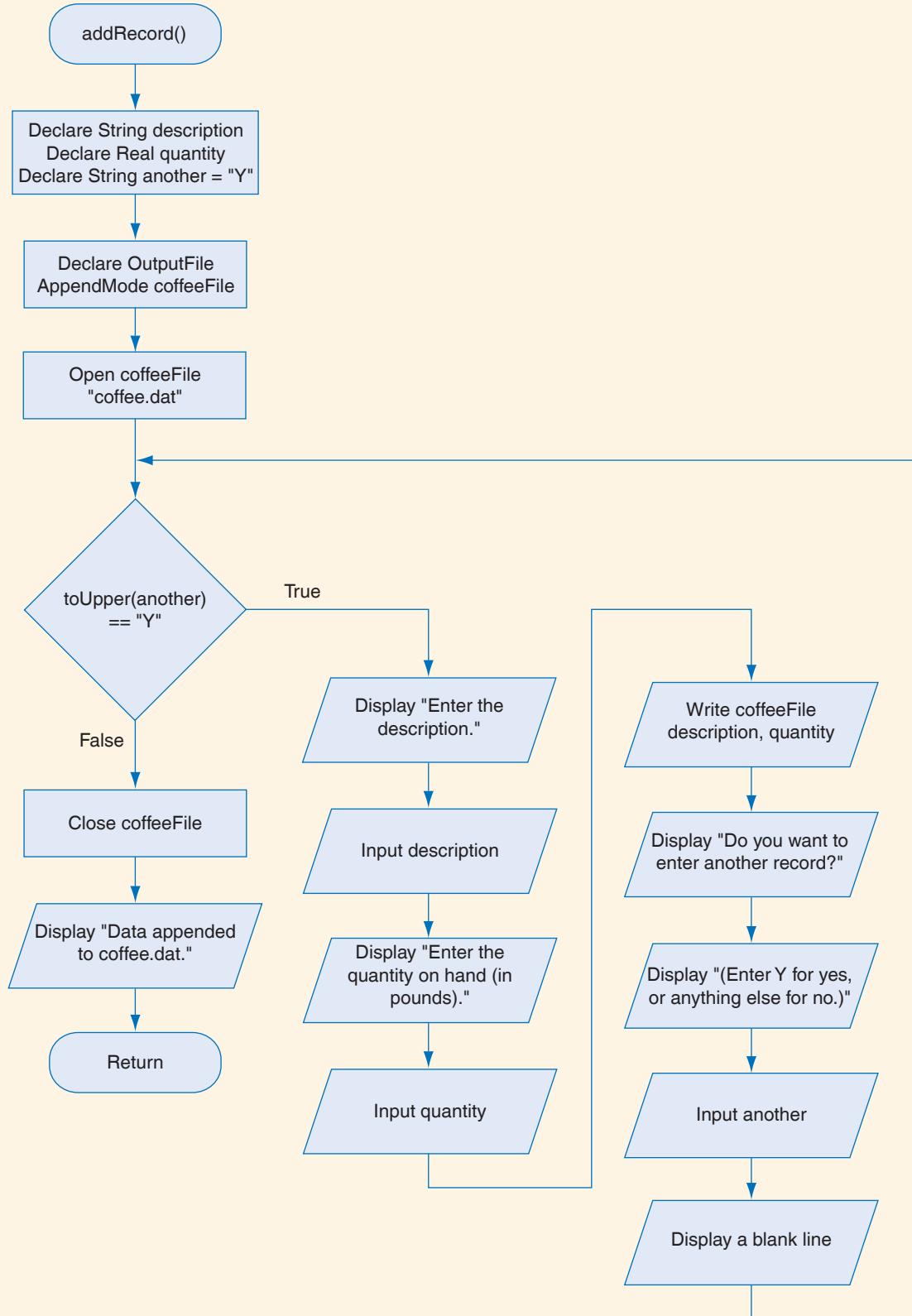


**Figure 11-9** Flowchart for the `displayMenu` module in Program 11-6

The pseudocode for the `addRecord` module follows. Figure 11-10 shows a flowchart for the `addRecord` module.

**Program 11-6****Coffee inventory program (continued):  
addRecord module**

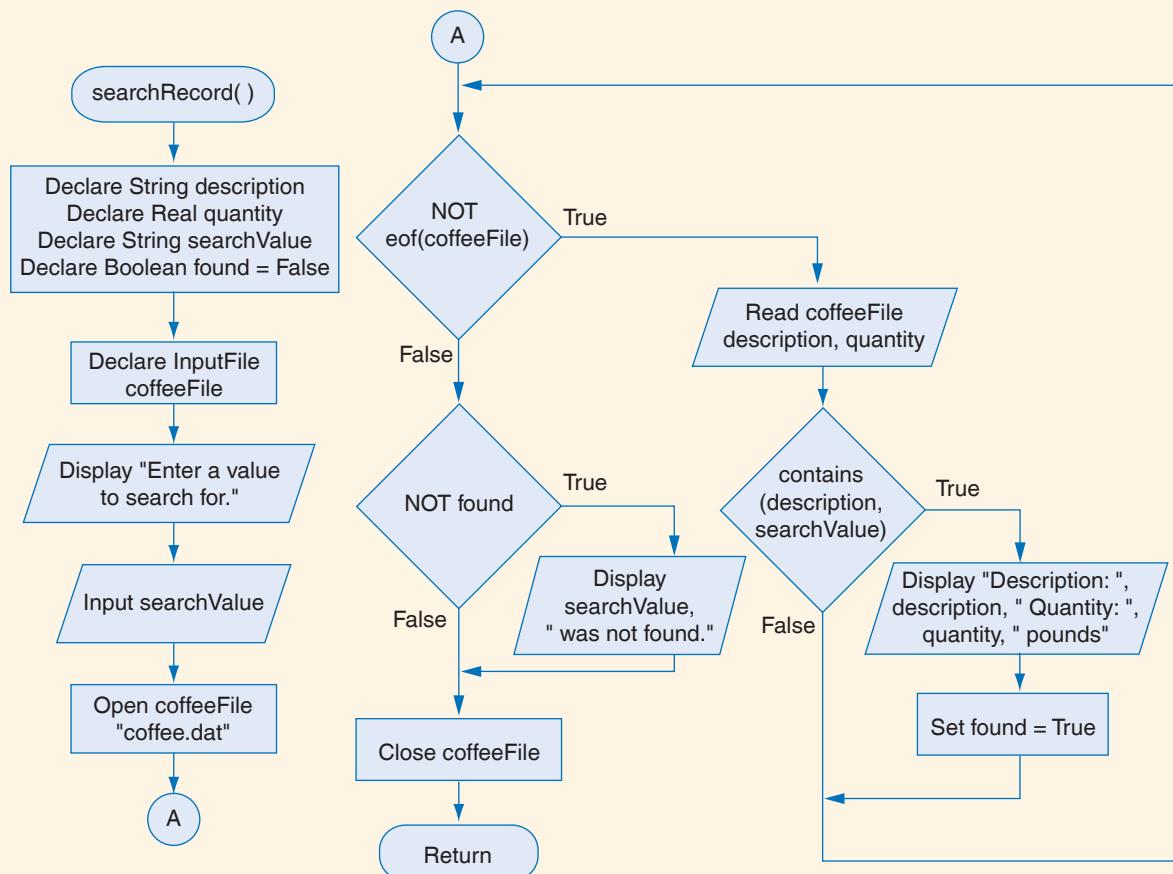
```
54 // The addRecord module lets the user add a record
55 // to the inventory file.
56 Module addRecord()
57 // Variables for the fields
58 Declare String description
59 Declare Real quantity
60
61 // Variable to control the loop
62 Declare String another = "Y"
63
64 // Declare an output file in append mode.
65 Declare OutputFile AppendMode coffeeFile
66
67 // Open the file.
68 Open coffeeFile "coffee.dat"
69
70 While toUpper(another) == "Y"
71 // Get the description.
72 Display "Enter the description."
73 Input description
74
75 // Get the quantity on hand.
76 Display "Enter the quantity on hand ",
77 "(in pounds)."
78 Input quantity
79
80 // Append the record to the file.
81 Write coffeeFile description, quantity
82
83 // Determine whether the user wants to enter
84 // another record.
85 Display "Do you want to enter another record?"
86 Display "(Enter Y for yes, or anything else for no.)"
87 Input another
88
89 // Display a blank line.
90 Display
91 End While
92
93 // Close the file.
94 Close coffeeFile
95 Display "Data appended to coffee.dat."
96 End Module
97
```

**Figure 11-10** Flowchart for the addRecord module in Program 11-6

The pseudocode for the searchRecord module follows. Figure 11-11 shows a flowchart for the searchRecord module.

**Program 11-6****Coffee inventory program (continued):  
searchRecord module**

```
98 // The searchRecord module allows the user to
99 // search for a record in the inventory file.
100 Module searchRecord()
101 // Variables for the fields
102 Declare String description
103 Declare Real quantity
104
105 // Variable to hold the search value
106 Declare String searchValue
107
108 // Flag to indicate whether the value was found
109 Declare Boolean found = False
110
111 // Declare an input file.
112 Declare InputFile coffeeFile
113
114 // Get the value to search for.
115 Display "Enter a value to search for."
116 Input searchValue
117
118 // Open the file.
119 Open coffeeFile "coffee.dat"
120
121 While NOT eof(coffeeFile)
122 // Read a record from the file.
123 Read coffeeFile description, quantity
124
125 // If the record contains the search value,
126 // then display it.
127 If contains(description, searchValue) Then
128 // Display the record.
129 Display "Description: ", description,
130 "Quantity: ", quantity, " pounds"
131
132 // Set the found flag to true.
133 Set found = True
134 End If
135 End While
136
137 // If the value was not found in the file,
138 // display a message indicating so.
139 If NOT found Then
140 Display searchValue, " was not found."
141 End If
142
143 // Close the file.
144 Close coffeeFile
145 End Module
146
```

**Figure 11-11** Flowchart for the searchRecord module in Program 11-6

The pseudocode for the `modifyRecord` module follows. Figures 11-12 and 11-13 show a flowchart for the `modifyRecord` module.

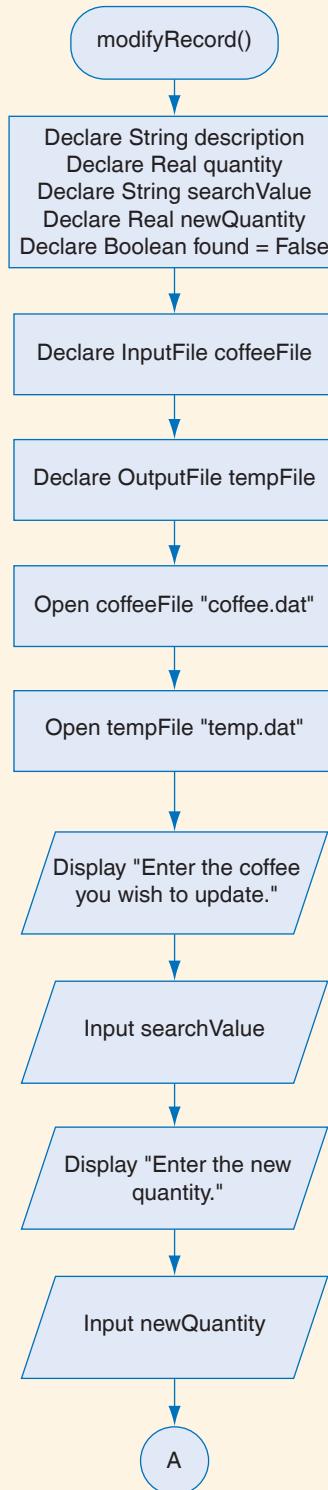
**Program 11-6****Coffee inventory program (continued):  
modifyRecord module**

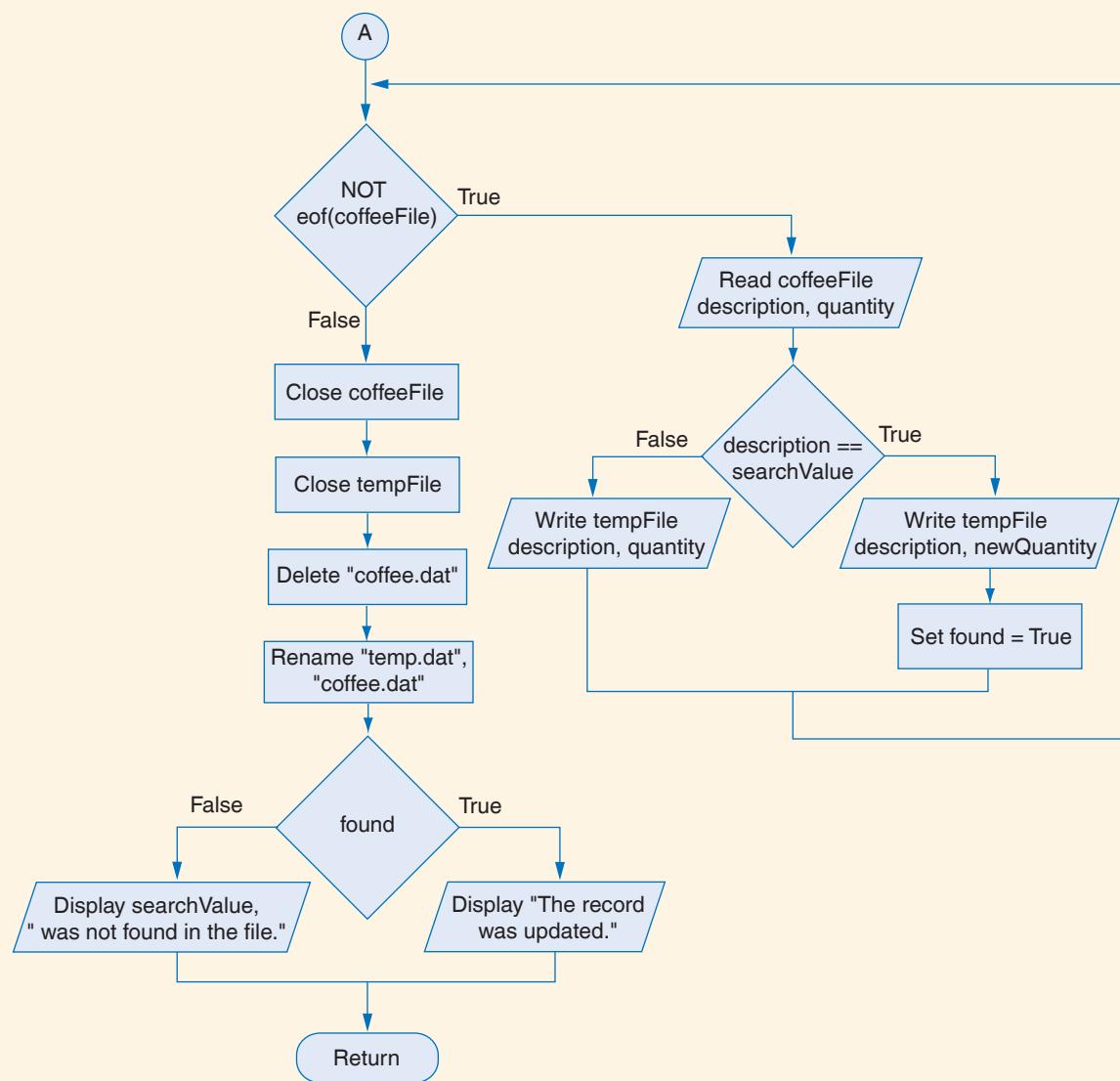
```

147 // The modifyRecord module allows the user to modify
148 // an existing record in the inventory file.
149 Module modifyRecord()
150 // Variables for the fields
151 Declare String description
152 Declare Real quantity
153
154 // Variable to hold the search value
155 Declare String searchValue
156
157 // Variable to hold the new quantity
158 Declare Real newQuantity
159
160 // Flag to indicate whether the value was found

```

```
161 Declare Boolean found = False
162 // Declare an input file.
163 Declare InputFile coffeeFile
164
165 // Declare an output file to copy the original
166 // file to.
167 Declare OutputFile tempFile
168
169 // Open the files.
170 Open coffeeFile "coffee.dat"
171 Open tempFile "temp.dat"
172
173 // Get the value to search for.
174 Display "Enter the coffee you wish to update."
175 Input searchValue
176
177 // Get the new quantity.
178 Display "Enter the new quantity."
179 Input newQuantity
180
181 While NOT eof(coffeeFile)
182 // Read a record from the file.
183 Read coffeeFile description, quantity
184
185 // Write either this record to the temporary
186 // file, or the new record if this is the
187 // one that is to be changed.
188 If description == searchValue Then
189 Write tempFile description, newQuantity
190 Set found = True
191 Else
192 Write tempFile description, quantity
193 End If
194 End While
195
196 // Close the two files.
197 Close coffeeFile
198 Close tempFile
199
200 // Delete the original file.
201 Delete "coffee.dat"
202
203 // Rename the temporary file.
204 Rename "temp.dat", "coffee.dat"
205
206 // Indicate whether the operation was successful.
207 If found Then
208 Display "The record was updated."
209 Else
210 Display searchValue, "was not found in the file."
211 End If
212
213 End Module
214
```

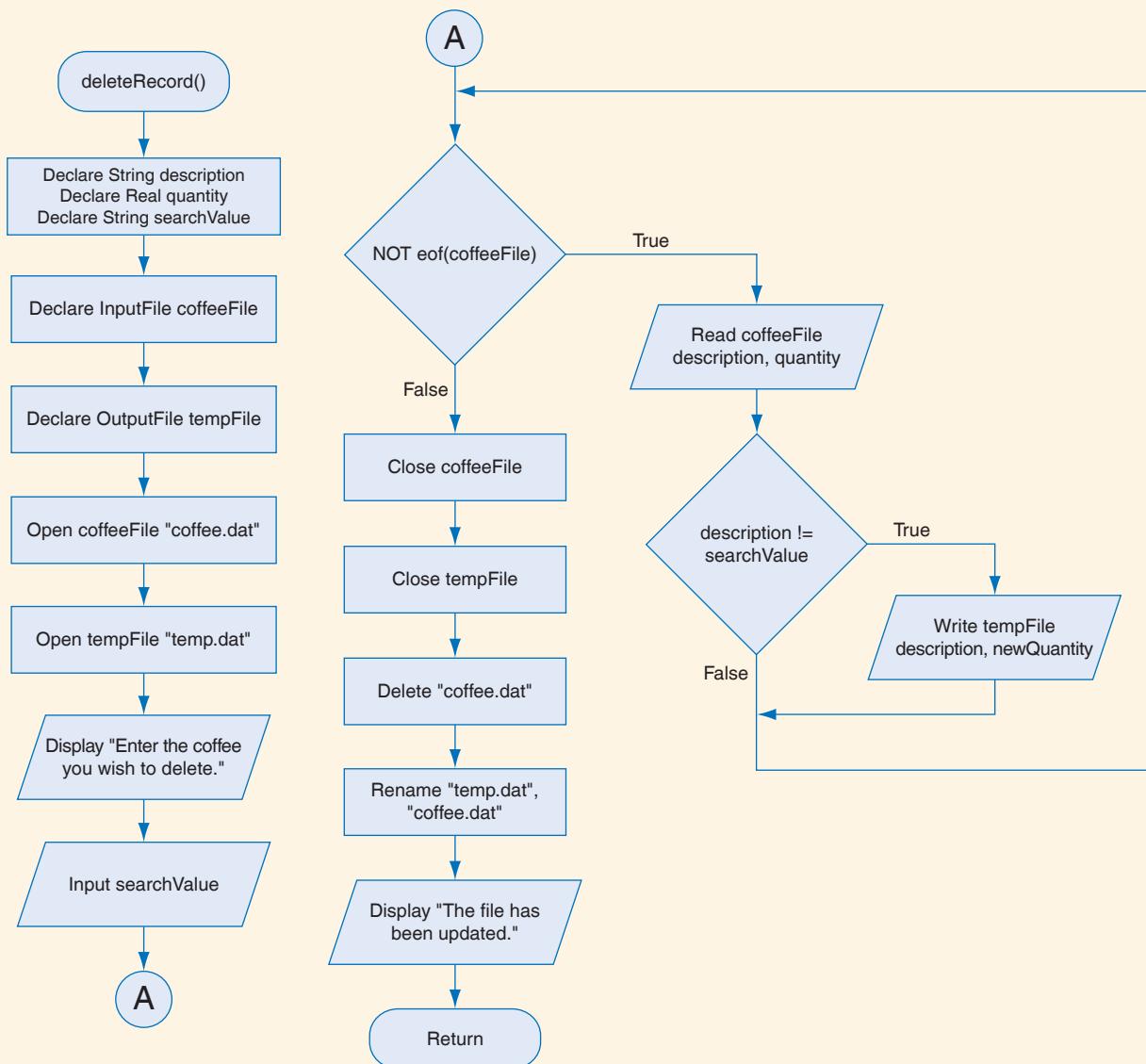
**Figure 11-12** First part of the flowchart for the modifyRecord module in Program 11-6

**Figure 11-13** Second part of the flowchart for the modifyRecord module in Program 11-6

The pseudocode for the `deleteRecord` module follows. Figure 11-14 shows a flowchart for the `deleteRecord` module.

**Program 11-6****Coffee inventory program (continued):  
deleteRecord module**

```
215 // The deleteRecord module allows the user to delete
216 // a record from the inventory file.
217 Module deleteRecord()
218 // Variables for the fields
219 Declare String description
220 Declare Real quantity
221
222 // Variable to hold the search value
223 Declare String searchValue
224
225 // Declare an input file.
226 Declare InputFile coffeeFile
227
228 // Declare an output file to copy the original
229 // file to.
230 Declare OutputFile tempFile
231
232 // Open the files.
233 Open coffeeFile "coffee.dat"
234 Open tempFile "temp.dat"
235
236 // Get the value to search for.
237 Display "Enter the coffee you wish to delete."
238 Input searchValue
239
240 While NOT eof(coffeeFile)
241 // Read a record from the file.
242 Read coffeeFile description, quantity
243
244 // If this is not the record to delete, then
245 // write it to the temporary file.
246 If description != searchValue Then
247 Write tempFile description, newQuantity
248 End If
249 End While
250
251 // Close the two files.
252 Close coffeeFile
253 Close tempFile
254
255 // Delete the original file.
256 Delete "coffee.dat"
257
258 // Rename the temporary file.
259 Rename "temp.dat", "coffee.dat"
260
261 Display "The file has been updated."
262 End Module
263
```

**Figure 11-14** Flowchart for the deleteRecord module in Program 11-6

The pseudocode for the displayRecords module follows. Figure 11-15 shows a flowchart for the displayRecords module.

**Program 11-6****Coffee inventory program (continued):  
displayRecords module**

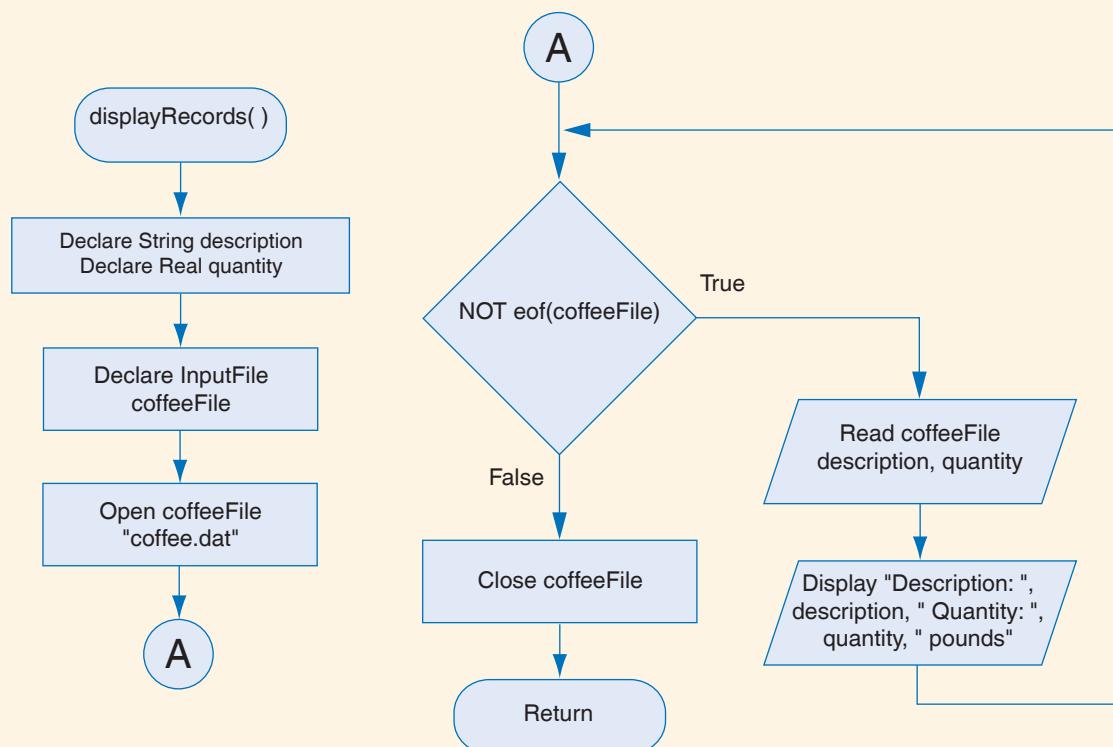
```

264 // The displayRecords module displays all
265 // of the records in the inventory file.
266 Module displayRecords()

```

```
267 // Variables for the fields
268 Declare String description
269 Declare Real quantity
270
271 // Declare an input file.
272 Declare InputFile coffeeFile
273
274 // Open the file.
275 Open coffeeFile "coffee.dat"
276
277 While NOT eof(coffeeFile)
278 // Read a record from the file.
279 Read coffeeFile description, quantity
280
281 // Display the record.
282 Display "Description: ", description,
283 "Quantity: ", quantity, " pounds"
284 End While
285
286 // Close the file.
287 Close coffeeFile
288 End Module
```

**Figure 11-15** Flowchart for the displayRecords module in Program 11-6





## Checkpoint

- 11.4 Explain why most menu-driven programs use a loop to redisplay the menu after the user's selected action has been performed.
- 11.5 If a program uses a loop to display a menu repeatedly, how does the user end the program?

### 11.4

## Multiple-Level Menus

**CONCEPT:** A multiple-level menu has a main menu and one or more submenus.

The programs that you have seen in this chapter are simple enough that all of their menu selections fit nicely in a single menu. When the user selects an operation from the menu, the program immediately performs that operation and then the program redispairs the menu (or the program ends if it does not use a loop to redisplay the menu). This type of menu system is called a *single-level menu*.

Often, programs are more complex and one menu isn't sufficient. For example, suppose you are designing a program that a business can use to perform the following operations:

1. Process a sale
2. Process a return
3. Add a record to the inventory file
4. Search for a record in the inventory file
5. Modify a record in the inventory file
6. Delete a record in the inventory file
7. Print an inventory list report
8. Print a list of inventory items by cost
9. Print a list of inventory items by age
10. Print a list of inventory items by retail value

Because there are so many items in this list, you probably shouldn't display them all in one menu. Users often have trouble sorting through the items in a menu when given too many choices.

A better approach is to use a multiple-level menu. A program that uses a *multiple-level menu* typically displays a *main menu* when the program starts, showing only a few items, and then displays smaller *submenus* when the user makes a selection. For example, the main menu might appear as follows:

- Main Menu
1. Process a Sale or a Return
  2. Update the Inventory File
  3. Print an Inventory Report
  4. Exit the Program

When the user selects item 1 from the main menu, the following submenu would appear:

- Sales and Returns Menu
1. Process a Sale
  2. Process a Return
  3. Go Back to the Main Menu

When the user selects item 2 from the main menu, the following submenu would appear:

- Update Inventory File Menu
1. Add a Record
  2. Search for a Record
  3. Modify a Record
  4. Delete a Record
  5. Go Back to the Main Menu

When the user selects item 3 from the main menu, the following submenu would appear:

- Inventory Report Menu
1. Print an inventory list report
  2. Print a list of inventory items by cost
  3. Print a list of inventory items by age
  4. Print a list of inventory items by retail value
  5. Go Back to the Main Menu

Let's take a look at how the logic for this program might be designed. (We won't look at all of the modules in the program, but we will examine the ones involved in producing the menus and responding to the user's menu selections.) Figure 11-16 shows how the `main` module might be designed. First, a module named `displayMainMenu` is called. The purpose of that module is to display the main menu and get the user's selection. Next, the case structure calls the following modules:

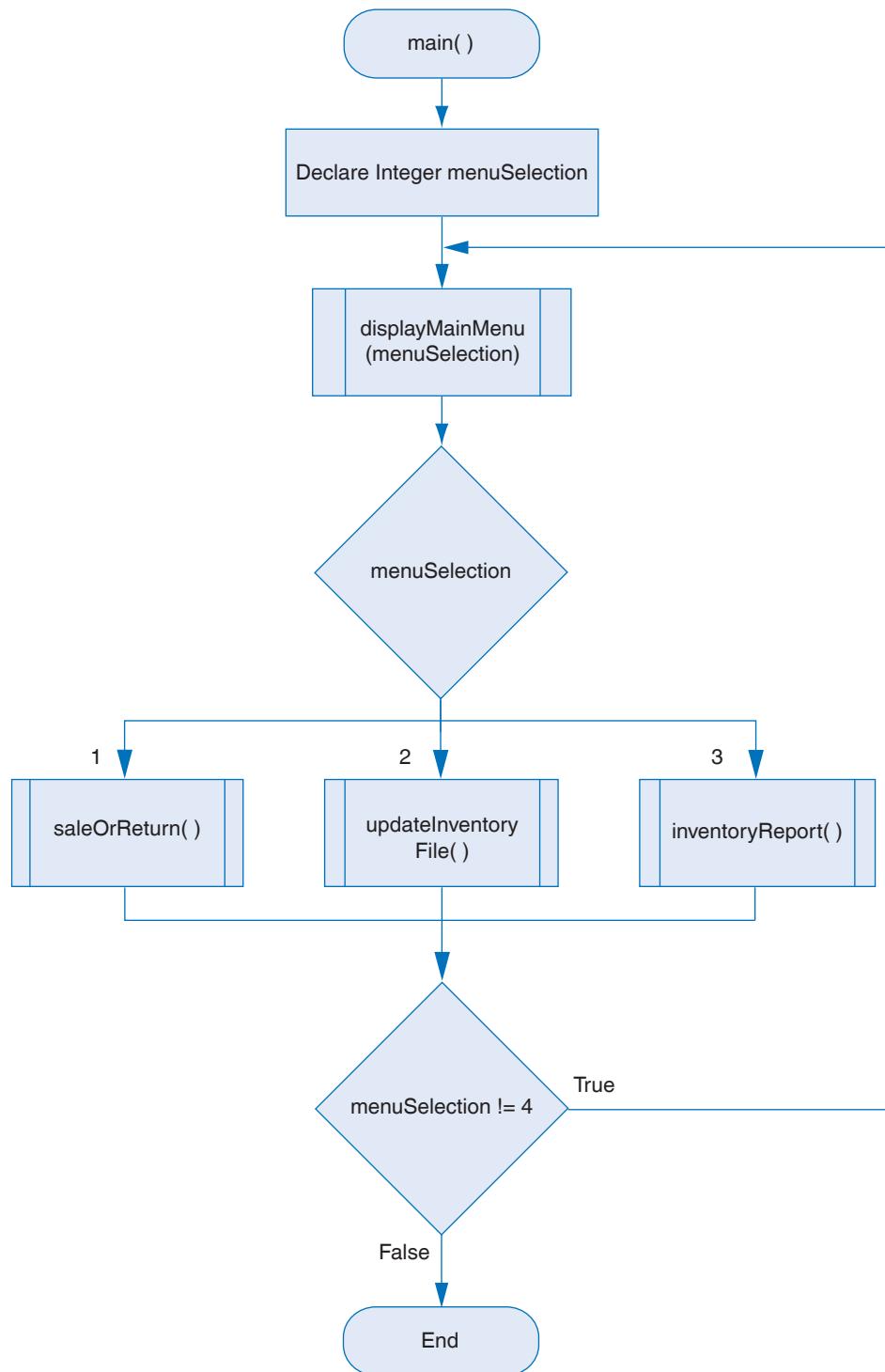
- `saleOrReturn` if the user selected menu item 1
- `updateInventory` if the user selected menu item 2
- `inventoryReport` if the user selected menu item 3

If the user selects item 4, Exit the Program, the program ends.

Figure 11-17 shows the logic for the `saleOrReturn` module. First, a module named `displaySaleOrReturnMenu` is called. The purpose of that module is to display the Sales and Returns menu and get the user's selection. The case structure calls the following modules:

- `processSale` if the user selected menu item 1
- `processReturn` if the user selected menu item 2

If the user selects item 3, Go Back to the Main Menu, the program returns to the `main` module and the main menu is displayed again.

**Figure 11-16** Logic for the main module

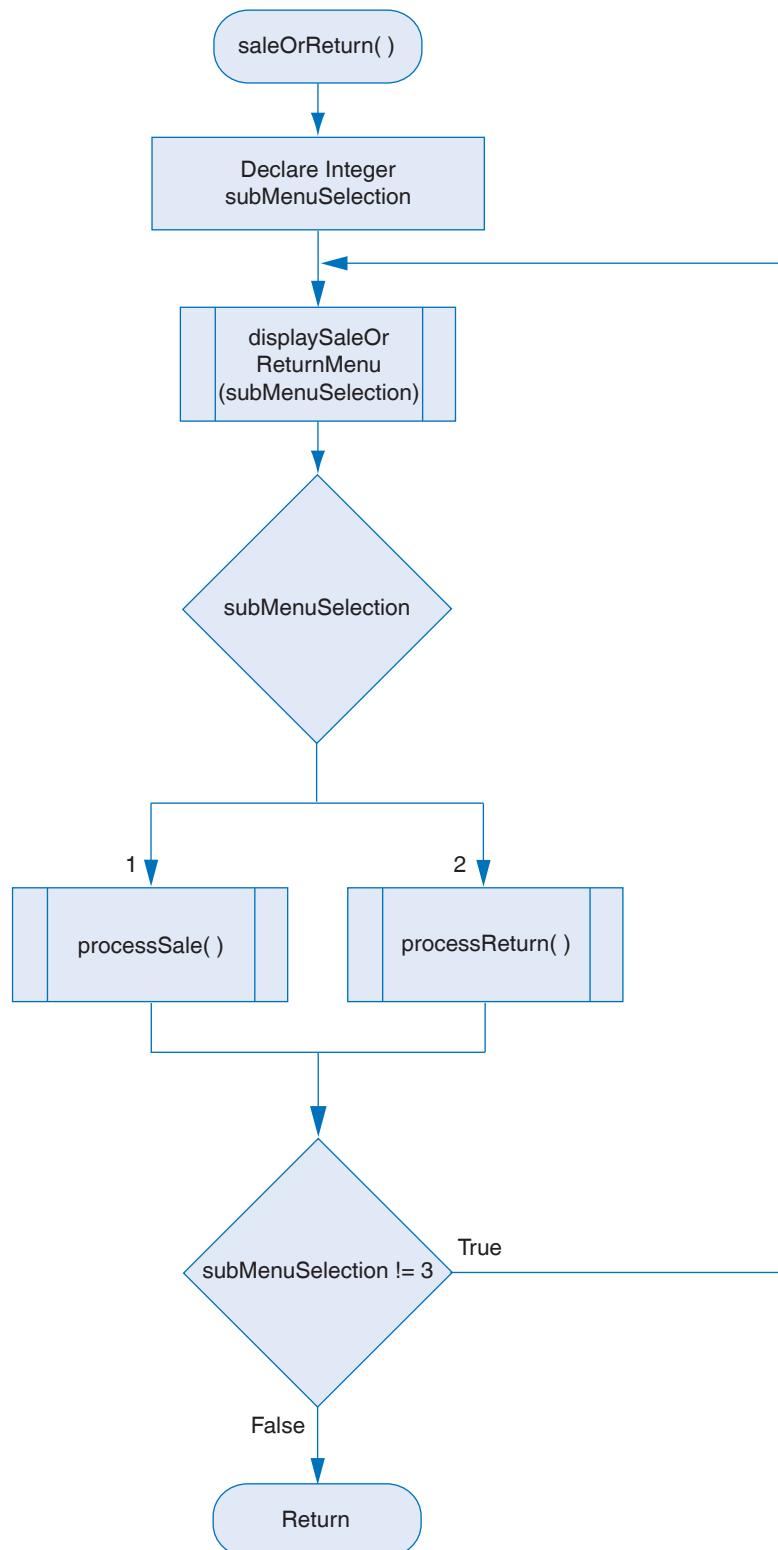
**Figure 11-17** Logic for the saleOrReturn module

Figure 11-18 shows the logic for the `updateInventory` module. First, a module named `displayUpdateInventoryMenu` is called. The purpose of that module is to display the Update Inventory File menu and get the user's selection. The case structure calls the following modules:

- `addRecord` if the user selected menu item 1
- `searchRecord` if the user selected menu item 2
- `modifyRecord` if the user selected menu item 3
- `deleteRecord` if the user selected menu item 4

If the user selects item 5, Go Back to the Main Menu, the program returns to the `main` module and the main menu is displayed again.

**Figure 11-18** Logic for the `updateInventory` module

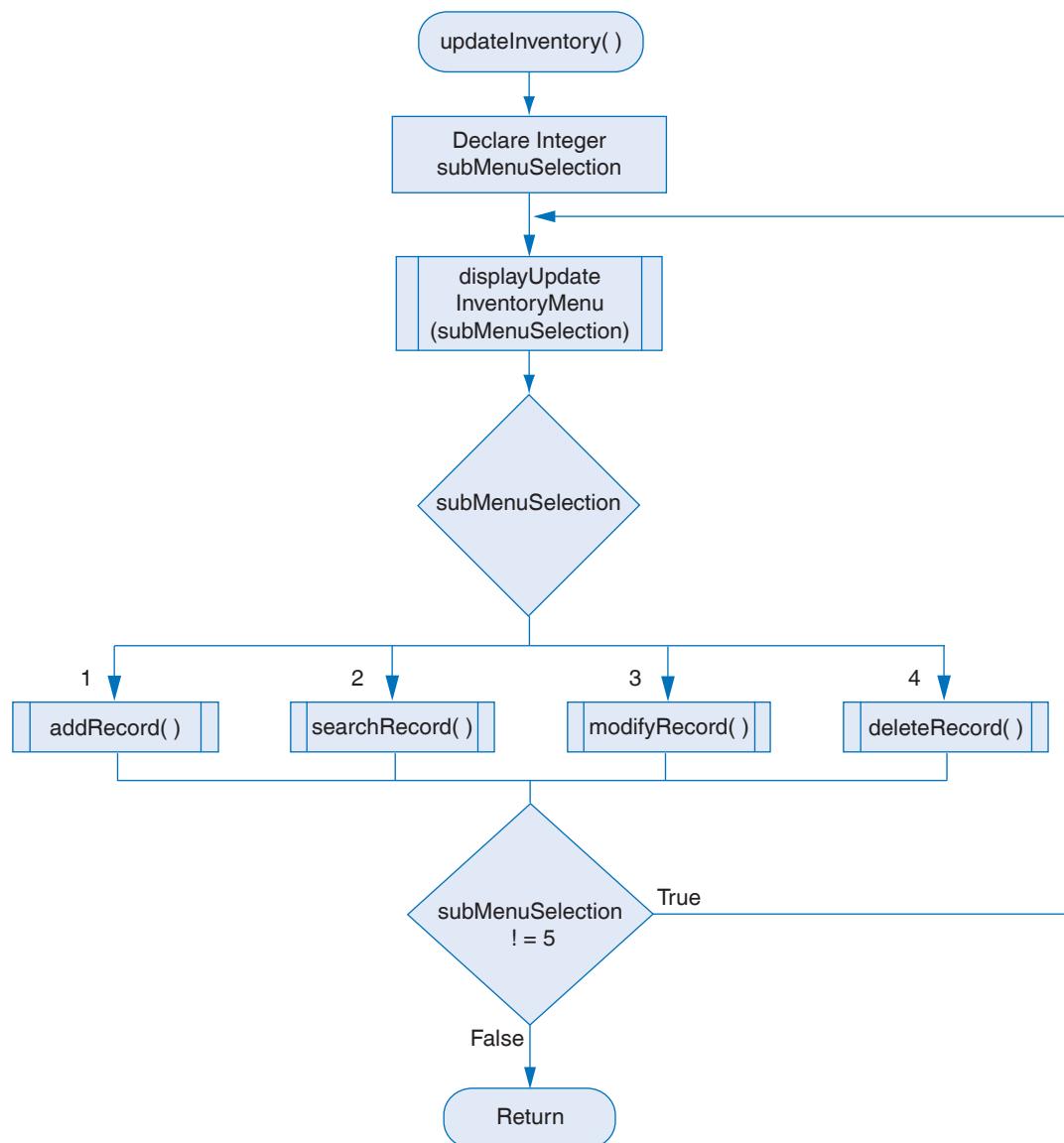
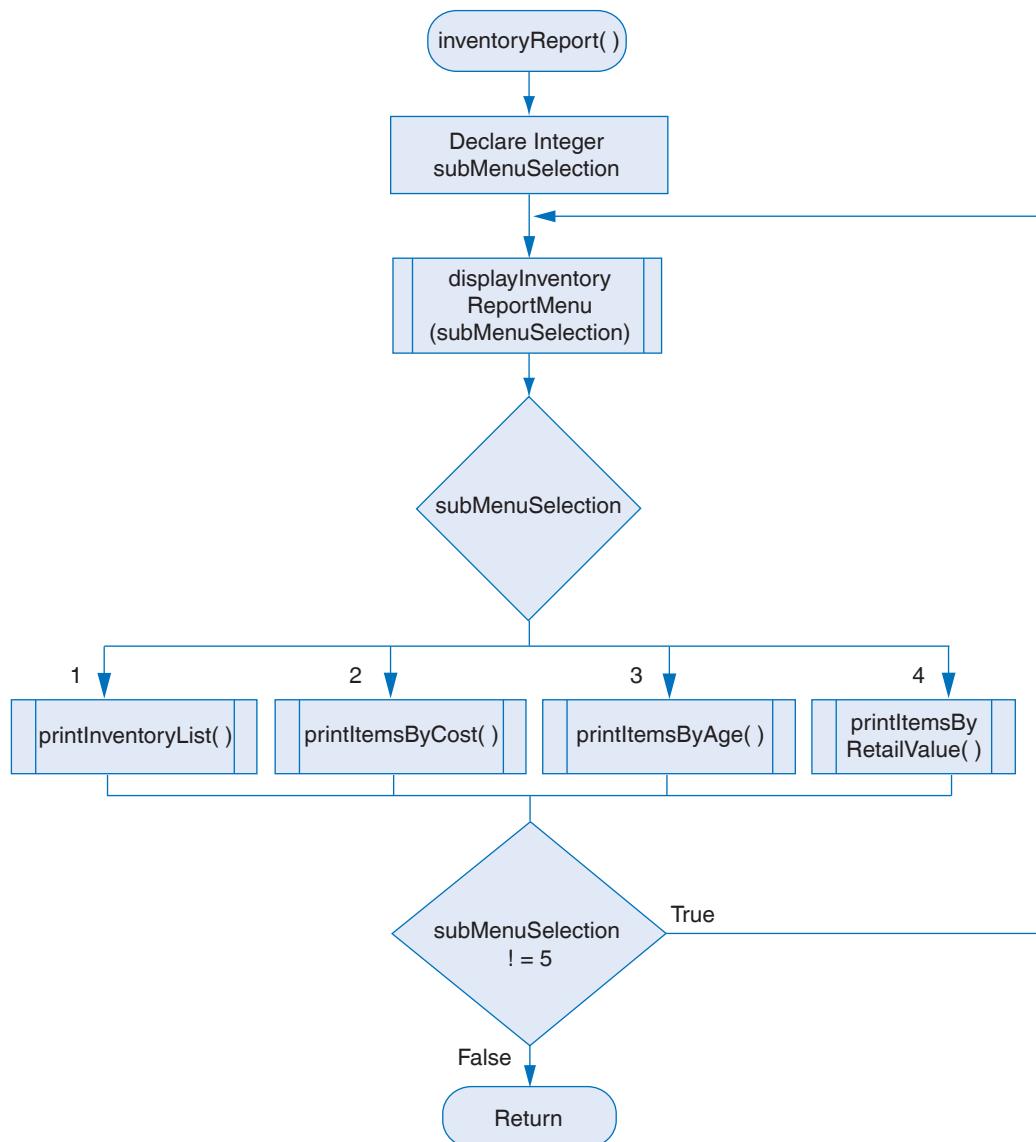


Figure 11-19 shows the logic for the `inventoryReport` module. First, a module named `displayInventoryReportMenu` is called. The purpose of that module is to display the Inventory Report menu and get the user's selection. The case structure calls the following modules:

- `printInventoryList` if the user selected menu item 1
- `printItemsByCost` if the user selected menu item 2
- `printItemsByAge` if the user selected menu item 3
- `printItemsByRetailValue` if the user selected menu item 4

If the user selects item 5, Go Back to the Main Menu, the program returns to the `main` module and the main menu is displayed again.

**Figure 11-19** Logic for the `inventoryReport` module



**Checkpoint**

- 11.6 What is a single-level menu?
- 11.7 What is a multiple-level menu?
- 11.8 When a program has a lot of items for the user to select from, why should you avoid displaying all of the items in one menu?

**11.5****Focus on Languages: Java, Python, and C++**

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

**Java**

There are no new language features introduced in the chapter, so here we will simply show you a Java program that is menu-driven. Program 11-7 is the Java version of the pseudocode Program 11-3.

**Program 11-7 (MenuDriven.java)**

```

1 import java.util.Scanner;
2
3 public class MenuDriven
4 {
5 public static void main(String[] args)
6 {
7 // Declare a variable to hold the
8 // user's menu selection.
9 int menuSelection;
10
11 // Declare variables to hold the units
12 // of measurement.
13 double inches, centimeters, feet, meters,
14 miles, kilometers;
15
16 // Create a Scanner object for keyboard input.
17 Scanner keyboard = new Scanner(System.in);
18
19 // Display the menu.
20 System.out.println("1. Convert inches to centimeters.");
21 System.out.println("2. Convert feet to meters.");

```

```
22 System.out.println("3. Convert miles to kilometers.");
23 System.out.println();
24
25 // Prompt the user for a selection
26 System.out.print("Enter your selection: ");
27 menuSelection = keyboard.nextInt();
28
29 // Validate the menu selection.
30 while (menuSelection < 1 || menuSelection > 3)
31 {
32 System.out.println("That is an invalid selection.");
33 System.out.print("Enter 1, 2, or 3: ");
34 menuSelection = keyboard.nextInt();
35 }
36
37 // Perform the selected operation.
38 switch(menuSelection)
39 {
40 case 1:
41 // Convert inches to centimeters.
42 System.out.print("Enter the number of inches: ");
43 inches = keyboard.nextDouble();
44 centimeters = inches * 2.54;
45 System.out.println("That is equal to " + centimeters +
46 " centimeters.");
47 break;
48
49 case 2:
50 // Convert feet to meters.
51 System.out.print("Enter the number of feet: ");
52 feet = keyboard.nextDouble();
53 meters = feet * 0.3048;
54 System.out.println("That is equal to " + meters +
55 " meters.");
56 break;
57
58 case 3:
59 // Convert miles to kilometers.
60 System.out.print("Enter the number of miles: ");
61 miles = keyboard.nextDouble();
62 kilometers = miles * 1.609;
63 System.out.println("That is equal to " + kilometers +
64 " kilometers.");
65 break;
66 }
67 }
68 }
```

**Program Output**

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection: 1 [Enter]  
 Enter the number of inches: 10 [Enter]  
 That is equal to 25.4 centimeters.

**Program Output**

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection: 2 [Enter]  
 Enter the number of feet: 10 [Enter]  
 That is equal to 3.048 meters.

**Program Output**

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection: 4 [Enter]  
 That is an invalid selection.  
 Enter 1, 2, or 3: 3 [Enter]  
 Enter the number of miles: 10 [Enter]  
 That is equal to 16.09 kilometers.

## Python

There are no new language features introduced in the chapter, so here we will simply show you a Python program that is menu-driven. Program 11-8 is the Python version of the pseudocode Program 11-3.

**Program 11-8** (*menu\_driven.py*)

```

1 # Display the menu.
2 print('1. Convert inches to centimeters.')
3 print('2. Convert feet to meters.')
4 print('3. Convert miles to kilometers.')
5 print()
6
7 # Prompt the user for a selection.
8 menu_selection = int(input('Enter your selection: '))
9
10 # Validate the menu selection.
11 while menu_selection < 1 or menu_selection > 3:

```

```
12 print('That is an invalid selection.')
13 menu_selection = int(input('Enter 1, 2, or 3: '))
14
15 # Perform the selected operation.
16 if menu_selection == 1:
17 # Convert inches to centimeters.
18 inches = float(input('Enter the number of inches: '))
19 centimeters = inches * 2.54
20 print('That is equal to', centimeters, 'centimeters.')
21 elif menu_selection == 2:
22 # Convert feet to meters.
23 feet = float(input('Enter the number of feet: '))
24 meters = feet * 0.3048
25 print('That is equal to', meters, 'meters.')
26 elif menu_selection == 3:
27 # Convert miles to kilometers.
28 miles = float(input('Enter the number of miles: '))
29 kilometers = miles * 1.609
30 print('That is equal to', kilometers, 'kilometers.)
```

### Program Output

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

```
Enter your selection: 1 [Enter]
Enter the number of inches: 10 [Enter]
That is equal to 25.4 centimeters.
```

### Program Output

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

```
Enter your selection: 2 [Enter]
Enter the number of feet: 10 [Enter]
That is equal to 3.048 meters.
```

### Program Output

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

```
Enter your selection: 4 [Enter]
That is an invalid selection.
Enter 1, 2, or 3: 3 [Enter]
Enter the number of miles: 10 [Enter]
That is equal to 16.09 kilometers.
```

**C++**

There are no new language features introduced in the chapter, so here we will simply show you a C++ program that is menu-driven. Program 11-9 is the C++ version of the pseudocode Program 11-3.

**Program 11-9 (MenuDriven.cpp)**

```
1 #include <iostream>
2 using namespace std;
3
4 int main()
5 {
6 // Declare a variable to hold the
7 // user's menu selection.
8 int menuSelection;
9
10 // Declare variables to hold the units
11 // of measurement.
12 double inches, centimeters, feet, meters,
13 miles, kilometers;
14
15 // Display the menu.
16 cout << "1. Convert inches to centimeters." << endl;
17 cout << "2. Convert feet to meters." << endl;
18 cout << "3. Convert miles to kilometers." << endl;
19 cout << endl;
20
21 // Prompt the user for a selection
22 cout << "Enter your selection." << endl;
23 cin >> menuSelection;
24
25 // Validate the menu selection.
26 while (menuSelection < 1 || menuSelection > 3)
27 {
28 cout << "That is an invalid selection." << endl;
29 cout << "Enter 1, 2, or 3." << endl;
30 cin >> menuSelection;
31 }
32
33 // Perform the selected operation.
34 switch(menuSelection)
35 {
36 case 1:
37 // Convert inches to centimeters.
38 cout << "Enter the number of inches." << endl;
39 cin >> inches;
40 centimeters = inches * 2.54;
41 cout << "That is equal to " << centimeters
42 << " centimeters." << endl;
43 break;
44
45 case 2:
46 // Convert feet to meters.
47 cout << "Enter the number of feet." << endl;
```

```
48 cin >> feet;
49 meters = feet * 0.3048;
50 cout << "That is equal to " << meters
51 << " meters." << endl;
52 break;
53
54 case 3:
55 // Convert miles to kilometers.
56 cout << "Enter the number of miles." << endl;
57 cin >> miles;
58 kilometers = miles * 1.609;
59 cout << "That is equal to " << kilometers
60 << " kilometers." << endl;
61 break;
62 }
63 return 0;
64 }
```

### Program Output

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

1 [Enter]

Enter the number of inches.

10 [Enter]

That is equal to 25.4 centimeters.

### Program Output

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

2 [Enter]

Enter the number of feet.

10 [Enter]

That is equal to 3.048 meters.

### Program Output

1. Convert inches to centimeters.
2. Convert feet to meters.
3. Convert miles to kilometers.

Enter your selection.

4 [Enter]

That is an invalid selection.

Enter 1, 2, or 3.

3 [Enter]

Enter the number of miles.

10 [Enter]

That is equal to 16.09 kilometers.

## Review Questions

### Multiple Choice

1. A menu is a \_\_\_\_\_.
  - a. case structure that selects an operation in a program
  - b. group of modules that perform individual tasks
  - c. list of operations displayed on the screen that the user may choose from
  - d. table of Boolean choices
2. When the user selects an item from a menu, the program must use a \_\_\_\_\_ structure to perform an action based on that selection.
  - a. repetition
  - b. sequence
  - c. menu selection
  - d. decision
3. If a menu-driven program uses a loop to redisplay the menu after a selected operation has been performed, the menu should probably have an item that the user can select to \_\_\_\_\_.
  - a. end the program
  - b. perform the same operation again
  - c. undo the previous operation
  - d. reboot the computer
4. A program that uses a multiple-level menu displays \_\_\_\_\_ when it starts.
  - a. a warning to the user
  - b. the main menu
  - c. a submenu
  - d. the grand menu
5. When the user selects an item from a multiple-level menu, \_\_\_\_\_ might be displayed next.
  - a. the main menu
  - b. a user information form
  - c. a submenu
  - d. a question asking the user whether they want to continue
6. When the user selects an operation from a \_\_\_\_\_, the program immediately performs that operation and then the program redisperslays the menu (or the program ends if it does not use a loop to redisplay the menu).
  - a. multiple-level menu
  - b. single-level menu
  - c. submenu
  - d. master menu
7. When the user selects an operation from a(n) \_\_\_\_\_, the program might display another menu.
  - a. multiple-level menu
  - b. single-level menu
  - c. submenu
  - d. interleaved menu

**True or False**

1. You cannot use nested If-Then-Else statements to perform the action selected by the user from a menu.
2. It is not usually necessary to validate the user's menu selection.
3. In most cases, a menu-driven program should be modularized.
4. If a menu-driven program does not use a loop to redisplay the menu after each operation, the user will have to rerun the program to select another operation from the menu.
5. In a single-level menu, the user might see a submenu appear when an item from the main menu is selected.

**Short Answer**

1. What type of structure do you use in a program to perform the action that the user has selected from a menu?
2. What ways for validating a user's menu selection did we discuss in this chapter?
3. How can you design a menu-driven program so that the menu is redisplayed after the selected operation has been performed?
4. What is the difference between a program that uses a single-level menu and a program that uses a multiple-level menu?
5. When a program has a lot of items for the user to select from, why should you avoid displaying all of the items on one menu?

**Algorithm Workbench**

1. Design an algorithm that displays the following menu, gets the user's selection, and validates the selection.

Main Menu

1. Open a new document.  
2. Close the current document.  
3. Print the current document.  
4. Exit the program.  
Enter your selection.
2. Design a case structure that can be used with the algorithm you designed for question 1. The case structure should call a module named `openDocument` if the user selected item 1, should call a module named `closeDocument` if the user selected item 2, and should call a module named `printDocument` if the user selected item 3.
3. Put the algorithms that you designed for questions 1 and 2 together inside a loop that redisplays the menu after the user's selected operation is performed, or exits if the user selects item 4 from the menu.
4. Look for ways to modularize the algorithm that you designed for question 3 and modify it accordingly.



VideoNote

The Language  
Translator Problem

## Programming Exercises

### 1. Language Translator

Design a program that displays the following menu:

```
Select a Language and I Will Say Good Morning
1. English
2. Italian
3. Spanish
4. German
5. End the Program
Enter your selection.
```

If the user selects item 1, the program should display “Good morning.” If the user selects item 2, the program should display “Buongiorno.” If the user selects item 3, the program should display “Buenos dias.” If the user selects item 4, the program should display “Guten morgen.” If the user selects item 5, the program should end.

### 2. University Meal Plan Selector

The university offers the following meal plans:

```
Plan 1: 7 meals per week for $560 per semester
Plan 2: 14 meals per week for $1,095 per semester
Plan 3: Unlimited meals for $1,500 per semester
```

Design a menu-driven program that allows the user to select a meal plan. The program should ask the user for the number of semesters and then display the total price for the plan.

### 3. Geometry Calculator

Write a program that displays the following menu:

```
Geometry Calculator
1. Calculate the Area of a Circle
2. Calculate the Area of a Rectangle
3. Calculate the Area of a Triangle
4. Quit
Enter your choice (1-4).
```

If the user enters 1, the program should ask for the radius of the circle and then display its area. Use the following formula to calculate the circle’s area:

$$\text{area} = \pi r^2$$

Use 3.14159 for  $\pi$  and the radius of the circle for  $r$ .

If the user enters 2, the program should ask for the length and width of the rectangle, and then display the rectangle’s area. Use the following formula to calculate the rectangle’s area:

$$\text{area} = \text{length} \times \text{width}$$

If the user enters 3, the program should ask for the length of the triangle’s base and its height, and then display its area. Use the following formula to calculate the area of the triangle:

$$\text{area} = \text{base} \times \text{height} \times .5$$

If the user enters 4, the program should end.

#### 4. Astronomy Helper

Create an application that displays the following menu:

```
Select a Planet
1. Mercury
2. Venus
3. Earth
4. Mars
5. Exit the program
Enter your selection.
```

When the user selects a planet from the menu, the program should display data about the planet's average distance from the sun, the planet's mass, and the planet's surface temperature. Use the following data in your program:

##### Mercury

|                               |                             |
|-------------------------------|-----------------------------|
| Average distance from the sun | 57.9 million kilometers     |
| Mass                          | $3.31 \times 10^{23}$ kg    |
| Surface temperature           | -173 to 430 degrees Celsius |

##### Venus

|                               |                          |
|-------------------------------|--------------------------|
| Average distance from the sun | 108.2 million kilometers |
| Mass                          | $4.87 \times 10^{24}$ kg |
| Surface temperature           | 472 degrees Celsius      |

##### Earth

|                               |                           |
|-------------------------------|---------------------------|
| Average distance from the sun | 149.6 million kilometers  |
| Mass                          | $5.967 \times 10^{24}$ kg |
| Surface temperature           | -50 to 50 degrees Celsius |

##### Mars

|                               |                            |
|-------------------------------|----------------------------|
| Average distance from the sun | 227.9 million kilometers   |
| Mass                          | $0.6424 \times 10^{24}$ kg |
| Surface temperature           | -140 to 20 degrees Celsius |

#### 5. Golf Score Modification

In Programming Exercise 6 in Chapter 10 you designed the following two programs for the Springfork Amateur Golf Club:

- (1) A program that reads each player's name and golf score as keyboard input, and then saves these as records in a file named *golf.dat*.
- (2) A program that reads the records from the *golf.dat* file and displays them.

Consolidate these programs into a single program that presents a menu, allowing the user to select the operation they want to perform.

#### 6. Phone Book Program

Design a program that you can use to keep all of your friends' names and phone numbers in a file. The program should be menu-driven and offer the following operations:

1. Add a new record
2. Search for a name.
3. Modify a phone number.
4. Delete a record.
5. Exit the program.

### 7. The Speed of Sound

The following table shows the approximate speed of sound in air, water, and steel.

| <u>Medium</u> | <u>Speed</u>           |
|---------------|------------------------|
| Air           | 1,100 feet per second  |
| Water         | 4,900 feet per second  |
| Steel         | 16,400 feet per second |

Design a program that displays a menu allowing the user to select air, water, or steel. After the user has made a selection, the program should ask the user to enter the number of seconds the sound will travel in the selected medium. The program should then display the distance the sound will travel.

**TOPICS**

12.1 Introduction

12.2 Character-by-Character Text Processing

12.3 Focus on Languages: Java, Python,  
and C++**12.1****Introduction**

Sometimes the data that a program must work with comes in the form of text. Word processors, text messaging programs, email applications, Web browsers, and spell-checkers are just a few examples of programs that work extensively with text.

The earlier chapters in this book have demonstrated some text processing techniques, such as case-sensitive and case-insensitive string comparisons, sorting strings in an array, and searching for substrings within a string. In addition, Chapter 6 introduced several library functions that perform operations on strings. For your convenience, these functions are summarized in Table 12-1.

The functions shown in Table 12-1 are very useful, but sometimes you need to operate on strings at a more detailed level. Some operations require that you access or manipulate the individual characters in a string. For example, you've probably used programs or web sites that require you to set up a password that meets certain requirements. Some systems require that passwords have a minimum length, contain at least one uppercase letter, at least one lowercase letter, and at least one numeric digit. These requirements are intended to prevent ordinary words from being used as passwords, and thus make the passwords more secure. When a new password is created, the system has to examine each of the password's characters to determine whether it meets the requirements. In the next section you will see an example of an algorithm that performs this very operation. First, however, we will discuss the process of accessing and manipulating the individual characters in a string.

**Table 12-1** Common string functions

| Function                                   | Description                                                                                                                                                                                                                                                                                                                                        |
|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>length(string)</code>                | Returns the number of characters in <i>string</i> .<br>For example, the expression <code>length("Test")</code> would return 4.                                                                                                                                                                                                                     |
| <code>append(string1, string2)</code>      | Returns a string that is created by appending <i>string2</i> to the end of <i>string1</i> .<br>For example, the expression <code>append("Hello ", "World")</code> would return the string "Hello World".                                                                                                                                           |
| <code>toUpperCase(string)</code>           | Returns a string that is an uppercase copy of <i>string</i> .<br>For example, the expression <code>toUpperCase("Test")</code> would return the string "TEST".                                                                                                                                                                                      |
| <code>toLowerCase(string)</code>           | Returns a string that is a lowercase copy of <i>string</i> .<br>For example, the expression <code>toLowerCase("TEST")</code> would return the string "test".                                                                                                                                                                                       |
| <code>substring(string, start, end)</code> | Returns a substring of <i>string</i> . The substring is the set of characters starting at the position specified by <i>start</i> and ending at the position specified by <i>end</i> . (The first character in <i>string</i> is at position 0.)<br>For example, the expression <code>substring("Kevin", 2, 4)</code> would return the string "vin". |
| <code>contains(string1, string2)</code>    | Returns True if <i>string1</i> contains <i>string2</i> . Otherwise it returns False.<br>For example, the expression <code>contains("smiley", "mile")</code> would return True, and the expression <code>contains("Smiley", "xyz")</code> would return False.                                                                                       |
| <code>stringToInteger(string)</code>       | Converts <i>string</i> to an Integer and returns that value.<br>For example, the expression <code>stringToInteger("77")</code> would return the Integer value 77.                                                                                                                                                                                  |
| <code>stringToReal(string)</code>          | Converts <i>string</i> to a Real and returns that value.<br>For example, the expression <code>stringToInteger("1.5")</code> would return the Real value 1.5.                                                                                                                                                                                       |
| <code>isInteger(string)</code>             | Returns True if <i>string</i> can be converted to an Integer, or False otherwise.<br>For example, the expression <code>isInteger("77")</code> would return True, and the expression <code>isInteger("x4yz")</code> would return False.                                                                                                             |
| <code>isReal(string)</code>                | Returns True if <i>string</i> can be converted to a Real, or False otherwise.<br>For example, the expression <code>isReal("3.2")</code> would return True, and the expression <code>isReal("x4yz")</code> would return False.                                                                                                                      |

**12.2**

## Character-by-Character Text Processing

**CONCEPT:** Some tasks require that you access and/or manipulate the individual characters that appear in a string.

Although each programming language has its own way of providing access to the individual characters in a string, many languages allow you to use subscript notation. This makes it possible to work with a string as if it were an array of characters. You use subscript 0 to access the first character, subscript 1 to access the second character, and so on. The subscript of the last character would be one less than the string's length. This is the approach that we will use in our pseudocode, as demonstrated in Program 12-1.

**Program 12-1**

```
1 // Declare and initialize a string.
2 Declare String name = "Jacob"
3
4 // Use subscript notation to display the
5 // individual characters in the string.
6 Display name[0]
7 Display name[1]
8 Display name[2]
9 Display name[3]
10 Display name[4]
```

**Program Output**

```
J
a
c
o
b
```

In line 2 we declare `name` as a `String` variable, and initialize it with the string "Jacob". The string has five characters, so we can use the subscripts 0 through 4 to access those characters, as shown in lines 6 through 10. As with arrays, an error will occur at runtime if we attempt to use an invalid subscript with a string.

Program 12-2 shows how a loop can be used to step through the characters in a string. Notice that in the `For` loop (in line 8) the `index` variable has a starting value of 0 and an ending value of `length(name) - 1`.

**Program 12-2**

```
1 // Declare and initialize a string.
2 Declare String name = "Jacob"
```

```

3
4 // Declare a variable to step through the string.
5 Declare Integer index
6
7 // Display the characters in the string.
8 For index = 0 To length(name) - 1
9 Display name[index]
10 End For

```

### Program Output

```

J
a
c
o
b

```

Program 12-3 shows an example of changing individual characters in a string. The program reads a string as input from the keyboard, and then changes each occurrence of the letter “t” to the letter “d.”

### Program 12-3



```

1 // Declare a string to hold input.
2 Declare String str
3
4 // Declare a variable to step through the string.
5 Declare Integer index
6
7 // Prompt the user to enter a sentence.
8 Display "Enter a sentence."
9 Input str
10
11 // Change each "t" to a "d".
12 For index = 0 To length(str) - 1
13 If str[index] == "t" Then
14 Set str[index] = "d"
15 End If
16 End For
17
18 // Display the modified string.
19 Display str

```

### Program Output (with Input Shown in Bold)

```

Enter a sentence.
Look at that kitty cat! [Enter]
Look ad dhad kiddy cad!

```

The programs you have seen so far in this chapter demonstrate how you can access and modify individual characters at specific locations in a string. In most programming languages, when you use a subscript or other mechanism to access an individual character position within a string, that character position must already exist or an error will occur. For example, if a string contains four characters, we cannot use subscript notation to append a fifth character to it. The following pseudocode illustrates this:

```
Declare String word = "mist" // This string has 4 characters.
Set word[4] = "y" // Error!
```

In the first statement the `word` variable is initialized with the string `"mist"`, which has four characters. The subscript of the last character is 3. The second statement attempts to assign the character `"y"` to `word[4]`, but an error will occur because that character position does not exist. If you wish to append characters to a string, you must typically use an operator or a library function that is designed for that purpose.



**WARNING!** An error will also occur if you use a subscript on an uninitialized `String` variable. Because an uninitialized variable contains no data, you cannot access or manipulate its contents.

## Character Testing Library Functions

In addition to string library functions, such as the ones shown in Table 12-1, most programming languages also provide library functions that are designed to work with single characters. Table 12-2 shows examples of commonly supported functions that test the value of a character. Note that each of the functions listed in the table returns a Boolean value of `True` or `False`.

**Table 12-2** Common character testing functions

| Function                                  | Description                                                                                                                                                              |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>isDigit(character)</code>           | Returns <code>True</code> if <code>character</code> is a numeric digit, or <code>False</code> otherwise.                                                                 |
| <code>isLetter(character)</code>          | Returns <code>True</code> if <code>character</code> is an alphabetic letter or <code>False</code> otherwise.                                                             |
| <code>isLower(character)</code>           | Returns <code>True</code> if <code>character</code> is a lowercase letter or <code>False</code> otherwise.                                                               |
| <code>isUpper(character)</code>           | Returns <code>True</code> if <code>character</code> is an uppercase letter or <code>False</code> otherwise.                                                              |
| <code>isWhiteSpace<br/>(character)</code> | Returns <code>True</code> if <code>character</code> is a whitespace character or <code>False</code> otherwise. (A whitespace character is a space, a tab, or a newline.) |

Program 12-4 shows an example using one of these functions. The program reads a string as input from the keyboard, and then counts the number of uppercase characters in that string.

### Program 12-4



```

1 // Declare a string to hold input.
2 Declare String str
3
4 // Declare a variable to step through the string.
5 Declare Integer index
6
7 // Declare an accumulator variable to keep count
8 // of the number of uppercase letters.
9 Declare Integer upperCaseCount = 0
10
11 // Prompt the user to enter a sentence.
12 Display "Enter a sentence."
13 Input str
14
15 // Count the number of uppercase letters.
16 For index = 0 To length(str) - 1
17 If isUpper(str[index]) Then
18 Set upperCaseCount = upperCaseCount + 1
19 End If
20 End For
21
22 // Display the number of uppercase characters.
23 Display "That string has ", upperCaseCount, " uppercase letters."

```

### Program Output (with Input Shown in Bold)

```

Enter a sentence.
Ms. Martinez will arrive TODAY! [Enter]
That string has 7 uppercase letters.

```

The For loop that appears in lines 16 through 20 steps through the String variable str. The If-Then statement that begins in line 17 calls the isUpper function, passing str[index] as an argument. If that character is uppercase, the function returns True and the value of upperCaseCount is incremented in line 18. After the loop finishes, upperCaseCount will contain the number of uppercase characters in str.

### In the Spotlight: Validating a Password



Many password-protected systems allow users to set up their own passwords. For increased security, systems usually require that passwords meet minimum specifications. When a user creates a password, the system must examine the password to determine whether it meets the minimum specifications. If it does not, the system rejects the password and requires the user to create another, more secure, password.

The pseudocode shown in Program 12-5 demonstrates how a password can be validated by a system that has the following requirements:

- Passwords must be at least 8 characters long.
- Passwords must contain at least one uppercase character.
- Passwords must contain at least one lowercase character.
- Passwords must contain at least one numeric digit.

The pseudocode is modularized with functions that perform much of the validation. The `main` module gets a password from the user and then calls the following functions to validate that password:

- The `length` library function is called to determine the password's length.
- The `numberUpperCase` function is called with the `password` variable passed as an argument. This function returns the number of uppercase letters in the string argument.
- The `numberLowerCase` function is called with the `password` variable passed as an argument. This function returns the number of lowercase letters in the string argument.
- The `numberDigits` function is called with the `password` variable passed as an argument. This function returns the number of numeric digits in the string argument.

Rather than presenting the entire program at once, let's first look at the `main` module and then each function separately. Here is the `main` module:

**Program 12-5****Password validation program:  
main module**

```
1 Module main()
2 // Constant for the minimum password length
3 Constant Integer MIN_LENGTH = 8
4
5 // Local variable to hold the user's password
6 Declare String password
7
8 // Display some information about the program.
9 Display "This program determines whether a password"
10 Display "meets the following requirements:"
11 Display "(1) It must be at least 8 characters long."
12 Display "(2) It must contain at least one uppercase letter."
13 Display "(3) It must contain at least one lowercase letter."
14 Display "(4) It must contain at least one numeric digit."
15 Display
16
17 // Get a password from the user.
18 Display "Enter a password."
19 Input password
20
21 // Validate the password.
22 If length(password) >= MIN_LENGTH AND
23 numberUpperCase(password) >= 1 AND
24 numberLowerCase(password) >= 1 AND
25 numberDigits(password) >= 1 Then
```

```

26 Display "The password is valid."
27 Else
28 Display "The password does not meet the requirements."
29 End If
30 End Module
31

```

Line 3 declares a constant for the minimum password length and line 6 declares a String variable named `password` to hold the user's password. Lines 9 through 15 display information on the screen informing the user of the password requirements. Lines 18 and 19 prompt the user to enter a password, which is read from the keyboard and assigned to the `password` variable.

The `If-Then-Else` statement that begins in line 22 evaluates a compound Boolean expression. In plain English the statement should be interpreted like this:

If the password's length is at least 8 and  
 the number of uppercase letters in the password is at least 1 and  
 the number of lowercase letters in the password is at least 1 and  
 the number of numeric digits in the password is at least 1, Then the password is valid.  
 Else  
 The password does not meet the requirements.

The `numberUpperCase` function is shown next:

### Program 12-5

### Password validation program (continued): numberUpperCase function

```

32 // The numberUpperCase function accepts a string
33 // argument and returns the number of uppercase
34 // letters it contains.
35 Function Integer numberUpperCase(String str)
36 // Variable to hold the number of uppercase letters
37 Declare Integer count = 0
38
39 // Variable to use stepping through str
40 Declare Integer index
41
42 // Step through str counting the number
43 // of uppercase letters.
44 For index = 0 To length(str) - 1
45 If isUpper(str[index]) Then
46 Set count = count + 1
47 End If
48 End For
49
50 // Return the number of uppercase letters.
51 Return count
52 End Function
53

```

The function accepts a string as an argument, which is passed into the parameter variable `str`. Line 37 declares an Integer variable named `count`, initialized with the value 0.

This variable will be used as an accumulator to hold the number of uppercase letters found in the parameter variable `str`. Line 40 declares another Integer variable, `index`. The `index` variable is used in the loop that begins in line 44 to step through the characters in the `str` parameter variable. The If–Then statement that begins in line 45 calls the `isUpper` library function to determine whether the character at `str[index]` is uppercase. If so, the `count` variable is incremented in line 46. After the loop has finished, the `count` variable will contain the number of uppercase letters found in the `str` parameter variable. The `count` variable's value is returned from the function in line 51.

The `numberLowerCase` function is shown next:

**Program 12-5****Password validation program (continued):  
numberLowerCase function**

```
54 // The numberLowerCase function accepts a string
55 // argument and returns the number of lowercase
56 // letters it contains.
57 Function Integer numberLowerCase(String str)
58 // Variable to hold the number of lowercase letters
59 Declare Integer count = 0
60
61 // Variable to use stepping through str
62 Declare Integer index
63
64 // Step through str counting the number
65 // of lowercase letters.
66 For index = 0 To length(str) - 1
67 If isLower(str[index]) Then
68 Set count = count + 1
69 End If
70 End For
71
72 // Return the number of lowercase letters.
73 Return count
74 End Function
75
```

This function is nearly identical to the `numberUpperCase` function, except that line 67 calls the `isLower` library function to determine whether the character at `str[index]` is lowercase. When the function ends, the statement in line 73 returns the value of the `count` variable, which contains the number of lowercase letters found in the `str` parameter variable.

The `numberDigits` function is shown next:

**Program 12-5****Password validation program (continued):  
numberDigits function**

```
76 // The numberDigits function accepts a string
77 // argument and returns the number of numeric
78 // digits it contains.
```

```
79 Function Integer numberDigits(String str)
80 // Variable to hold the number of digits
81 Declare Integer count = 0
82
83 // Variable to use stepping through str
84 Declare Integer index
85
86 // Step through str counting the number
87 // of digits.
88 For index = 0 To length(str) - 1
89 If isDigit(str[index]) Then
90 Set count = count + 1
91 End If
92 End For
93
94 // Return the number of digits.
95 Return count
96 End Function
```

This function is nearly identical to the `numberUpperCase` and `numberLowerCase` functions, except that line 89 calls the `isDigit` library function to determine whether the character at `str[index]` is a numeric digit. When the function ends, the statement in line 95 returns the value of the `count` variable, which contains the number of numeric digits found in the `str` parameter variable.

### Program Output (with Input Shown in Bold)

This program determines whether a password meets the following requirements:

- (1) It must be at least 8 characters long.
- (2) It must contain at least one uppercase letter.
- (3) It must contain at least one lowercase letter.
- (4) It must contain at least one numeric digit.

Enter a password.  
**love [Enter]**  
The password does not meet the requirements.

### Program Output (with Input Shown in Bold)

This program determines whether a password meets the following requirements:

- (1) It must be at least 8 characters long.
- (2) It must contain at least one uppercase letter.
- (3) It must contain at least one lowercase letter.
- (4) It must contain at least one numeric digit.

Enter a password.  
**ToVe679g [Enter]**  
The password is valid.

## Inserting and Deleting Characters in a String

Most programming languages provide library functions or modules for inserting and deleting characters in a string. In our pseudocode we will use the library modules described in Table 12-3 for these purposes.

**Table 12-3** String insertion and deletion modules

| Function                                        | Description                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>insert(string1, position, string2)</code> | <i>string1</i> is a String, <i>position</i> is an Integer, and <i>string2</i> is a String. The function inserts <i>string2</i> into <i>string1</i> , beginning at <i>position</i> .                                                                                                                                             |
| <code>delete(string, start, end)</code>         | <i>string</i> is a String, <i>start</i> is an Integer, and <i>end</i> is an Integer. The function deletes from <i>string</i> all of the characters beginning at the position specified by <i>start</i> , and ending at the position specified by <i>end</i> . The character at the ending position is included in the deletion. |

Here is an example of how we might use the `insert` module:

```
Declare String str = "New City"
insert(str, 4, "York ")
Display str
```

The second statement inserts the string "York " into the `str` variable, beginning at position 4. The characters that are currently in the `str` variable beginning at position 4 are moved to the right. In memory, the `str` variable is automatically expanded in size to accommodate the inserted characters. If these statements were a complete program and we ran it, we would see "New York City" displayed on the screen.

Here is an example of how we might use the `delete` module:

```
Declare String str = "I ate 1000 blueberries!"
delete(str, 8, 9)
Display str
```

The second statement deletes the characters at positions 8 through 9 in the `str` variable. The characters that previously appeared beginning at position 10 are shifted left to occupy the space left by the deleted characters. If these statements were a complete program and we ran it, we would see "I ate 10 blueberries!" displayed on the screen.

## In the Spotlight: Formatting and Unformatting Telephone Numbers



Telephone numbers in the United States are commonly formatted to appear in the following manner:

(XXX)XXX-XXXX

In the format, X represents a digit. The three digits that appear inside the parentheses are the area code. The three digits following the area code are the prefix, and the four digits after the hyphen are the line number. Here is an example:

(919)555-1212

Although the parentheses and the hyphen make the number easier for people to read, those characters are unnecessary for processing by a computer. In a computer system, a telephone number is commonly stored as an unformatted series of digits, as shown here:

9195551212

A program that works with telephone numbers usually needs to unformat numbers that have been entered by the user. This means that the parentheses and the hyphen must be removed prior to storing the number in a file or processing it in some other way. In addition, such programs need the ability to format a number so it contains the parentheses and the hyphen before displaying it on the screen or printing it on paper.

The pseudocode shown in Program 12-6 demonstrates an algorithm for unformatting telephone numbers. The `main` module prompts the user to enter a formatted telephone number. It then calls the `isValidFormat` function to determine whether the telephone number is properly formatted. If it is, it then calls the `unformat` module to remove the parentheses and the hyphen. The unformatted telephone number is then displayed. Rather than presenting the entire program at once, let's first look at the `main` module:

### Program 12-6

#### Phone number unformatting program: `main` module

```
1 Module main()
2 // Declare a variable to hold a telephone number.
3 Declare String phoneNumber
4
5 // Prompt the user to enter a telephone number.
6 Display "Enter a telephone number. The number you"
7 Display "enter should be formatted as (XXX)XXX-XXXX."
8 Input phoneNumber
9
10 // If the input is properly formatted, unformat it.
11 If isValidFormat(phoneNumber) Then
12 unformat(phoneNumber)
13 Display "The unformatted number is ", phoneNumber
14 Else
```

```
15 Display "That number is not properly formatted."
16 End If
17 End Module
18
```

Line 3 declares a `String` variable, `phoneNumber`, to hold the telephone number that the user will enter. Lines 6 through 8 prompt the user to enter a properly formatted telephone number, read it from the keyboard, and store it in the `phoneNumber` variable.

The `If-Then-Else` statement that begins in line 11 passes `phoneNumber` as an argument to the `isValidFormat` function. This function returns `True` if the argument is properly formatted, or `False` otherwise. If the function returns `True`, line 12 passes `phoneNumber` as an argument to the `unformat` function. The `unformat` function receives its argument by reference, and removes the parentheses and hyphen. Line 13 then displays the unformatted telephone number.

If the telephone number that was entered by the user was not properly formatted, the `isValidFormat` function returns `False` in line 11 and the `Display` statement in line 15 executes.

The `isValidFormat` function is shown next:

**Program 12-6****Phone number unformatting program (continued):  
`isValidFormat` function**

```
19 // The isValidFormat function accepts a string argument
20 // and determines whether it is properly formatted as
21 // a US telephone number in the following manner:
22 // (XXX)XXX-XXXX
23 // If the argument is properly formatted, the function
24 // returns True, otherwise False.
25 Function Boolean isValidFormat(str)
26 // Local variable to indicate valid format
27 Declare Boolean valid
28
29 // Determine whether str is properly formatted.
30 If length(str) == 13 AND str[0] == "(" AND
31 str[4] == ")" AND str[8] == "-" Then
32 Set valid = True
33 Else
34 Set valid = False
35 End If
36
37 // Return the value of valid.
38 Return valid
39 End Function
40
```

The function accepts a string as an argument, which is passed into the parameter variable `str`. Line 27 declares a local Boolean variable named `valid`, which will serve as a flag to indicate whether the string in `str` is properly formatted as a US telephone number.

The If-Then-Else statement that begins in line 30 evaluates a compound Boolean expression. In plain English the statement should be interpreted like this:

```
If the string's length is 13 and the character at position 0 is "(" and
the character at position 4 is ")" and the character at position 8 is "-" Then
Set valid to True.

Else
 Set valid to False.
```

After the If-Then-Else statement executes, the `valid` variable will be set to either `True` or `False` indicating whether `str` is properly formatted. The statement in line 38 returns the value of the `valid` variable.

The `unformat` module is shown next:

### Program 12-6

### Phone number unformatting program (continued): unformat module

```
41 // The unformat module accepts a string, by reference,
42 // assumed to contain a telephone number formatted in
43 // this manner: (XXX)XXX-XXXX.
44 // The module unformats the string by removing the
45 // parentheses and the hyphen.
46 Module unformat(String Ref str)
47 // First, delete the left paren at position 0.
48 delete(str, 0, 0)
49
50 // Next, delete the right paren. Because of the
51 // previous deletion it is now located at
52 // position 3.
53 delete(str, 3, 3)
54
55 // Next, delete the hyphen. Because of the
56 // previous deletions it is now located at
57 // position 6.
58 delete(str, 6, 6)
59 End Module
```

The module accepts a string argument by reference, passed into the parameter variable `str`. The module assumes that the string is properly formatted as `(XXX)XXX-XXXX`. Line 48 deletes the character at position 0, which is the “(” character. All of the remaining characters are automatically shifted left by one position to occupy the space left by the deleted character. Next, line 53 deletes the character at position 3, which is the “)” character. The characters that previously appeared beginning at position 4 are automatically shifted left to occupy the space left by the deleted character. Next, line 58 deletes the character at position 6, which is the hyphen. The characters previously appearing to the right of the hyphen are automatically moved left by one position. After this statement executes, the string in `str` will be unformatted, appearing simply as a string of digits.

**Program Output (with Input Shown in Bold)**

Enter a telephone number. The number you enter should be formatted as (XXX)XXX-XXXX.  
**(919)555-1212 [Enter]**  
The unformatted number is 9195551212

Now let's look at Program 12-7. It demonstrates an algorithm that takes an unformatted telephone number, which is a series of 10 digits, and formats it by inserting the parentheses and hyphen at the correct locations. The **main** module is shown here:

**Program 12-7****Phone number formatting program:  
main module**

```

1 Module main()
2 // Declare a variable to hold a telephone number.
3 Declare String phoneNumber
4
5 // Prompt the user to enter a telephone number.
6 Display "Enter an unformatted 10 digit telephone number."
7 Input phoneNumber
8
9 // If the input is 10 characters long, format it.
10 If length(phoneNumber) == 10 Then
11 format(phoneNumber)
12 Display "The formatted number is ", phoneNumber
13 Else
14 Display "That number is not 10 digits."
15 End If
16 End Module
17

```

Line 3 declares a **String** variable, **phoneNumber**, to hold the telephone number that the user will enter. Line 6 prompts the user to enter an unformatted 10 digit telephone number, and line 7 stores the user's input in the **phoneNumber** variable. The **If-Then** statement that begins in line 10 calls the **length** library function to determine whether the user's input is 10 characters long. If it is, the **format** function is called in line 11 with **phoneNumber** passed as an argument. The **format** function accepts its argument by reference, and inserts the parentheses and the hyphen at the proper locations so it appears in the form (XXX)XXX-XXXX. The formatted telephone number is then displayed in line 12. If the user's input is not 10 characters long, an error message is displayed in line 14.

The **format** module is shown next:

**Program 12-7****Phone number formatting program (continued):  
format module**

```

18 // The format module accepts a string, by reference,
19 // assumed to contain an unformatted 10 digit telephone
20 // number. The module formats the string in the following

```

```

21 // manner: (XXX)XXX-XXXX.
22 Module format(String Ref str)
23 // First, insert the left paren at position 0.
24 insert(str, 0, "(")
25
26 // Next, insert the right paren at position 4.
27 insert(str, 4, ")")
28
29 // Next, insert the hyphen at position 8.
30 insert(str, 8, "-")
31 End Module

```

The module accepts a string argument by reference, passed into the parameter variable `str`. Line 24 calls the `insert` library module to insert the “(” character at position 0. All of the characters in the string are automatically shifted right one space to accommodate the inserted character. Line 27 inserts the “)” character at position 4, shifting the characters that previously appeared beginning at position 4 to the right one space. Line 30 inserts the “-” character at position 8, shifting the characters that previously appeared beginning at position 8 to the right one space. After this statement executes, the string in `str` will be formatted as (XXX)XXX-XXXX.

### Program Output (with Input Shown in Bold)

```

Enter an unformatted 10 digit telephone number.
9195551212 [Enter]
The formatted number is (919)555-1212

```



### Checkpoint

- 12.1 Assume the following declaration appears in a program:

`Declare String name = "Joy"`

What would the following statement display?

`Display name[2]`

- 12.2 Assume the following declaration appears in a program:

`Declare String str = "Tiger"`

Write a statement that changes the `str` variable’s first character to “L”.

- 12.3 Design an algorithm that determines whether the first character in the `String` variable `str` is a numeric digit, and if it is, deletes that character.

- 12.4 Design an algorithm that determines whether the first character in the `String` variable `str` is uppercase, and if it is, changes that character to “0”.

- 12.5 Assume the following declaration appears in a program:

`Declare String str = "World"`

Write a statement that inserts the string "Hello " at the beginning of the `str` variable. After the statement executes, the `str` variable should contain the string "Hello World".

- 12.6 Assume the following declaration appears in a program:

```
Declare String city = "Boston"
```

Write a statement that deletes the first three characters in the `city` variable.

## 12.3

# Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

## Java

### Text Processing

#### Character Literals in Java

In Java, there is a difference between a string literal and a character literal. String literals are enclosed in double quotes, and character literals are enclosed in single quotes. For example, the following is a string literal:

```
"A"
```

And, the following is a character literal:

```
'A'
```

#### Character-by-Character Text Processing in Java

In Java, strings are immutable objects, which means that once they have been created in memory, their value cannot be changed. This limits some of the text processing that can be done with `String` variables. As an alternative to the `String` variable, Java allows you to create `StringBuilder` objects. You can store a string in a `StringBuilder` object, and it allows you to directly modify the individual characters that it contains. In this chapter, we will be working with `StringBuilder` objects.

Here is an example of how you create a `StringBuilder` object:

```
StringBuilder cityName = new StringBuilder("Charleston");
```

This statement creates a `StringBuilder` object named `cityName`. The object contains the string "Charleston". We can use this `StringBuilder` object to manipulate the individual characters of the string.

You use the `StringBuilder` method `charAt` to access a character at a specific location. For example, suppose you have the following declaration:

```
StringBuilder name = new StringBuilder("Jacob");
```

For example, the following code displays the first character in the string, which is the letter J:

```
System.out.println(name.charAt(0));
```

### **Changing the Value of a Specific Character**

The `StringBuilder` method `charAt` returns the value of a character at a specific location. If you want to change the value of a specific character, you must use the `setCharAt` method. The `setCharAt` method takes two arguments: the position of the character that you want to change, and the character that you want to change it to. The following code shows an example:

```
StringBuilder str = new StringBuilder("ticket");
str.setCharAt(0, 'p');
System.out.println(str);
```

This code will display:

picket

### **Character Testing Methods**

Java provides methods that are similar to the character testing library functions shown in Table 12-2. The Java methods that are similar to those functions are shown here, in Table 12-4.

**Table 12-4** Character testing methods

| Function                                       | Description                                                                                                                                    |
|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>Character.isDigit(character)</code>      | Returns True if <code>character</code> is a numeric digit, or False otherwise.                                                                 |
| <code>Character.isLetter(character)</code>     | Returns True if <code>character</code> is an alphabetic letter or False otherwise.                                                             |
| <code>Character.isLowerCase(character)</code>  | Returns True if <code>character</code> is a lowercase letter or False otherwise.                                                               |
| <code>Character.isUpperCase(character)</code>  | Returns True if <code>character</code> is an uppercase letter or False otherwise.                                                              |
| <code>Character.isWhiteSpace(character)</code> | Returns True if <code>character</code> is a whitespace character or False otherwise. (A whitespace character is a space, a tab, or a newline.) |

### **Inserting and Deleting Characters in a `StringBuilder`**

There are `StringBuilder` methods for inserting and deleting characters in a string. These methods are similar to the library modules that are shown in Table 12-3. The `StringBuilder` methods that are similar to those functions are shown here, in Table 12-5.

**Table 12-5** **StringBuilder** insertion and deletion methods

| Function                                              | Description                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>objectName.insert<br/>(position, string)</code> | <code>objectName</code> is the name of a <code>StringBuilder</code> object, <code>position</code> is an <code>int</code> , and <code>string</code> is a <code>String</code> . The method inserts <code>string</code> into the <code>StringBuilder</code> object, beginning at <code>position</code> .                                                                                                                                                  |
| <code>objectName.delete<br/>(start, end)</code>       | <code>objectName</code> is the name of a <code>StringBuilder</code> object, <code>start</code> is an <code>int</code> , and <code>end</code> is an <code>int</code> . The method deletes from the <code>StringBuilder</code> object all of the characters beginning at the position specified by <code>start</code> , and ending at the position specified by <code>end</code> . The character at the ending position is NOT included in the deletion. |

Here is an example of how we might use the `insert` method:

```
StringBuilder str = new StringBuilder("New City");
str.insert(4, "York ");
System.out.println(str);
```

The second statement inserts the string "York " into the `StringBuilder`, beginning at position 4. The characters that are currently in the `StringBuilder` beginning at position 4 are moved to the right. In memory, the `StringBuilder` is automatically expanded in size to accommodate the inserted characters. If these statements were a complete program and we ran it, we would see New York City displayed on the screen.

Here is an example of how we might use the `delete` method:

```
StringBuilder str = new StringBuilder("I ate 1000 blueberries!");
str.delete(8, 10);
System.out.println(str);
```

The second statement deletes the characters at positions 8 through 9 in the `StringBuilder`. It should be noted that the position specified by the second argument is not included in the deletion. (This differs from the way the `delete` library module is described in your textbook.) The characters that previously appeared beginning at position 10 are shifted left to occupy the space left by the deleted characters. If these statements were a complete program and we ran it, we would see I ate 10 blueberries! displayed on the screen.

## Python

### Text Processing

#### Accessing Characters Within a String in Python

Python allows you to retrieve the individual characters in a string using subscript notation, as described earlier in this chapter. For example, the following code creates the string 'Hello', and then uses subscript notation to print the first character in the string:

```
greeting = 'Hello'
print(greeting[0])
```

Although you can use subscript notation to retrieve the individual characters in a string, you cannot use it to change the value of a character within a string. This is because strings in Python are immutable, which means that once they are created, they cannot be changed.

Because Python strings are immutable, you cannot use an expression in the form `string[index]` on the left side of an assignment operator. For example, the following code will cause an error:

```
Assign 'Bill' to friend.
friend = 'Bill'
Can we change the first character to 'J'?
friend[0] = 'J' # No, this will cause an error!
```

The last statement in this code will cause an error because it attempts to change the value of the first character in the string 'Bill'. Because strings are immutable, there are no methods for inserting and deleting characters, so we will not discuss those topics in this section.

### Character Testing Methods

Python provides string testing methods that are similar to the character testing library functions shown in Table 12-2. The Python methods that are similar to those functions are shown in Table 12-6.

**Table 12-6** Character testing methods

| Method                 | Description                                                                                                                                                                                         |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>isalnum()</code> | Returns true if the string contains only alphabetic letters or digits and is at least one character in length. Returns false otherwise.                                                             |
| <code>isalpha()</code> | Returns true if the string contains only alphabetic letters, and is at least one character in length. Returns false otherwise.                                                                      |
| <code>isdigit()</code> | Returns true if the string contains only numeric digits and is at least one character in length. Returns false otherwise.                                                                           |
| <code>islower()</code> | Returns true if all of the alphabetic letters in the string are lowercase, and the string contains at least one alphabetic letter. Returns false otherwise.                                         |
| <code>isspace()</code> | Returns true if the string contains only whitespace characters, and is at least one character in length. Returns false otherwise. (Whitespace characters are spaces, newlines (\n), and tabs (\t).) |
| <code>isupper()</code> | Returns true if all of the alphabetic letters in the string are uppercase, and the string contains at least one alphabetic letter. Returns false otherwise.                                         |

The difference between these methods and the character testing functions discussed in the textbook is that the Python functions operate on an entire string. For example, the following code determines whether all the characters in the string referenced by the `my_string` variable are uppercase:

```
my_string = "ABC"
if my_string.isupper():
 print('That string is all uppercase.')
```

This code will print the message *That string is all uppercase* because all of the characters in the string that is assigned to `my_string` are uppercase.

These methods can be applied to an individual character in a string, however. Here is an example:

```
my_string = "Abc"
if my_string[0].isupper():
 print('The first character is uppercase.')
```

This code determines whether the character at subscript 0 in `my_string` is uppercase (and, it is).

## C++

### Text Processing

#### Character Literals in C++

In C++, there is a difference between a string literal and a character literal. String literals are enclosed in double quotes, and character literals are enclosed in single quotes. For example, the following is a string literal:

```
"A"
```

And, the following is a character literal:

```
'A'
```

#### Character-by-Character Text Processing in C++

C++ allows you to work with the individual characters in a string using subscript notation, as described in the book. The following code shows an example:

```
string name = "Jacob";
cout << name[0] << endl;
cout << name[1] << endl;
cout << name[2] << endl;
cout << name[3] << endl;
cout << name[4] << endl;
```

This code displays the following:

```
J
a
c
o
b
```

The following code shows how subscript notation can be used to change a specific character in a string:

```
string str = "ticket";
str[0] = 'p';
cout << str << endl;
```

This code will display:

```
picket
```

Variables of the `string` type have a built-in `length()` function that returns the number of characters in the string. The following code shows an example. It uses a loop to step through all of the characters in a `string`.

```
string name = "Jacob";
for (index = 0; index < name.length(); index++)
 cout << name[index] << endl;
```

This code displays the following:

```
J
a
c
o
b
```

### Character Testing Functions

C++ provides functions that are similar to the character testing library functions shown in Table 12-2. The C++ functions that are similar to those functions are shown here, in Table 12-7. (To use these functions, be sure to write the `#include <cctype>` directive in your program.)

**Table 12-7** Character testing functions

| Function               | Description                                                                                                                                                                                                                       |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>isalnum()</code> | Returns true if the string contains only alphabetic letters or digits and is at least one character in length. Returns false otherwise.                                                                                           |
| <code>isalpha()</code> | Returns true if the string contains only alphabetic letters, and is at least one character in length. Returns false otherwise.                                                                                                    |
| <code>isdigit()</code> | Returns true if the string contains only numeric digits and is at least one character in length. Returns false otherwise.                                                                                                         |
| <code>islower()</code> | Returns true if all of the alphabetic letters in the string are lowercase, and the string contains at least one alphabetic letter. Returns false otherwise.                                                                       |
| <code>isspace()</code> | Returns true if the string contains only whitespace characters, and is at least one character in length. Returns false otherwise. (Whitespace characters are spaces, newlines ( <code>\n</code> ), and tabs ( <code>\t</code> ).) |
| <code>isupper()</code> | Returns true if all of the alphabetic letters in the string are uppercase, and the string contains at least one alphabetic letter. Returns false otherwise.                                                                       |

### Inserting and Deleting Characters in a `string` in C++

There are built-in `string` functions for inserting and deleting characters in a `string`. These functions are similar to the library modules that are shown in Table 12-3. The `string` functions that are similar to those functions are shown here, in Table 12-8.

**Table 12-8** string insertion and deletion functions

| Function                                          | Description                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <code>stringName.insert(position, string2)</code> | <code>stringName</code> is the name of a <code>string</code> variable, <code>position</code> is an <code>int</code> , and <code>string2</code> is a <code>string</code> . The function inserts <code>string2</code> into the <code>string</code> variable, beginning at <code>position</code> .                     |
| <code>stringName.erase(start, numChars)</code>    | <code>stringName</code> is the name of a <code>string</code> variable, <code>start</code> is an <code>int</code> , and <code>numChars</code> is an <code>int</code> . The function erases the number of characters specified by <code>numChars</code> , beginning at the position specified by <code>start</code> . |

Here is an example of how we might use the `insert` function:

```
string str = "New City";
str.insert(4, "York ");
cout << str << endl;
```

The second statement inserts the string "York " into the `string`, beginning at position 4. The characters that are currently in the `string` beginning at position 4 are moved to the right. In memory, the `string` is automatically expanded in size to accommodate the inserted characters. If these statements were a complete program and we ran it, we would see `New York City` displayed on the screen.

Here is an example of how we might use the `erase` function:

```
string str = "I ate 1000 blueberries!";
str.erase(8, 2);
cout << str << endl;
```

The second statement deletes 2 characters, beginning at position 8 in the `string`. The characters that previously appeared beginning at position 10 are shifted left to occupy the space left by the two deleted characters. If these statements were a complete program and we ran it, we would see `I ate 10 blueberries!` displayed on the screen.

## Review Questions

### Multiple Choice

1. Which pseudocode statement displays the first character in the `String` variable `str`?
  - a. `Display str[1]`
  - b. `Display str[0]`
  - c. `Display str[first]`
  - d. `Display str`
  
2. Which pseudocode statement displays the last character in the `String` variable `str`?
  - a. `Display str[-1]`
  - b. `Display str[length(str)]`
  - c. `Display str[last]`
  - d. `Display str[length(str) - 1]`

3. If the `str` variable contains the string "berry", which pseudocode statement changes its contents to "blackberry"?
  - a. `Set str[0] = "black"`
  - b. `Set str = str + "black"`
  - c. `insert(str, 0, "black")`
  - d. `insert(str, 1, "black")`
  
4. If the `str` variable contains the string "Redmond", which pseudocode statement changes its contents to "Red"?
  - a. `delete(str, 3, length(str))`
  - b. `delete(str, 3, 6)`
  - c. `Set str = str - "mond"`
  - d. `Set str[0] = "Red"`
  
5. What will the following pseudocode result in?
 

```
Declare String name = "Sall"
Set name[4] = "y"
```

  - a. An error will occur.
  - b. The variable name will contain the string "Sally".
  - c. The variable name will contain the string "Saly".
  - d. The variable name will contain the string "Sall y".

### True or False

1. When subscripts are used to specify character positions in a string, the first character's subscript is 0.
2. When subscripts are used to specify character positions in a string, the last character's subscript is the same as the string's length.
3. If the `String` variable `str` contains the string "Might", then the statement `Set str[5] = "y"` will change its contents to "Mighty".
4. The `insert` library module automatically expands the size of the string to accommodate the inserted characters.
5. The `delete` library module does not actually remove characters from a string, but replaces them with spaces.
6. The `isUpper` library function converts a character to uppercase, and the `isLower` library function converts a character to lowercase.
7. An error will occur if you use a subscript on an empty `String` variable.

### Short Answer

1. When using subscript notation to specify a character position in a string, what are the subscripts of the first and last characters?
2. If the following pseudocode were an actual program, what would it display?
 

```
Declare String greeting = "Happy"
insert(greeting, 0, "Birthday")
Display greeting
```

3. If the following pseudocode were an actual program, what would it display?

```
Declare String str = "Yada yada yada"
delete(str, 4, 9)
Display str
```

4. If the following pseudocode were an actual program, what would it display?

```
Declare String str = "AaBbCcDd"
Declare Integer index
For Index = 0 To length(str) - 1
 If isLower(str[index]) Then
 Set str[index] = "-"
 End If
End For
Display str
```

5. If the following pseudocode were an actual program, what would it display?

```
Declare String str = "AaBbCcDd"
delete(str, 0, 0)
delete(str, 3, 3)
delete(str, 3, 3)
Display str
```

### Algorithm Workbench

1. Design an algorithm that counts the number of digits that appear in the **String** variable **str**.
2. Design an algorithm that counts the number of lowercase characters that appear in the **String** variable **str**.
3. Design an algorithm that counts the number of uppercase characters that appear in the **String** variable **str**.
4. Design an algorithm that deletes the first and last characters in the **String** variable **str**.
5. Design an algorithm that converts each occurrence of the character “t” in the **String** variable **str** to uppercase.
6. Design an algorithm that replaces each occurrence of the character “x” in the **String** variable **str** with a space.
7. Assume the following declaration exists in a program:  
`Declare String str = "Mr. Bean"`  
Design an algorithm that replaces “Mr.” with “Mister” in the variable.

### Debugging Exercises

1. What is wrong with the following pseudocode?

```
// This program assigns a character to the first element in
// a string.
Declare String letters
Set letters[0] = "A"
Display "The first letter of the alphabet is ", letters
```

2. What is wrong with the following pseudocode?

```
// This program determines whether the user's input is a single
// digit.
Declare Integer digit

// Get the input from the user.
Display "Enter a single digit."
Input digit

// Determine if the input is a single digit.
If isDigit(digit[0]) AND length(digit) == 1 Then
 Display digit, " is a single digit."
Else
 Display digit, " is NOT a single digit."
End If
```

3. Why doesn't the following pseudocode perform as indicated in the comments?

```
// This program counts the characters in a string.
Declare String word
Declare Integer index
Declare Integer letters = 0

// Get the input from the user.
Display "Enter a word."
Input word

// Count the characters in the string.
For index = 0 To length(word)
 Set count = count + 1
End For

Display "That word contains ", count, " characters."
```



VideoNote  
The Backward  
String Problem

## Programming Exercises

### 1. Backward String

Design a program that prompts the user to enter a string and then displays the string contents backward. For instance, if the user enters “gravity” the program should display “ytivarg.”

### 2. Sentence Capitalizer

Design a program that prompts the user to enter a string containing multiple sentences, and then displays the string with the first character of each sentence capitalized. For instance, if the user enters “hello. my name is Joe. what is your name?” the program should display “Hello. My name is Joe. What is your name?” (*Hint:* The `toUpperCase` library function can be used to convert a single character to uppercase.)

### 3. Vowels and Consonants

Design a program that prompts the user to enter a string. The program should then display the number of vowels and the number of consonants in the string.

#### 4. Sum of Digits in a String

Design a program that asks the user to enter a string containing a series of single digit numbers with nothing separating them. The program should display the sum of all the single digit numbers in the string. For example, if the user enters 2514, the method should return 12, which is the sum of 2, 5, 1, and 4. (*Hint:* The `stringToInteger` library function can be used to convert a single character to an integer.)

#### 5. Most Frequent Character

Design a program that prompts the user to enter a string, and displays the character that appears most frequently in the string.

#### 6. Alphabetic Telephone Number Translator

Many companies use telephone numbers like 555-GET-FOOD so the number is easier for their customers to remember. On a standard telephone, the alphabetic letters are mapped to numbers in the following fashion:

A, B, and C = 2  
D, E, and F = 3  
G, H, and I = 4  
J, K, and L = 5  
M, N, and O = 6  
P, Q, R, and S = 7  
T, U, and V = 8  
W, X, Y, and Z = 9

Design a program that asks the user to enter a 10-character telephone number in the format XXX-XXX-XXXX. The program should display the telephone number with any alphabetic characters that appeared in the original translated to their numeric equivalent. For example, if the user enters 555-GET-FOOD the program should display 555-438-3663.

#### 7. Word Separator

Design a program that accepts as input a sentence in which all of the words are run together, but the first character of each word is uppercase. Convert the sentence to a string in which the words are separated by spaces and only the first word starts with an uppercase letter. For example, the string “StopAndSmellTheRoses.” would be converted to “Stop and smell the roses.” (*Hint:* The `toLower` library function can be used to convert a single character to lowercase.)

#### 8. Pig Latin

Design a program that reads a sentence as input and converts each word to “Pig Latin.” In one version of Pig Latin you convert a word by removing the first letter, placing that letter at the end of the word, and then appending “ay” to the word. Here is an example:

English:      I SLEPT MOST OF THE NIGHT

Pig Latin:     IAY LEPTSAY OSTMAY FOAY HETAY IGHTNAY

#### 9. Morse Code Converter

Design a program that asks the user to enter a string, and then converts that string to Morse code. Morse code is a code where each letter of the English alpha-

bet, each digit, and various punctuation characters are represented by a series of dots and dashes. Table 12-9 shows part of the code.

**Table 12-9** Morse code

| Character | Code         | Character | Code   | Character | Code   | Character | Code  |
|-----------|--------------|-----------|--------|-----------|--------|-----------|-------|
| space     | <i>space</i> | 6         | -..... | G         | ---    | Q         | -...- |
| comma     | -....-       | 7         | -....- | H         | ...    | R         | ..-   |
| period    | .----.       | 8         | -----  | I         | ..     | S         | ...   |
| ?         | ....-        | 9         | -----  | J         | .---   | T         | -     |
| 0         | -----        | A         | .-     | K         | -..    | U         | ...-  |
| 1         | .----        | B         | -...   | L         | .-..   | V         | ....- |
| 2         | .----        | C         | -..-   | M         | --     | W         | ..--  |
| 3         | .----        | D         | -..    | N         | -.     | X         | -...- |
| 4         | .----        | E         | .      | O         | ---    | Y         | -.-.. |
| 5         | .----        | F         | ...-   | P         | .----. | Z         | -.... |

## 10. File Encryption

File encryption is the science of writing the contents of a file in a secret code. For this assignment you will design a program that opens a file and encrypts its contents. Assume the file that you are encrypting contains a list of strings.

The program should open the file and read its contents, one string at a time. As the program reads a string from the file, it substitutes each character of the string for an alternate character. It then writes the encoded string out to a second file. When the program is finished, the second file will be a version of the first file, but written in a secret code.

## 11. File Decryption Filter

Design a program that decrypts the file produced by the program in Programming Exercise 10. The decryption program should read the contents of the coded file, restore the data to its original state, and write it to another file.

## 12. Password Weakness Detector

Design a program that asks the user to enter a password, and then analyzes the password for the following weaknesses:

- Fewer than 8 characters
- Does not contain at least one uppercase letter and one lowercase letter
- Does not contain at least one numeric digit
- Does not contain at least one special character (a character that is not a letter or a numeric digit)
- Is a sequence of consecutive uppercase letters (such as ABCDE)
- Is a sequence of consecutive lowercase letters (such as abcde)
- Is a sequence of consecutive numeric digits (such as 12345)
- Is a repeating sequence of characters (such as ZZZZZ or 55555)

The program should display messages indicating whether any of these weaknesses are found in the password.

**TOPICS**

- 13.1 Introduction to Recursion
- 13.2 Problem Solving with Recursion

- 13.3 Examples of Recursive Algorithms
- 13.4 Focus on Languages: Java, Python, and C++

**13.1****Introduction to Recursion**

**CONCEPT:** A recursive module is a module that calls itself.

You have seen instances of modules calling other modules. In a program, the `main` module might call module A, which then might call module B. It's also possible for a module to call itself. A module that calls itself is known as a *recursive module*. For example, look at the `message` module shown in Program 13-1.

**Program 13-1**

```
1 Module main()
2 Call message()
3 End Module
4
5 Module message()
6 Display "This is a recursive module."
7 Call message()
8 End Module
```

**Program Output**

This is a recursive module.  
*... and this output repeats infinitely!*

The `message` module displays the string “This is a recursive module.” and then calls itself. Each time it calls itself, the cycle is repeated. Can you see a problem with the module? There’s no way to stop the recursive calls. This module is like an infinite loop because there is no code to stop it from repeating.

Like a loop, a recursive module must have some way to control the number of times it repeats. The pseudocode in Program 13-2 shows a modified version of the `message` module. In this program, the `message` module receives an `Integer` argument that specifies the number of times the module should display the message.

### Program 13-2



```

1 Module main()
2 // By passing the argument 5 to the message module,
3 // we are telling it to display the message
4 // five times.
5 Call message(5)
6 End Module
7
8 Module message(Integer times)
9 If times > 0 Then
10 Display "This is a recursive module."
11 Call message(times - 1)
12 End If
13 End Module

```

### Program Output

```

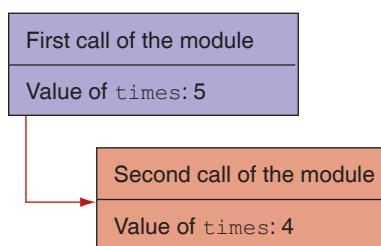
This is a recursive module.

```

The `message` module in this program contains an If-Then statement (in lines 9 through 12) that controls the repetition. As long as the `times` parameter is greater than zero, the message “This is a recursive module.” is displayed, and then the module calls itself again. Each time it calls itself, it passes `times - 1` as the argument.

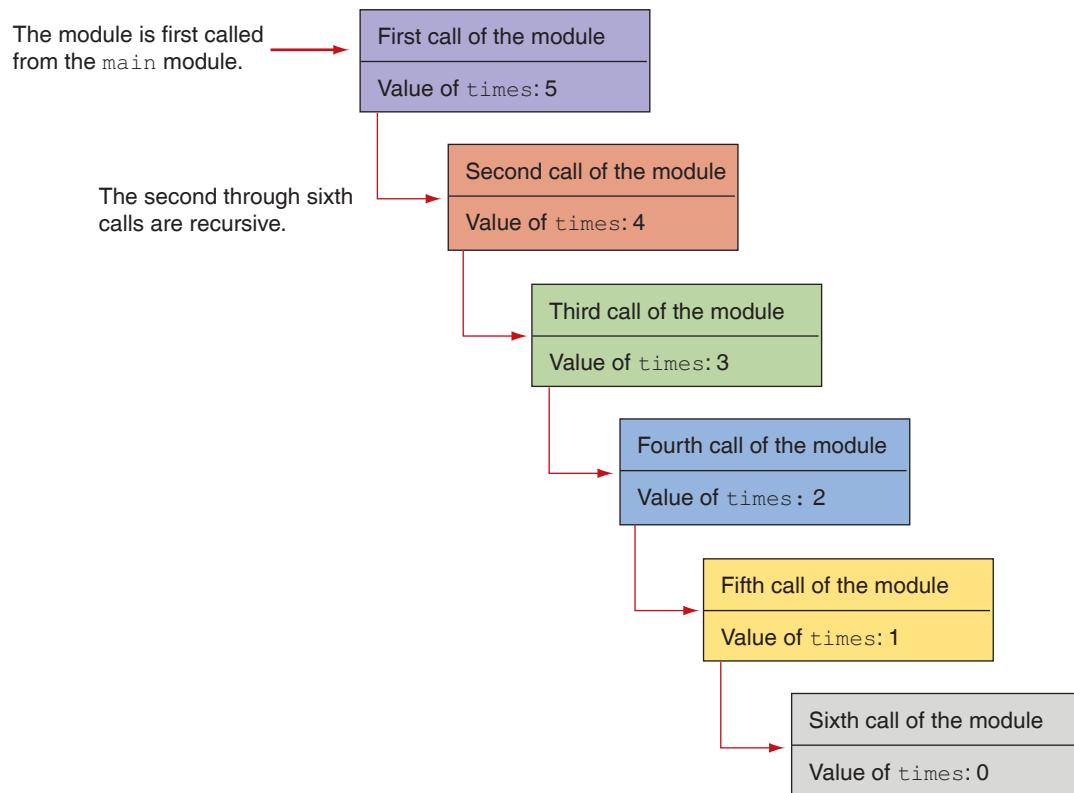
The `main` module calls the `message` module passing the argument 5. The first time the module is called, the If-Then statement displays the message and then calls itself with 4 as the argument. Figure 13-1 illustrates this.

**Figure 13-1** First two calls of the module

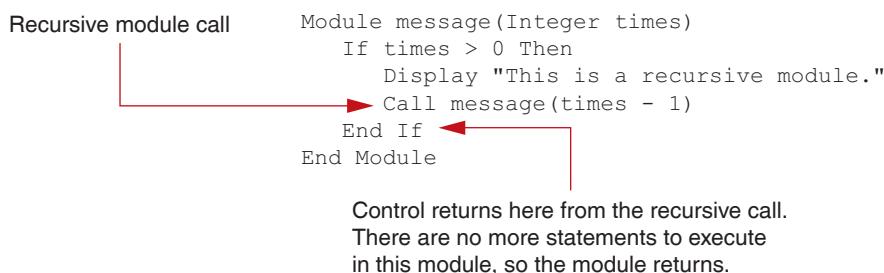


The diagram shown in Figure 13-1 illustrates two separate calls of the `message` module. Each time the module is called, a new instance of the `times` parameter is created in memory. The first time the module is called, the `times` parameter is set to 5. When the module calls itself, a new instance of the `times` parameter is created, and the value 4 is passed into it. This cycle repeats until finally zero is passed as an argument to the module. This is illustrated in Figure 13-2.

**Figure 13-2** Six calls to the `message` module



As you can see in the figure, the module is called six times. The first time it is called from the `main` module, and the other five times it calls itself. The number of times that a module calls itself is known as the *depth of recursion*. In this example, the depth of recursion is five. When the module reaches its sixth call, the `times` parameter is set to 0. At that point, the If-Then statement's conditional expression is false, so the module returns. Control of the program returns from the sixth instance of the module to the point in the fifth instance directly after the recursive module call. This is illustrated in Figure 13-3.

**Figure 13-3** Control returns to the point after the recursive module call

Because there are no more statements to be executed after the module call, the fifth instance of the module returns control of the program back to the fourth instance. This repeats until all instances of the module return.

## 13.2

## Problem Solving with Recursion

**CONCEPT:** A problem can be solved with recursion if it can be broken down into successive smaller problems that are identical to the overall problem.

The pseudocode shown in Program 13-2 demonstrates the mechanics of a recursive module. Recursion can be a powerful tool for solving repetitive problems and is commonly studied in upper-level computer science courses. It may not yet be clear to you how to use recursion to solve a problem.

First, note that recursion is never required to solve a problem. Any problem that can be solved recursively can also be solved with a loop. In fact, recursive algorithms are usually less efficient than loops. This is because the process of calling a module requires several actions to be performed by the computer. These actions include allocating memory for parameters and local variables, and storing the address of the program location where control returns after the module terminates. These actions, which are sometimes referred to as *overhead*, take place with each module call. Such overhead is not necessary with a loop.

Some repetitive problems, however, are more easily solved with recursion than with a loop. Where a loop might result in faster execution time, the programmer might be able to design a recursive algorithm faster. In general, a recursive module works as follows:

- If the problem can be solved now, without recursion, then the module solves it and returns.
- If the problem cannot be solved now, then the module reduces it to a smaller but similar problem and calls itself to solve the smaller problem.

In order to apply this approach, first, we identify at least one case in which the problem can be solved without recursion. This is known as the *base case*. Second, we determine a way to solve the problem in all other circumstances using recursion. This is called the *recursive case*. In the recursive case, we must always reduce the problem to a smaller version of the original problem. By reducing the problem with each recursive call, the base case will eventually be reached and the recursion will stop.

## Using Recursion to Calculate the Factorial of a Number

The previous examples demonstrated recursive modules. Most programming languages also allow you to create recursive functions. Let's take an example from mathematics to examine an application of recursive functions. In mathematics, the notation  $n!$  represents the factorial of the number  $n$ . The factorial of a nonnegative number can be defined by the following rules:

If  $n = 0$  then  $n! = 1$   
If  $n > 0$  then  $n! = 1 \times 2 \times 3 \times \dots \times n$

Let's replace the notation  $n!$  with  $\text{factorial}(n)$ , which looks a bit more like computer code, and rewrite these rules as follows:

If  $n = 0$  then  $\text{factorial}(n) = 1$   
If  $n > 0$  then  $\text{factorial}(n) = 1 \times 2 \times 3 \times \dots \times n$

These rules state that when  $n$  is 0, its factorial is 1. When  $n$  is greater than 0, its factorial is the product of all the positive integers from 1 up to  $n$ . For instance,  $\text{factorial}(6)$  is calculated as  $1 \times 2 \times 3 \times 4 \times 5 \times 6$ .

When designing a recursive algorithm to calculate the factorial of any number, first we identify the base case, which is the part of the calculation that we can solve without recursion. That is the case where  $n$  is equal to 0 as follows:

If  $n = 0$  then  $\text{factorial}(n) = 1$

This tells how to solve the problem when  $n$  is equal to 0, but what do we do when  $n$  is greater than 0? That is the recursive case, or the part of the problem that we use recursion to solve. This is how we express it:

If  $n > 0$  then  $\text{factorial}(n) = n \times \text{factorial}(n - 1)$

This states that if  $n$  is greater than 0, the factorial of  $n$  is  $n$  times the factorial of  $n - 1$ . Notice how the recursive call works on a reduced version of the problem,  $n - 1$ . So, our recursive rule for calculating the factorial of a number might look like this:

If  $n = 0$  then  $\text{factorial}(n) = 1$   
If  $n > 0$  then  $\text{factorial}(n) = n \times \text{factorial}(n - 1)$

The pseudocode in Program 13-3 shows how we might design a factorial function in a program.

**Program 13-3**

```

1 Module main()
2 // Local variable to hold a number
3 // entered by the user.
4 Declare Integer number
5
6 // Local variable to hold the
7 // factorial of the number
8 Declare Integer numFactorial
9
10 // Get a number from the user.
11 Display "Enter a nonnegative integer."
12 Input number
13
14 // Get the factorial of the number.
15 Set numFactorial = factorial(number)
16
17 // Display the factorial.
18 Display "The factorial of ", number,
19 " is ", numFactorial
20 End Module
21
22 // The factorial function uses recursion to
23 // calculate the factorial of its argument,
24 // which is assumed to be nonnegative.
25 Function Integer factorial(Integer n)
26 If n == 0 Then
27 Return 1
28 Else
29 Return n * factorial(n - 1)
30 End If
31 End Function

```

**Program Output (with Input Shown in Bold)**

```

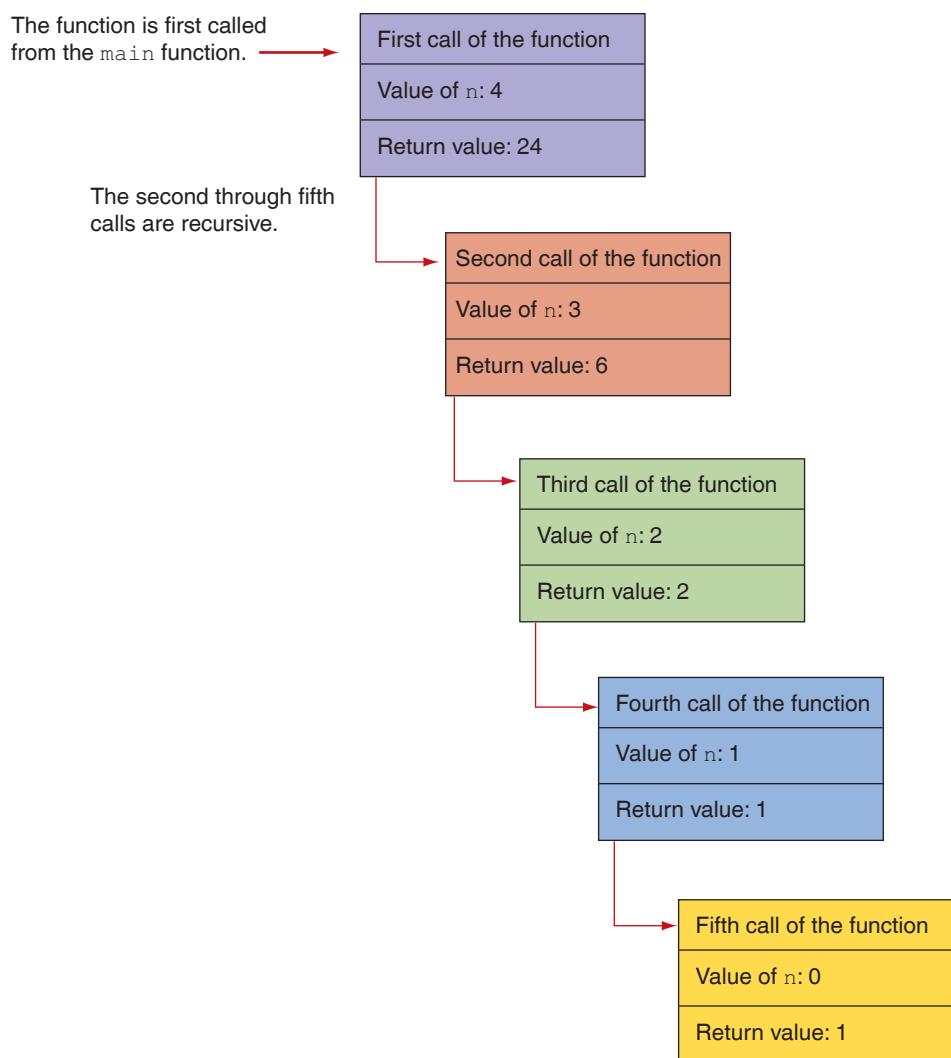
Enter a nonnegative integer.
4 [Enter]
The factorial of 4 is 24

```

In the sample run of the program, the `factorial` function is called with the argument 4 passed into `n`. Because `n` is not equal to 0, the `If` statement's `Else` clause executes the following statement:

```
Return n * factorial(n - 1)
```

Although this is a `Return` statement, it does not immediately return. Before the return value can be determined, the value of `factorial(n - 1)` must be determined. The `factorial` function is called recursively until the fifth call, in which the `n` parameter will be set to zero. Figure 13-4 illustrates the value of `n` and the return value during each call of the function.

**Figure 13-4** The value of n and the return value during each call of the function

The figure illustrates why a recursive algorithm must reduce the problem with each recursive call. Eventually, the recursion has to stop in order for a solution to be reached.

If each recursive call works on a smaller version of the problem, then the recursive calls work toward the base case. The base case does not require recursion, so it stops the chain of recursive calls.

Usually, a problem is reduced by making the value of one or more parameters smaller with each recursive call. In our factorial function, the value of the parameter `n` gets closer to 0 with each recursive call. When the parameter reaches 0, the function returns a value without making another recursive call.

## Direct and Indirect Recursion

The examples we have discussed so far show recursive modules or functions that directly call themselves. This is known as *direct recursion*. There is also the possibility of creating indirect recursion in a program. This occurs when module A calls module B, which in turn calls module A. There can even be several modules involved in the recursion. For example, module A could call module B, which could call module C, which calls module A.



### Checkpoint

- 13.1 It is said that a recursive algorithm has more overhead than an iterative algorithm. What does this mean?
- 13.2 What is a base case?
- 13.3 What is a recursive case?
- 13.4 What causes a recursive algorithm to stop calling itself?
- 13.5 What is direct recursion? What is indirect recursion?

### 13.3

## Examples of Recursive Algorithms

### Summing a Range of Array Elements with Recursion

In this example, we look at a function named `rangeSum` that uses recursion to sum a range of array elements. The function takes the following arguments: an `Integer` array that contains the range of elements to be summed, an `Integer` specifying the starting element of the range, and an `Integer` specifying the ending element of the range. Here is an example of how the function might be used:

```
Constant Integer SIZE = 9
Declare Integer numbers[SIZE] = 1, 2, 3, 4, 5, 6, 7, 8, 9
Declare Integer sum;
Set sum = rangeSum(numbers, 3, 7)
```

The last statement in this pseudocode specifies that the `rangeSum` function should return the sum of elements 3 through 7 in the `numbers` array. The return value, which in this case would be 30, is assigned to the `sum` variable. Here is the pseudocode definition of the `rangeSum` function:

```
Function Integer rangeSum(Integer array[], Integer start,
 Integer end)
 If start > end Then
 Return 0
 Else
 Return array[start] + rangeSum(array, start + 1, end)
 End If
End Function
```

This function's base case is when the `start` parameter is greater than the `end` parameter. If this is true, the function returns the value 0. Otherwise, the function executes the following statement:

```
Return array[start] + rangeSum(array, start + 1, end)
```

This statement returns the sum of `array[start]` plus the return value of a recursive call. Notice that in the recursive call, the starting element in the range is `start + 1`. In essence, this statement says, "return the value of the first element in the range plus the sum of the rest of the elements in the range." The pseudocode in Program 13-4 demonstrates the function.

#### Program 13-4

```
1 Module main()
2 // Declare a constant for the array size.
3 Constant Integer SIZE = 9
4
5 // Declare an Integer array.
6 Declare Integer numbers[SIZE] = 1, 2, 3, 4, 5, 6, 7, 8, 9
7
8 // Declare a variable to hold a sum.
9 Declare Integer sum
10
11 // Get the sum of elements 2 through 5.
12 Set sum = rangeSum(numbers, 2, 5)
13
14 // Display the sum.
15 Display "The sum of elements 2 through 5 is ", sum
16 End Module
17
18 // The rangeSum function returns the sum of a specified
19 // range of elements in array. The start parameter
20 // specifies the starting element. The end parameter
21 // specifies the ending element.
22 Function Integer rangeSum(Integer array[], Integer start,
23 Integer end)
24 If start > end Then
25 Return 0
26 Else
27 Return array[start] + rangeSum(array, start + 1, end)
28 End If
29 End Function
```

#### Program Output

```
The sum of elements 2 through 5 is 18
```

## The Fibonacci Series

Some mathematical problems are solved recursively. One well-known example is the calculation of Fibonacci numbers. The Fibonacci numbers, named after the

Italian mathematician Leonardo Fibonacci (born circa 1170), are the following sequence:

0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, . . .

Notice that after the second number, each number in the series is the sum of the two previous numbers. The Fibonacci series can be defined as follows:

```
If n = 0 then Fib(n) = 0
If n = 1 then Fib(n) = 1
If n >= 2 then Fib(n) = Fib(n - 1) + Fib(n - 2)
```

A recursive function to calculate the  $n$ th number in the Fibonacci series is shown here:

```
Function Integer fib(Integer n)
 If n == 0 then
 Return 0
 Else If n == 1 Then
 Return 1
 Else
 Return fib(n - 1) + fib(n - 2)
 End If
End Function
```

Notice that this function actually has two base cases: when  $n$  is equal to 0, and when  $n$  is equal to 1. In either case, the function returns a value without making a recursive call. The pseudocode in Program 13-5 demonstrates this function by displaying the first 10 numbers in the Fibonacci series.

### Program 13-5

```
1 Module main()
2 // Local variable to use as a counter.
3 Declare Integer counter
4
5 // Display an introductory message.
6 Display "The first 10 numbers in the ",
7 "Fibonacci series are:"
8
9 // Use a loop to call the fib function, passing
10 // the values 1 through 10 as an argument.
11 For counter = 1 To 10
12 Display fib(counter)
13 End For
14 End Module
15
16 // The fib function returns the nth number
17 // in the Fibonacci series.
18 Function Integer fib(Integer n)
19 If n == 0 then
20 Return 0
21 Else If n == 1 Then
22 Return 1
23 Else
24 Return fib(n - 1) + fib(n - 2)
```

```
25 End If
26 End Function
```

### Program Output

The first 10 numbers in the Fibonacci series are:

```
0 1 1 2 3 5 8 13 21 34
```

## Finding the Greatest Common Divisor

Our next example of recursion is the calculation of the greatest common divisor (GCD) of two numbers. The GCD of two positive integers,  $x$  and  $y$ , is determined as follows:

If  $x$  can be evenly divided by  $y$ , then  $\text{gcd}(x, y) = y$   
Otherwise,  $\text{gcd}(x, y) = \text{gcd}(y, \text{remainder of } x/y)$

This definition states that the GCD of  $x$  and  $y$  is  $y$  if  $x/y$  has no remainder. This is the base case. Otherwise, the answer is the GCD of  $y$  and the remainder of  $x/y$ . The pseudo-code in Program 13-6 shows a recursive method for calculating the GCD.

### Program 13-6

```
1 Module main()
2 // Local variables to hold user input.
3 Declare Integer num1, num2
4
5 // Get a number from the user.
6 Display "Enter an integer."
7 Input num1
8
9 // Get another number from the user.
10 Display "Enter another integer."
11 Input num2
12
13 // Display the GCD.
14 Display "The greatest common divisor of these"
15 Display "two numbers is ", gcd(num1, num2)
16 End Module
17
18 // The gcd function returns the greatest common
19 // divisor of the arguments passed into x and y.
20 Function Integer gcd(Integer x, Integer y)
21 // Determine whether x can be divided evenly by y.
22 // If so, we've reached the base case.
23 If x MOD y == 0 Then
24 Return y
25 Else
26 // This is the recursive case.
27 Return gcd(x, x MOD y)
28 End If
29 End Function
```

**Program Output**

```
Enter an integer.
49 [Enter]
Enter another integer.
28 [Enter]
The greatest common divisor of these
two numbers is 7
```

**A Recursive Binary Search Function**

In Chapter 9, you learned about the binary search algorithm and saw an example that uses a loop. The binary search algorithm can also be implemented recursively. For example, the procedure can be expressed as follows:

```
If array[middle] equals the search value, then
 the value is found.
Else if array[middle] is less than the search value, then
 perform a binary search on the upper half of the array.
Else if array[middle] is greater than the search value, then
 perform a binary search on the lower half of the array.
```

When you compare the recursive algorithm to its counterpart that uses a loop, it becomes evident that the recursive version is much more elegant and easier to understand. The recursive binary search algorithm is also a good example of repeatedly breaking a problem down into smaller pieces until it is solved. Here is the pseudocode for a recursive binarySearch function:

```
Function Integer binarySearch(Integer array[],
 Integer first, Integer last, Integer value)
 // Local variable to hold the subscript of the element
 // in the middle of the search area.
 Declare Integer middle
 // First, see if there are any elements to search.
 If first > last Then
 Return -1
 End If
 // Calculate the mid point of the search area.
 Set middle = (first + last) / 2
 // See if the value is found at the mid point . . .
 If array[middle] == value Then
 Return middle
 End If
 // Search either the upper or lower half.
 If array[middle] < value Then
 Return binarySearch(array, middle + 1, last, value)
 Else
 Return binarySearch(array, first, middle - 1, value)
 End If
End Function
```

The first parameter, `array`, is the array to be searched. The next parameter, `first`, holds the subscript of the first element in the search area (the portion of the array to be searched). The next parameter, `last`, holds the subscript of the last element in the search area. The last parameter, `value`, holds the value to be searched for. Like the `binarySearch` function shown in Chapter 9, this function returns the subscript of the value if it is found, or `-1` if the value is not found. Program 13-7 demonstrates the function.

### Program 13-7

```
1 Module main()
2 // Declare a constant for the array size.
3 Constant Integer SIZE = 20
4
5 // Declare an array of employee ID numbers.
6 Declare Integer numbers[SIZE] = 101, 142, 147, 189, 199,
7 207, 222, 234, 289, 296,
8 310, 319, 388, 394, 417,
9 429, 447, 521, 536, 600
10
11 // Declare a variable to hold an ID number.
12 Declare Integer empID
13
14 // Declare a variable to hold the search results.
15 Declare Integer results
16
17 // Get an employee ID number to search for.
18 Display "Enter an employee ID number."
19 Input empID
20
21 // Search for the ID number in the array.
22 result = binarySearch(numbers, 0, SIZE - 1, empID)
23
24 // Display the results of the search.
25 If result == -1 Then
26 Display "That employee ID number was not found."
27 Else
28 Display "That employee ID number was found ",
29 "at subscript ", result
30 End If
31
32 End Module
33
34 // The binarySearch function performs a recursive binary search
35 // on a range of elements in an Integer array. The parameter
36 // array holds the array to be searched. The parameter first
37 // holds the subscript of the range's starting element, and the
38 // parameter last holds the subscript of the range's last element.
39 // The parameter value holds the search value. If the search value
40 // is found, its array subscript is returned. Otherwise, -1 is
41 // returned indicating the value is not in the array.
42 Function Integer binarySearch(Integer array[],
43 Integer first, Integer last, Integer value)
44 // Local variable to hold the subscript of the element
```

```

45 // in the middle of the search area.
46 Declare Integer middle
47
48 // First, see if there are any elements to search.
49 If first > last Then
50 Return -1
51 End If
52
53 // Calculate the mid point of the search area.
54 Set middle = (first + last) / 2
55
56 // See if the value is found at the mid point . . .
57 If array[middle] == value Then
58 Return middle
59 End If
60
61 // Search either the upper or lower half.
62 If array[middle] < value Then
63 Return binarySearch(array, middle + 1, last, value)
64 Else
65 Return binarySearch(array, first, middle - 1, value)
66 End If
67 End Function

```

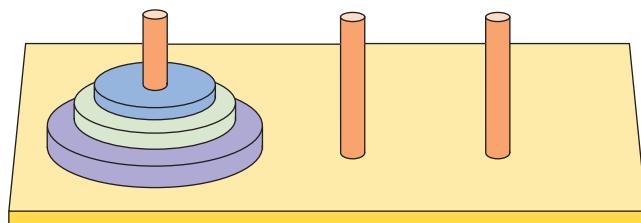
### Program Output (with Input Shown in Bold)

Enter an employee ID number.  
**521 [Enter]**  
 That employee ID number was found at subscript 17

## The Towers of Hanoi

The Towers of Hanoi is a mathematical game that is often used in computer science textbooks to illustrate the power of recursion. The game uses three pegs and a set of discs with holes through their centers. The discs are stacked on one of the pegs as shown in Figure 13-5.

**Figure 13-5** The pegs and discs in the Towers of Hanoi game



Notice that the discs are stacked on the leftmost peg, in order of size with the largest disc at the bottom. The game is based on a legend where a group of monks in a temple in Hanoi have a similar set of pegs with 64 discs. The job of the monks is to move the discs from the first peg to the third peg. The middle peg can be used as a temporary holder. Furthermore, the monks must follow these rules while moving the discs:

- Only one disk may be moved at a time
- A disk cannot be placed on top of a smaller disc
- All discs must be stored on a peg except while being moved

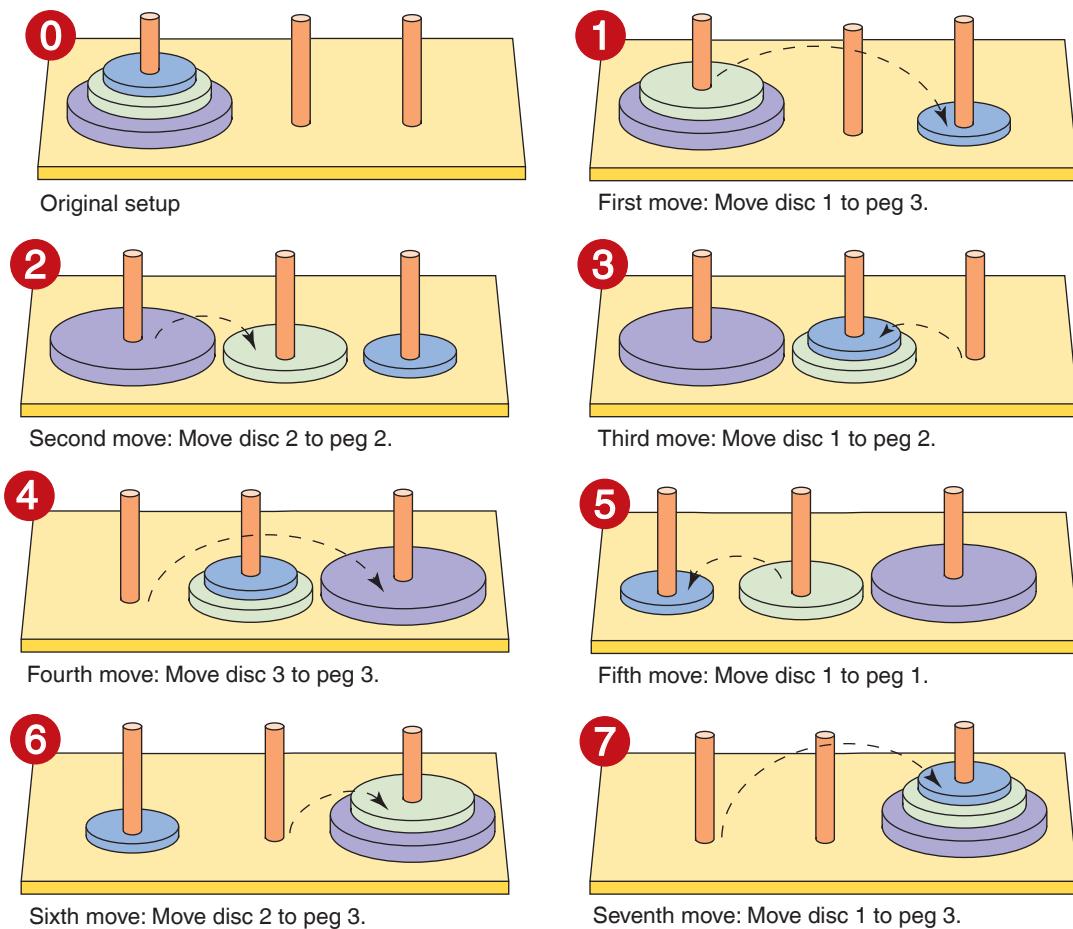
According to the legend, when the monks have moved all of the discs from the first peg to the last peg, the world will come to an end.

To play the game, you must move all of the discs from the first peg to the third peg, following the same rules as the monks. Let's look at some example solutions to this game, for different numbers of discs. If you have only one disc, the solution to the game is simple: move the disc from peg 1 to peg 3. If you have two discs, the solution requires three moves:

- Move disc 1 to peg 2
- Move disc 2 to peg 3
- Move disc 1 to peg 3

Notice that this approach uses peg 2 as a temporary location. The complexity of the moves continues to increase as the number of discs increases. To move three discs requires the seven moves shown in Figure 13-6.

**Figure 13-6** Steps for moving three discs



The following statement describes the overall solution to the problem:

*Move n discs from peg 1 to peg 3 using peg 2 as a temporary peg.*

The following summary describes a recursive algorithm that simulates the solution to the game. Notice that in this algorithm we use the variables A, B, and C to hold peg numbers.

*To move n discs from peg A to peg C, using peg B as a temporary peg, do the following:*

*If n > 0 then*

*Move n – 1 discs from peg A to peg B, using peg C as a temporary peg.*

*Move the remaining disc from peg A to peg C.*

*Move n – 1 discs from peg B to peg C, using peg A as a temporary peg.*

*End if*

The base case for the algorithm is reached when there are no more discs to move. The following pseudocode is for a module that implements this algorithm. Note that the module does not actually move anything, but displays instructions indicating all of the disc moves to make.

```
Module moveDiscs(Integer num, Integer fromPeg,
 Integer toPeg, Integer tempPeg)
 If num > 0 Then
 moveDiscs(num - 1, fromPeg, tempPeg, toPeg)
 Display "Move a disc from peg ", fromPeg,
 " to peg ", toPeg
 moveDiscs(num - 1, tempPeg, toPeg, fromPeg)
 End If
End Module
```

This module accepts arguments into the following parameters:

|         |                                    |
|---------|------------------------------------|
| num     | The number of discs to move.       |
| fromPeg | The peg to move the discs from.    |
| toPeg   | The peg to move the discs to.      |
| tempPeg | The peg to use as a temporary peg. |

If num is greater than 0, then there are discs to move. The first recursive call is as follows:

`moveDiscs(num - 1, fromPeg, tempPeg, toPeg)`

This statement is an instruction to move all but one disc from fromPeg to tempPeg, using toPeg as a temporary peg. The next statement is as follows:

`Display "Move a disc from peg ", fromPeg,  
          " to peg ", toPeg`

This simply displays a message indicating that a disc should be moved from fromPeg to toPeg. Next, another recursive call is executed as follows:

`moveDiscs(num - 1, tempPeg, toPeg, fromPeg)`

This statement is an instruction to move all but one disc from tempPeg to toPeg, using fromPeg as a temporary peg. The pseudocode in Program 13-8 demonstrates the module by displaying a solution for the Tower of Hanoi game.

**Program 13-8**

```
1 Module main()
2 // A constant for the number of discs to move.
3 Constant Integer NUM_DISCS = 3
4
5 // A constant for the initial "from" peg.
6 Constant Integer FROM_PEG = 1
7
8 // A constant for the initial "to" peg.
9 Constant Integer TO_PEG = 3
10
11 // A constant for the initial "temp" peg.
12 Constant Integer TEMP_PEG = 2
13
14 // Play the game.
15 Call moveDiscs(NUM_DISCS, FROM_PEG, TO_PEG, TEMP_PEG)
16 Display "All the pegs are moved!"
17 End Module
18
19
20 // The moveDiscs function displays a disc move in
21 // the Towers of Hanoi game.
22 // The parameters are:
23 // num: The number of discs to move.
24 // fromPeg: The peg to move from.
25 // toPeg: The peg to move to.
26 // empPeg: The temporary peg.
27 Module moveDiscs(Integer num, Integer fromPeg,
28 Integer toPeg, Integer tempPeg)
29 If num > 0 Then
30 moveDiscs(num - 1, fromPeg, tempPeg, toPeg)
31 Display "Move a disc from peg ", fromPeg,
32 " to peg ", toPeg
33 moveDiscs(num - 1, tempPeg, toPeg, fromPeg)
34 End If
35 End Module
```

**Program Output**

```
Move a disc from peg 1 to peg 3
Move a disc from peg 1 to peg 2
Move a disc from peg 3 to peg 2
Move a disc from peg 1 to peg 3
Move a disc from peg 2 to peg 1
Move a disc from peg 2 to peg 3
Move a disc from peg 1 to peg 3
All the pegs are moved!
```

## Recursion versus Looping

Any algorithm that can be coded with recursion can also be coded with a loop. Both approaches achieve repetition, but which is best to use?

There are several reasons not to use recursion. Recursive algorithms are certainly less efficient than iterative algorithms. Each time a module or function is called, the system incurs overhead that is not necessary with a loop. Also, in many cases a solution using a loop may be more evident than a recursive solution. In fact, the majority of repetitive programming tasks are best done with loops.

Some problems, however, are more easily solved with recursion than with a loop. For example, the mathematical definition of the GCD formula is well suited for a recursive approach. The speed and amount of memory available to modern computers diminishes the performance impact of recursion so much that inefficiency is no longer a strong argument against it. Today, the choice of recursion or a loop is primarily a design decision. If a problem is more easily solved with a loop, you should take that approach. If recursion results in a better design, you should make that choice.

### 13.4

## Focus on Languages: Java, Python, and C++

This section discusses how recursion can be used in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

### Java

Other than the technique of a method recursively calling itself, no new language features are introduced in this chapter. In this section, we will present Java versions of two of the pseudocode programs that are shown in this chapter. Program 13-9 is the Java version of pseudocode Program 13-2.

#### Program 13-9 (RecursionDemo.java)

```
1 public class RecursionDemo
2 {
3 public static void main(String[] args)
4 {
5 // By passing the argument 5 to the message method
6 // we are telling it to display the message 5 times.
7 message(5);
8 }
9
10 public static void message(int n)
11 {
12 if (n > 0)
13 {
14 System.out.println("This is a recursive method.");
15 }
16 }
17}
```

```
15 message(n - 1);
16 }
17 }
18 }
```

### Program Output

```
This is a recursive method.
```

Next, Program 13-10 is the Java version of pseudocode Program 13-3. This program recursively calculates the factorial of a number.

### Program 13-10 (RecursiveFactorial.java)

```
1 import java.util.Scanner;
2
3 public class RecursiveFactorial
4 {
5 public static void main(String[] args)
6 {
7 int number; // To hold a number
8
9 // Create a Scanner object for keyboard input.
10 Scanner keyboard = new Scanner(System.in);
11
12 // Get a number from the user.
13 System.out.print("Enter a non-negative integer: ");
14 number = keyboard.nextInt();
15
16 // Display the factorial of the number.
17 System.out.println("The factorial of " + number +
18 " is " + factorial(number));
19 }
20
21 // The factorial method uses recursion to calculate
22 // the factorial of its argument, which is assumed
23 // to be a nonnegative number.
24
25 private static int factorial(int n)
26 {
27 if (n == 0)
28 return 1; // Base case
29 else
30 return n * factorial(n - 1);
31 }
32 }
```

### Program Output

```
Enter a non-negative integer: 7 [Enter]
The factorial of 7 is 5040
```

## Python

Other than the technique of a method recursively calling itself, no new language features are introduced in this chapter. In this section, we will present Python versions of two of the pseudocode programs that are shown in this chapter. Program 13-11 is the Python version of pseudocode Program 13-2.

### Program 13-11 (*recursion\_demo.py*)

```

1 # This program has a recursive function.
2
3 def main():
4 # By passing the argument 5 to the message
5 # function we are telling it to display the
6 # message five times.
7 message(5)
8
9 def message(times):
10 if (times > 0):
11 print('This is a recursive function.')
12 message(times - 1)
13
14 # Call the main function.
15 main()

```

### Program Output

```

This is a recursive function.

```

Next, Program 13-12 is the Python version of pseudocode Program 13-3. This program recursively calculates the factorial of a number.

### Program 13-12 (*factorial.py*)

```

1 # This program uses recursion to calculate
2 # the factorial of a number.
3
4 def main():
5 # Get a number from the user.
6 number = int(input('Enter a nonnegative integer: '))
7
8 # Get the factorial of the number.
9 fact = factorial(number)
10
11 # Display the factorial.
12 print('The factorial of', number, 'is', fact)
13
14 # The factorial function uses recursion to
15 # calculate the factorial of its argument,

```

```
16 # which is assumed to be nonnegative.
17 def factorial(num):
18 if num == 0:
19 return 1
20 else:
21 return num * factorial(num - 1)
22
23 # Call the main function.
24 main()
```

### Program Output (with Input Shown in Bold)

Enter a nonnegative integer: **7** [Enter]

The factorial of 7 is 5040

## C++

Other than the technique of a method recursively calling itself, no new language features are introduced in this chapter. In this section, we will present C++ versions of two of the pseudocode programs that are shown in this chapter. Program 13-13 is the C++ version of pseudocode Program 13-2.

### Program 13-13 (RecursionDemo.cpp)

```
1 #include <iostream>
2 using namespace std;
3
4 // Function prototype
5 void message(int);
6
7 int main()
8 {
9 // By passing the argument 5 to the message function
10 // we are telling it to display the message 5 times.
11 message(5);
12
13 return 0;
14 }
15
16 void message(int n)
17 {
18 if (n > 0)
19 {
20 cout << "This is a recursive function." << endl;
21 message(n - 1);
22 }
23 }
```

### Program Output

This is a recursive function.  
This is a recursive function.

Next, Program 13-14 is the C++ version of pseudocode Program 13-3. This program recursively calculates the factorial of a number.

### Program 13-14

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 // Function prototype
6 int factorial(int);
7
8 int main()
9 {
10 int number; // To hold a number entered by the user
11 int numFactorial; // To hold the factorial of the number
12
13 // Get a number from the user.
14 cout << "Enter a nonnegative integer." << endl;
15 cin >> number;
16
17 // Get the factorial of the number.
18 numFactorial = factorial(number);
19
20 // Display the factorial of the number.
21 cout << "The factorial of " << number
22 << " is " << numFactorial << endl;
23
24 return 0;
25 }
26
27 // The factorial function uses recursion to calculate
28 // the factorial of its argument, which is assumed
29 // to be a nonnegative number.
30 int factorial(int n)
31 {
32 if (n == 0)
33 return 1; // Base case
34 else
35 return n * factorial(n - 1);
36 }
```

### Program Output

```
Enter a non-negative integer.
7 [Enter]
The factorial of 7 is 5040
```

## Review Questions

### Multiple Choice

1. A recursive module \_\_\_\_\_.
  - a. calls a different module
  - b. abnormally halts the program
  - c. calls itself
  - d. can be called only once
2. A module is called once from a program's `main` module, and then it calls itself four times. The depth of recursion is \_\_\_\_\_.
  - a. one
  - b. four
  - c. five
  - d. nine
3. The part of a problem that can be solved without recursion is the \_\_\_\_\_ case.
  - a. base
  - b. solvable
  - c. known
  - d. iterative
4. The part of a problem that is solved with recursion is the \_\_\_\_\_ case.
  - a. base
  - b. iterative
  - c. unknown
  - d. recursive
5. When a module explicitly calls itself it is called \_\_\_\_\_ recursion.
  - a. explicit
  - b. modal
  - c. direct
  - d. indirect
6. When module A calls module B, which calls module A, it is called \_\_\_\_\_ recursion.
  - a. implicit
  - b. modal
  - c. direct
  - d. indirect
7. Any problem that can be solved recursively can also be solved with a \_\_\_\_\_.
  - a. decision structure
  - b. loop
  - c. sequence structure
  - d. case structure

8. Actions taken by the computer when a module is called, such as allocating memory for parameters and local variables, are referred to as \_\_\_\_\_.
  - a. overhead
  - b. setup
  - c. cleanup
  - d. synchronization
9. A recursive algorithm must \_\_\_\_\_ in the recursive case.
  - a. solve the problem without recursion
  - b. reduce the problem to a smaller version of the original problem
  - c. acknowledge that an error has occurred and abort the program
  - d. enlarge the problem to a larger version of the original problem
10. A recursive algorithm must \_\_\_\_\_ in the base case.
  - a. solve the problem without recursion
  - b. reduce the problem to a smaller version of the original problem
  - c. acknowledge that an error has occurred and abort the program
  - d. enlarge the problem to a larger version of the original problem

### True or False

1. An algorithm that uses a loop will usually run faster than an equivalent recursive algorithm.
2. Some problems can be solved through recursion only.
3. It is not necessary to have a base case in all recursive algorithms.
4. In the base case, a recursive method calls itself with a smaller version of the original problem.

### Short Answer

1. In Program 13-2, presented earlier in this chapter, what is the base case of the message module?
2. In this chapter, the rules given for calculating the factorial of a number are as follows:

If  $n = 0$  then  $\text{factorial}(n) = 1$   
If  $n > 0$  then  $\text{factorial}(n) = n \times \text{factorial}(n - 1)$

If you were designing a module from these rules, what would the base case be?  
What would the recursive case be?

3. Is recursion ever required to solve a problem? What other approach can you use to solve a problem that is repetitive in nature?
4. When recursion is used to solve a problem, why must the recursive module call itself to solve a smaller version of the original problem?
5. How is a problem usually reduced with a recursive module?

## Algorithm Workbench

1. What will the following program display?

```
Module main()
 Declare Integer num = 0
 Call showMe(num)
End Module

Module showMe(Integer arg)
 If arg < 10 Then
 Call showMe(arg + 1)
 Else
 Display arg
 End If
End Module
```

2. What will the following program display?

```
Module main()
 Declare Integer num = 0
 Call showMe(num)
End Module

Module showMe(Integer arg)
 Display arg
 If arg < 10 Then
 Call showMe(arg + 1)
 End If
End Module
```

3. The following module uses a loop. Rewrite it as a recursive module that performs the same operation.

```
Module trafficSign(int n)
 While n > 0
 Display "No Parking"
 Set n = n - 1
 End While
End Module
```



VideoNote  
The Recursive Multiplication Problem

## Programming Exercises

### 1. Recursive Multiplication

Design a recursive function that accepts two arguments into the parameters  $x$  and  $y$ . The function should return the value of  $x$  times  $y$ . Remember, multiplication can be performed as repeated addition as follows:

$$7 \times 4 = 4 + 4 + 4 + 4 + 4 + 4 + 4$$

(To keep the function simple, assume that  $x$  and  $y$  will always hold positive non-zero integers.)

### 2. Largest Element

Design a function that accepts an array and the array's size as arguments, and returns the largest value in the array. The method should use recursion to find the largest element.

### 3. Recursive Array Sum

Design a function that accepts an Integer array and the size of the array as arguments. The function should recursively calculate the sum of all the numbers in the array and return that value.

### 4. Sum of Numbers

Design a function that accepts an integer argument and returns the sum of all the integers from 1 up to the number passed as an argument. For example, if 50 is passed as an argument, the function will return the sum of 1, 2, 3, 4, . . . 50. Use recursion to calculate the sum.

### 5. Recursive Power Method

Design a function that uses recursion to raise a number to a power. The function should accept two arguments: the number to be raised and the exponent. Assume that the exponent is a nonnegative integer.

### 6. Ackermann's Function

Ackermann's Function is a recursive mathematical algorithm that can be used to test how well a computer performs recursion. Design a function `ackermann(m, n)`, which solves Ackermann's Function. Use the following logic in your function:

*If m = 0 then return n + 1*

*If n = 0 then return ackermann(m - 1, 1)*

*Otherwise, return ackermann(m - 1, ackermann(m, n - 1))*

## TOPICS

- |                                                            |                                                                  |
|------------------------------------------------------------|------------------------------------------------------------------|
| 14.1 Procedural and Object-Oriented Programming            | 14.4 Finding the Classes and Their Responsibilities in a Problem |
| 14.2 Classes                                               | 14.5 Inheritance                                                 |
| 14.3 Using the Unified Modeling Language to Design Classes | 14.6 Polymorphism                                                |
|                                                            | 14.7 Focus on Languages: Java, Python, and C++                   |

## 14.1

## Procedural and Object-Oriented Programming

**CONCEPT:** Procedural programming is a method of writing software. It is a programming practice centered on the procedures or actions that take place in a program. Object-oriented programming is centered on the object. Objects are created from abstract data types that encapsulate data and functions together.

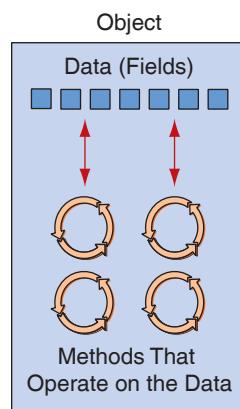
There are primarily two methods of programming in use today: procedural and object-oriented. The earliest programming languages were procedural, meaning a program was made of one or more procedures. A *procedure* is simply a module or function that performs a specific task such as gathering input from the user, performing calculations, reading or writing files, displaying output, and so on. The programs that you have written so far have been procedural in nature.

Typically, procedures operate on data items that are separate from the procedures. In a procedural program, the data items are commonly passed from one procedure to another. As you might imagine, the focus of procedural programming is on the creation of procedures that operate on the program's data. The separation of data and the code that operates on the data can lead to problems, however, as the program becomes larger and more complex.

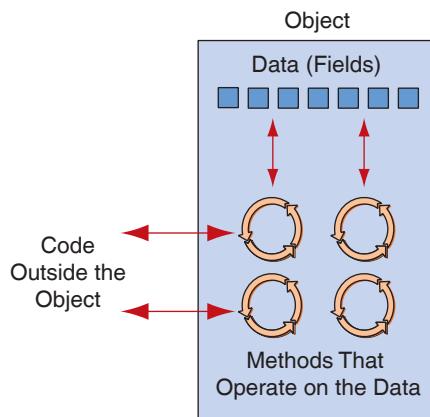
For example, suppose you are part of a programming team that has written an extensive customer database program. The program was initially designed so that a customer's name, address, and phone number were stored in three `String` variables. Your job was to design several modules that accept those three variables as arguments and perform operations on them. The software has been operating successfully for some time, but your team has been asked to update it by adding several new features. During the revision process, the senior programmer informs you that the customer's name, address, and phone number will no longer be stored in variables. Instead, they will be stored in a `String` array. This means that you will have to modify all of the modules that you have designed so that they accept and work with a `String` array instead of the three variables. Making these extensive modifications not only is a great deal of work, but also opens the opportunity for errors to appear in your code.

Whereas procedural programming is centered on creating procedures (which are modules and functions), *object-oriented programming (OOP)* is centered on creating objects. An *object* is a software entity that contains both data and procedures. The data contained in an object is known as the object's *fields*. An object's fields are simply variables, arrays, or other data structures that are stored in the object. The procedures that an object performs are known as *methods*. An object's methods are nothing more than modules or functions. The object is, conceptually, a self-contained unit that consists of data (fields) and procedures (methods). This is illustrated in Figure 14-1.

**Figure 14-1** An object contains data and procedures



OOP addresses the problem of code/data separation through encapsulation and data hiding. *Encapsulation* refers to the combining of data and code into a single object. *Data hiding* refers to an object's ability to hide its data from code that is outside the object. Only the object's methods may then directly access and make changes to the object's data. An object typically hides its data, but allows outside code to access its methods. As shown in Figure 14-2, the object's methods provide programming statements outside the object with indirect access to the object's data.

**Figure 14-2** Code outside the object interacts with the object's methods

When an object's internal data is hidden from outside code and access to that data is restricted to the object's methods, the data is protected from accidental corruption. In addition, the programming code outside the object does not need to know about the format or internal structure of the object's data. The code only needs to interact with the object's methods. When a programmer changes the structure of an object's internal data, the object's methods are also modified so they may properly operate on the data. The way in which outside code interacts with the methods, however, does not change.

## Object Reusability

In addition to solving the problems of code/data separation, the use of OOP has also been encouraged by the trend of *object reusability*. An object is not a stand-alone program, but is used by programs that need its service. For example, Kamila is a programmer who has developed an object for rendering 3D images. She is a math whiz and knows a lot about computer graphics, so her object is coded to perform all of the necessary 3D mathematical operations and handle the computer's video hardware. Omar, who is writing a program for an architectural firm, needs his application to display 3D images of buildings. Because he is working under a tight deadline and does not possess a great deal of knowledge about computer graphics, he can use Kamila's object to perform the 3D rendering (for a small fee, of course!).

## An Everyday Example of an Object

Think of your alarm clock as an object. It has the following fields:

- The current second (a value in the range of 0–59)
- The current minute (a value in the range of 0–59)
- The current hour (a value in the range of 1–12)
- The time the alarm is set for (a valid hour and minute)
- Whether the alarm is on or off ("on" or "off")

As you can see, the fields are merely data values that define the *state* that the alarm clock is currently in. You, the user of the alarm clock object, cannot directly manipulate these fields because they are *private*. To change a field's value, you must use one of the object's methods. The following are some of the alarm clock object's methods:

- Set time
- Set alarm time
- Turn alarm on
- Turn alarm off

Each method manipulates one or more of the fields. For example, the `Set time` method allows you to set the alarm clock's time. You activate the method by pressing a button on top of the clock. By using another button, you can activate the `Set alarm time` method.

In addition, another button allows you to execute the `Turn alarm on` and `Turn alarm off` methods. Notice that all of these methods can be activated by you, who are outside of the alarm clock. Methods that can be accessed by entities outside the object are known as *public methods*.

The alarm clock also has *private methods*, which are part of the object's private, internal workings. External entities (such as you, the user of the alarm clock) do not have direct access to the alarm clock's private methods. The object is designed to execute these methods automatically and hide the details from you. The following are the alarm clock object's private methods:

- Increment the current second
- Increment the current minute
- Increment the current hour
- Sound alarm

Every second, the `Increment the current second` method executes. This changes the value of the current second field. If the current second field is set to 59 when this method executes, the method is programmed to reset the current second to 0, and then cause the `Increment the current minute` method to execute. This method adds 1 to the current minute, unless it is set to 59. In that case, it resets the current minute to 0 and causes the `Increment the current hour` method to execute. (Note that the `Increment the current minute` method compares the new time to the alarm time. If the two times match and the alarm is turned on, the `Sound alarm` method is executed.)



## Checkpoint

- 14.1 What is an object?
- 14.2 What is encapsulation?
- 14.3 Why is an object's internal data usually hidden from outside code?
- 14.4 What are public methods? What are private methods?

**14.2**

## Classes

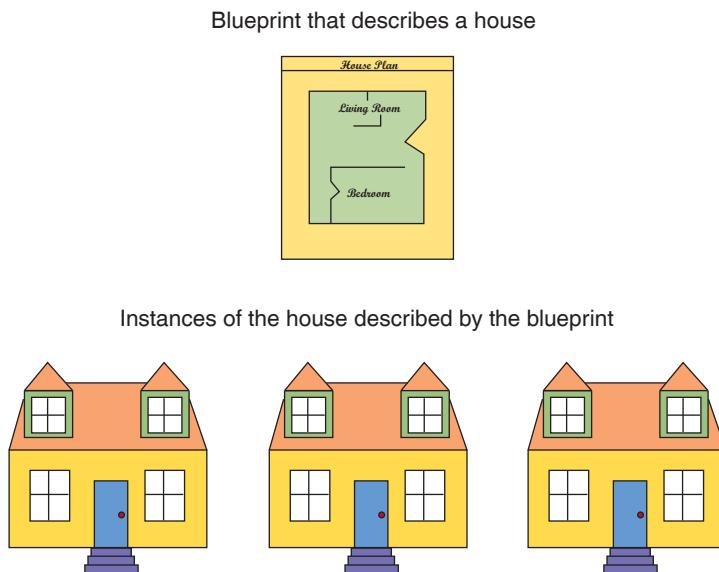
**CONCEPT:** A class is code that specifies the fields and methods for a particular type of object.



VideoNote  
Classes and Objects

Now, let's discuss how objects are created in software. Before an object can be created, it must be designed by a programmer. The programmer determines the fields and methods that are necessary, and then creates a *class*. A class is code that specifies the fields and methods of a particular type of object. Think of a class as a “blueprint” that objects may be created from. It serves a similar purpose as the blueprint for a house. The blueprint itself is not a house, but is a detailed description of a house. When we use the blueprint to build an actual house, we could say we are building an instance of the house described by the blueprint. If we so desire, we can build several identical houses from the same blueprint. Each house is a separate instance of the house described by the blueprint. This idea is illustrated in Figure 14-3.

**Figure 14-3** A blueprint and houses built from the blueprint

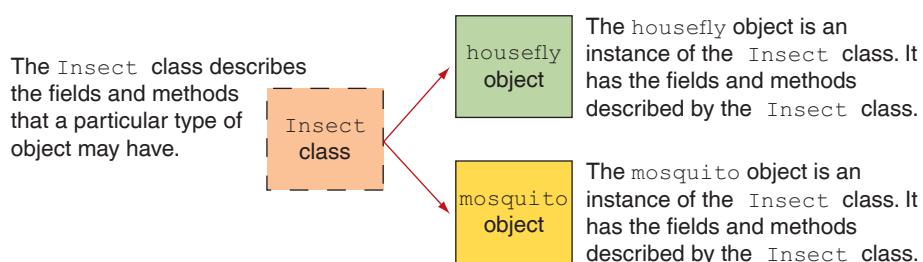


Another way of thinking about the difference between a class and an object is to think of the difference between a cookie cutter and a cookie. While a cookie cutter itself is not a cookie, it describes a cookie. The cookie cutter can be used to make one cookie, or several cookies. Think of a class as a cookie cutter and the objects created from the class as cookies.

So, a class is not an object, but it can be a description of an object. When the program is running, it can use the class to create, in memory, as many objects of a specific type as needed. Each object that is created from a class is called an *instance* of the class.

For example, Carmen is an entomologist (someone who studies insects) and she also enjoys writing computer programs. She designs a program to catalog different types of insects. As part of the program, she creates a class named `Insect`, which specifies fields and methods for holding and manipulating data common to all types of insects. The `Insect` class is not an object, but a specification that objects may be created from. Next, she writes programming statements that create a `housefly` object, which is an instance of the `Insect` class. The `housefly` object is an entity that occupies computer memory and stores data about a housefly. It has the fields and methods specified by the `Insect` class. Then she writes programming statements that create a `mosquito` object. The `mosquito` object is also an instance of the `Insect` class. It has its own area in memory, and stores data about a mosquito. Although the `housefly` and `mosquito` objects are separate entities in the computer's memory, they were both created from the `Insect` class. This means that each of the objects has the fields and methods described by the `Insect` class. This is illustrated in Figure 14-4.

**Figure 14-4** The `housefly` and `mosquito` objects are instances of the `Insect` class



## Creating a Class, Step by Step

The general format that we will use to write a class definition in pseudocode is as follows:

```

Class ClassName
 Field declarations and method definitions go here...
End Class

```

The first line starts with the word `Class`, followed by the name of the class. In most languages, you follow the same rules for naming variables as when naming classes. Next, you write the declarations for the class's fields and the definitions of the class's methods. (In general terms, the fields and methods that belong to a class are referred to as the class's *members*.) The words `End Class` appear at the end of the class definition.

Now we will demonstrate how a class is typically created in an object-oriented language. Because classes have several parts, we will not show the entire class all at once. Instead, we will put it together in a step-by-step fashion.

Suppose we are designing a program for Wireless Solutions, a business that sells cell phones and wireless service. The program will be used to keep track of the cell phones that the company has in inventory. The data that we need to keep for a cell phone is as follows:

- The name of the phone's manufacturer
- The phone's model number
- The phone's retail price

If we were designing a procedural program, we would simply use variables to hold this data. In this example, we are designing an object-oriented program, so we will create a class that represents a cell phone. The class will have fields to hold these items of data. The pseudocode in Class Listing 14-1 shows how we will start writing the class definition:

### Class Listing 14-1

```
1 Class CellPhone
2 // Field declarations
3 Private String manufacturer
4 Private String modelNumber
5 Private Real retailPrice
6
7 // This class is not finished!
8 End Class
```

First, notice that in line 1 we have named the class `CellPhone`. In this book, we will always begin class names with an uppercase letter. This is not required, but many programmers follow this practice because it helps distinguish class names from variable names.

Lines 3, 4, and 5 declare three fields. Line 3 declares a `String` field named `manufacturer`, line 4 declares a `String` field named `modelNumber`, and line 5 declares a `Real` field named `retailPrice`. Notice that each declaration begins with the word `Private`. When the word `Private` appears before a field declaration, it specifies that the field cannot be directly accessed by any statement outside the class. In most object-oriented programming languages, the word `Private` is known as an *access specifier*. It specifies how a class field or method can be accessed.

By using the `Private` access specifier, a class can hide its data from code outside the class. When a class's fields are hidden from outside code, the data is protected from accidental corruption. It is a common practice in object-oriented programming to make all of a class's fields private and to provide access to those fields only through methods. Next, we will add the following methods to the class, which will allow code outside the class to store values in the fields:

- `setManufacturer`: The `setManufacturer` method will be a module that stores a value in the `manufacturer` field.

- **setModelNumber:** The `setModelNumber` method will be a module that stores a value in the `modelNumber` field.
- **setRetailPrice:** The `setRetailPrice` method will be a module that stores a value in the `retailPrice` field.

The pseudocode in Class Listing 14-2 shows how the `CellPhone` class will appear with these methods added to it.

### Class Listing 14-2

```

1 Class CellPhone
2 // Field declarations
3 Private String manufacturer
4 Private String modelNumber
5 Private Real retailPrice
6
7 // Method definitions
8 Public Module setManufacturer(String manufact)
9 Set manufacturer = manufact
10 End Module
11
12 Public Module setModelNumber(String modNum)
13 Set modelNumber = modNum
14 End Module
15
16 Public Module setRetailPrice(Real retail)
17 Set retailPrice = retail
18 End Module
19
20 // This class is not finished!
21 End Class

```

The `setManufacturer` method appears in lines 8 through 10. This looks like a regular module definition, except that the word `Public` appears in the header. In most object-oriented languages, the word `Public` is an access specifier. When it is applied to a method, it specifies that the method can be called from statements outside the class.

The `setManufacturer` method has a `String` parameter named `manufact`. When the method is called, a string must be passed to it as an argument. In line 9, the value passed to the `manufact` parameter is assigned to the `manufacturer` field.

The `setModelNumber` method appears in lines 12 through 14. The method has a `String` parameter named `modNum`. When the method is called, a string must be passed to it as an argument. In line 13, the value passed to the `modNum` parameter is assigned to the `modelNumber` field.

The `setRetailPrice` method has a `Real` parameter named `retail`. When the method is called, a `Real` value must be passed to it as an argument. In line 17, the value passed to the `retail` parameter is assigned to the `retailPrice` field.

Because the `manufacturer`, `modelNumber`, and `retailPrice` fields are private, we wrote the `setManufacturer`, `setModelNumber`, and `setRetailPrice` methods to allow code outside the `CellPhone` class to store values in those fields. We must also write methods that allow code outside the class to get the values that are stored in these fields. For this purpose we will write the `getManufacturer`, `getModelNumber`, and `getRetailPrice` methods. The `getManufacturer` method will return the value stored in the `manufacturer` field, the `getModelNumber` method will return the value stored in the `modelNumber` field, and the `getRetailPrice` method will return the value stored in the `retailPrice` field.

The pseudocode in Class Listing 14-3 shows how the `CellPhone` class will appear with these methods added to it. The new methods are shown in lines 20 through 30.

### Class Listing 14-3



```
1 Class CellPhone
2 // Field declarations
3 Private String manufacturer
4 Private String modelNumber
5 Private Real retailPrice
6
7 // Method definitions
8 Public Module setManufacturer(String manufact)
9 Set manufacturer = manufact
10 End Module
11
12 Public Module setModelNumber(String modNum)
13 Set modelNumber = modNum
14 End Module
15
16 Public Module setRetailPrice(Real retail)
17 Set retailPrice = retail
18 End Module
19
20 Public Function String getManufacturer()
21 Return manufacturer
22 End Function
23
24 Public Function String getModelNumber()
25 Return modelNumber
26 End Function
27
28 Public Function Real getRetailPrice()
29 Return retailPrice
30 End Function
31 End Class
```

The `getManufacturer` method appears in lines 20 through 22. Notice that this method is written as a function instead of a module. When the method is called, the statement in line 21 returns the value stored in the `manufacturer` field.

The `getModelNumber` method in lines 24 through 26 and the `getRetailPrice` method in lines 28 through 30 are also functions. The `getModelNumber` method returns the value stored in the `modelNumber` field, and the `getRetailPrice` method returns the value stored in the `retailPrice` field.

The pseudocode in Class Listing 14-3 is a complete class, but it is not a program. It is a blueprint that objects may be created from. To demonstrate the class we must design a program that uses it to create an object, as shown in Program 14-1.

### Program 14-1



```

1 Module main()
2 // Declare a variable that can reference
3 // a CellPhone object.
4 Declare CellPhone myPhone
5
6 // The following statement creates an object
7 // using the CellPhone class as its blueprint.
8 // The myPhone variable will reference the object.
9 Set myPhone = New CellPhone()
10
11 // Store values in the object's fields.
12 Call myPhone.setManufacturer("Motorola")
13 Call myPhone.setModelNumber("M1000")
14 Call myPhone.setRetailPrice(199.99)
15
16 // Display the values stored in the fields.
17 Display "The manufacturer is ", myPhone.getManufacturer()
18 Display "The model number is ", myPhone.getModelNumber()
19 Display "The retail price is ", myPhone.getRetailPrice()
20 End Module

```

### Program Output

```

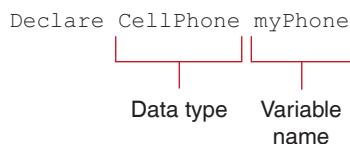
The manufacturer is Motorola
The model number is M1000
The retail price is 199.99

```

The statement in line 4 is a variable declaration. It declares a variable named `myPhone`. This statement looks like any other variable declaration that you have seen, except that the data type is the name of the `CellPhone` class. This is shown in Figure 14-5. When you declare a variable and specify the name of a class as the variable's data type, you

are creating a class variable. A *class variable* is a special type of variable that can reference an object in the computer's memory, and work with that object. The `myPhone` variable that is declared in line 4 can be used to reference an object that is created from the `CellPhone` class.

**Figure 14-5** Class variable declaration



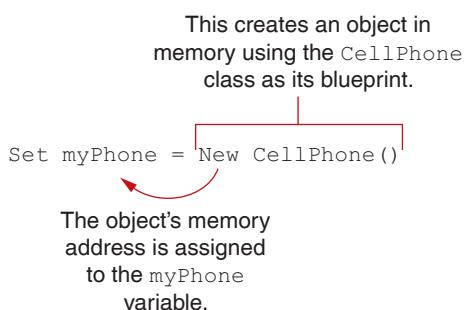
In many object-oriented languages, the act of declaring a class variable does not actually create an object in memory. It only creates a variable that can be used to work with an object. The next step is to create an object. This is done with the following assignment statement, which appears in line 9:

```
Set myPhone = New CellPhone()
```

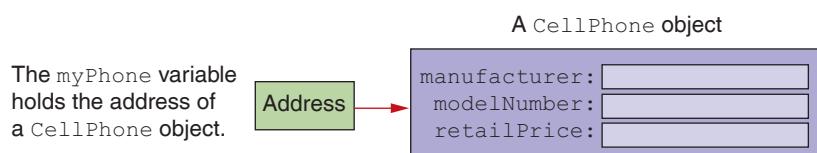
Notice that on the right side of the `=` operator, the key word `New` appears. In many programming languages, the key word `New` creates an object in memory. The name of a class appears next (in this case it is `CellPhone`), followed by a set of parentheses. This specifies the class that should be used as a blueprint to create the object. Once the object is created, the `=` operator assigns the memory address of the object to the `myPhone` variable. The actions performed by this statement are shown in Figure 14-6.

When a class variable is assigned the address of an object, it is said that the variable *references* the object. As shown in Figure 14-7, the `myPhone` variable will reference a `CellPhone` object after this statement executes.

**Figure 14-6** Creating an object and assigning its address to a class variable



**Figure 14-7** The `myPhone` variable references a `CellPhone` object





**NOTE:** In some languages, such as C++, the act of declaring a class variable also creates an object in memory. In these languages, it is not necessary to use the New key word to create the object as we did in line 9 of Program 14-1.

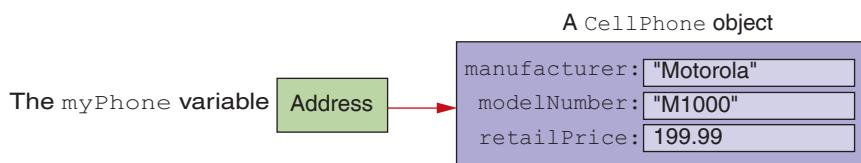
The following statement, which appears in line 12, is next:

```
Call myPhone.setManufacturer("Motorola")
```

This statement calls the `myPhone.setManufacturer` method. The expression `myPhone.setManufacturer` is written in *dot notation*. It's called dot notation because programmers refer to the period as a “dot.” On the left side of the dot is the name of a class variable that references an object. On the right side of the dot is the name of the method we are calling. When this statement executes, it uses the object referenced by `myPhone` to call the `setManufacturer` method, passing the string `"Motorola"` as an argument. As a result, the string `"Motorola"` will be assigned to the object’s `manufacturer` field.

Line 13 calls the `myPhone.setModelNumber` method, passing the string `"M1000"` as an argument. After this statement executes, the string `"M1000"` will be stored in the object’s `modelNumber` field. Line 14 calls the `myPhone.setRetailPrice` method, passing `199.99` as an argument. This causes `199.99` to be assigned to the `retailPrice` field. Figure 14-8 shows the state of the object after the statements in lines 12 through 14 execute.

**Figure 14-8** The state of the object referenced by `myPhone`



The statements in lines 17 through 19 display the values in the object’s fields. Here is the statement in line 17:

```
Display "The manufacturer is ", myPhone.getManufacturer()
```

This statement calls the `myPhone.getManufacturer` method, which returns the string `"Motorola"`. The following message is displayed on the screen:

```
The manufacturer is Motorola
```

The following statement, in line 18, executes next:

```
Display "The model number is ", myPhone.getModelNumber()
```

This statement calls the `myPhone.getModelNumber` method, which returns the string `"M1000"`. The following message is displayed on the screen:

```
The model number is M1000
```

The following statement, in line 19, executes next:

```
Display "The retail price is ", myPhone.getRetailPrice()
```

This statement calls the `myPhone.getRetailPrice` method, which returns the value 199.99. The following message is displayed on the screen:

```
The retail price is 199.99
```

## Accessor and Mutator Methods

As mentioned earlier, it is a common practice to make all of a class's fields private and to provide public methods for accessing and changing those fields. This ensures that the object owning those fields is in control of all changes being made to them. A method that gets a value from a class's field but does not change it is known as an *accessor method*. A method that stores a value in a field or changes the value of a field in some other way is known as a *mutator method*. In the `CellPhone` class, the methods `getManufacturer`, `getModelNumber`, and `getRetailPrice` are accessors, and the methods `setManufacturer`, `setModelNumber`, and `setRetailPrice` are mutators.



### NOTE:

Mutator methods are sometimes called “setters” and accessor methods are sometimes called “getters.”

## Constructors

A constructor is a method that is automatically called when an object is created. In most cases, a constructor is used to initialize an object's fields with starting values. These methods are called “constructors” because they help construct an object.

In many programming languages, a constructor has the same name as the class that the constructor is in. That is the convention followed in this book. For example, if we write a constructor in the `CellPhone` class, we will write a module named `CellPhone`. The pseudocode in Class Listing 14-4 shows a new version of the class with a constructor added to it. The constructor appears in lines 8 through 13.



### NOTE:

In Visual Basic, constructors are named `New`.

### Class Listing 14-4



```
1 Class CellPhone
2 // Field declarations
3 Private String manufacturer
4 Private String modelNumber
5 Private Real retailPrice
6
7 // Constructor
8 Public Module CellPhone(String manufact,
9 String modNum, Real retail)
10 Set manufacturer = manufact
11 Set modelNumber = modNum
12 Set retailPrice = retail
13 End Module
14
```

```

15 // Mutator methods
16 Public Module setManufacturer(String manufact)
17 Set manufacturer = manufact
18 End Module
19
20 Public Module setModelNumber(String modNum)
21 Set modelNumber = modNum
22 End Module
23
24 Public Module setRetailPrice(String retail)
25 Set retailPrice = retail
26 End Module
27
28 // Accessor methods
29 Public Function String getManufacturer()
30 Return manufacturer
31 End Function
32
33 Public Function String getModelNumber()
34 Return modelNumber
35 End Function
36
37 Public Function Real getRetailPrice()
38 Return retailPrice
39 End Function
40 End Class

```

The constructor accepts three arguments, which are passed into the `manufact`, `modNum`, and `retail` parameters. In lines 10 through 12, these parameters are assigned to the `manufacturer`, `modelNumber`, and `retailPrice` fields.

The pseudocode in Program 14-2 creates a `CellPhone` object and uses the constructor to initialize the object's fields. In line 9, notice that after the class name, the values "Motorola", "M1000", and 199.99 appear inside the parentheses. These arguments are passed to the `manufact`, `modelNum`, and `retail` parameters in the constructor. The code in the constructor then assigns those values to the `manufacturer`, `modelNumber`, and `retailPrice` fields.

### Program 14-2



```

1 Module main()
2 // Declare a variable that can reference
3 // a CellPhone object.
4 Declare CellPhone myPhone
5
6 // The following statement creates a CellPhone
7 // object and initializes its fields with the
8 // values passed to the constructor.
9 Set myPhone = New CellPhone("Motorola", "M1000", 199.99)
10
11 // Display the values stored in the fields.
12 Display "The manufacturer is ", myPhone.getManufacturer()
13 Display "The model number is ", myPhone.getModelNumber()
14 Display "The retail price is ", myPhone.getRetailPrice()
15 End Module

```

**Program Output**

```
The manufacturer is Motorola
The model number is M1000
The retail price is 199.99
```

The pseudocode in Program 14-3 shows another example that uses the `CellPhone` class. This program prompts the user to enter the data for a cell phone and then creates an object containing that data.

**Program 14-3**

```
1 Module main()
2 // Variables to hold data entered by the user.
3 Declare String manufacturer, model
4 Declare Real retail
5
6 // Declare a variable that can reference
7 // a CellPhone object.
8 Declare CellPhone phone
9
10 // Get the data for a cell phone from the user.
11 Display "Enter the phone's manufacturer."
12 Input manufacturer
13 Display "Enter the phone's model number."
14 Input model
15 Display "Enter the phone's retail price."
16 Input retail
17
18 // Create a CellPhone object initialized with the
19 // data entered by the user.
20 Set phone = New CellPhone(manufacturer, model, retail)
21
22 // Display the values stored in the fields.
23 Display "Here is the data you entered."
24 Display "The manufacturer is ", myPhone.getManufacturer()
25 Display "The model number is ", myPhone.getModelNumber()
26 Display "The retail price is ", myPhone.getRetailPrice()
27 End Module
```

**Program Output (with Input Shown in Bold)**

```
Enter the phone's manufacturer.
Samsung [Enter]
Enter the phone's model number.
S900 [Enter]
Enter the phone's retail price.
179.99 [Enter]
Here is the data you entered.
The manufacturer is Samsung
The model number is S900
The retail price is 179.99
```

## Default Constructors

In most object-oriented languages, when an object is created its constructor is *always* called. But what if we do not write a constructor in the class that the object is created from? If you do not write a constructor in a class, most languages automatically provide one when the class is compiled. The constructor that is automatically provided is usually known as the *default constructor*. The actions performed by the default constructor vary from one language to another. Typically, the default constructor assigns default starting values to the object's fields.



### Checkpoint

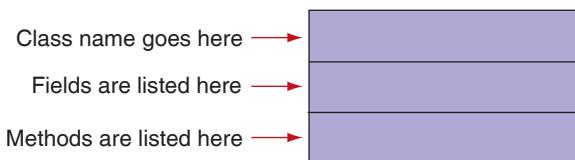
- 14.5 You hear someone make the following comment: “A blueprint is a design for a house. A carpenter can use the blueprint to build the house. If desired, the carpenter can build several identical houses from the same blueprint.” Think of this as a metaphor for classes and objects. Does the blueprint represent a class, or does it represent an object?
- 14.6 In this chapter, we use the metaphor of a cookie cutter and cookies that are made from the cookie cutter to describe classes and objects. In this metaphor, are objects the cookie cutter, or the cookies?
- 14.7 What is an access specifier?
- 14.8 What access specifier is commonly used with a class's fields?
- 14.9 When a class variable is said to reference an object, what is actually stored in the class variable?
- 14.10 What does the New key word do?
- 14.11 What is an accessor? What is a mutator?
- 14.12 What is a constructor? When does a constructor execute?
- 14.13 What is a default constructor?

**14.3**

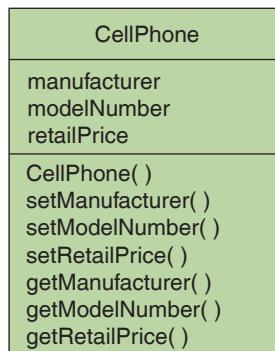
## Using the Unified Modeling Language to Design Classes

**CONCEPT:** The Unified Modeling Language (UML) is a standard way of drawing diagrams that describe object-oriented systems.

When designing a class, it is often helpful to draw a UML diagram. UML stands for Unified Modeling Language. It provides a set of standard diagrams for graphically depicting object-oriented systems. Figure 14-9 shows the general layout of a UML diagram for a class. Notice that the diagram is a box that is divided into three sections. The top section is where you write the name of the class. The middle section holds a list of the class's fields. The bottom section holds a list of the class's methods.

**Figure 14-9** General layout of a UML diagram for a class

Following this layout, Figure 14-10 shows a simplified UML diagram for our CellPhone class.

**Figure 14-10** Simplified UML diagram for the CellPhone class

## Data Type and Method Parameter Notation

The UML diagram in Figure 14-10 shows only basic information about the CellPhone class. It does not show details such as data types and the method's parameters. To indicate the data type of a field, place a colon followed by the name of the data type after the name of the field. For example, the manufacturer field in the CellPhone class is a String. It could be listed in the UML diagram as follows:

```
manufacturer : String
```

The return type of a method can be listed in the same manner. After the method's name, place a colon followed by the return type. The CellPhone class's getRetailPrice method returns a Real, so it could be listed in the UML diagram as follows:

```
getRetailPrice() : Real
```

Parameter variables and their data types may be listed inside a method's parentheses. For example, the CellPhone class's setManufacturer method has a String parameter named manufact, so it could be listed in the UML diagram as follows:

```
setManufacturer(manufact : String)
```

Figure 14-11 shows the UML diagram for the CellPhone class with data type and parameter notation added to it.

**Figure 14-11** UML diagram for the CellPhone class with data type and parameter notation

## Access Specification Notation

The UML diagrams in Figures 14-10 and 14-11 list all of the fields and methods in the CellPhone class but do not indicate which are private and which are public. In a UML diagram, you have the option to place a - character before a field or method name to indicate that it is private, or a + character to indicate that it is public. Figure 14-12 shows the UML diagram modified to include this notation.

**Figure 14-12** UML diagram for the CellPhone class with access specification notation

## Checkpoint

- 14.14 The typical UML diagram for a class has three sections. What appears in these three sections?
- 14.15 Suppose a class has a field named `description`. The field's data type is `String`. How would you indicate the field's data type in a UML diagram?
- 14.16 What symbols do you use in a UML diagram to indicate private and public access specification?

**14.4**

## Finding the Classes and Their Responsibilities in a Problem

**CONCEPT:** One of the first steps when designing an object-oriented program is finding the classes that should be created and determining those classes' responsibilities in the program.

So far, you have learned the basics of writing a class, creating an object from the class, and using the object to perform operations. Although this knowledge is necessary to create an object-oriented application, it is not the first step. The first step is to analyze the problem that you are trying to solve and determine the classes that you will need. The following two *In the Spotlight* sections lead you through a simple process for finding the classes in a problem and determining their responsibilities.

### In the Spotlight: Finding the Classes in a Problem



The owner of Joe's Automotive Shop has asked you to design a program that will print service quotes for customers. You decide to use an object-oriented approach to design the program. One of your first tasks is to identify the classes that you will need to create. In many cases, this means identifying the different types of real-world objects that are present in the problem, and then creating classes for those types of objects within your program.

Over the years, software professionals have developed numerous techniques for finding the classes in a given problem. One simple and popular technique involves the following steps:

1. Get a written description of the problem domain.
2. Identify all the nouns (including pronouns and noun phrases) in the description. Each of these is a potential class.
3. Refine the list to include only the classes that are relevant to the problem.

Let's take a closer look at each of these steps.

#### Writing a Description of the Problem Domain

The *problem domain* is the set of real-world objects, parties, and major events related to the problem. If you adequately understand the nature of the problem you are trying to solve, you can write a description of the problem domain yourself. If you do not thoroughly understand the nature of the problem, you should have an expert write the description for you.

A problem domain description should include any or all of the following:

- Physical objects, such as vehicles, machines, or products
- Roles played by people, such as manager, employee, customer, teacher, student, and so on

- The results of a business event, such as a customer order, or in this case a service quote
- Record-keeping items, such as customer histories and payroll records

Here is a description that was written by Joe, the owner of Joe's Automotive Shop:

Joe's Automotive Shop services foreign cars, and specializes in servicing cars made by Mercedes, Porsche, and BMW. When a customer brings a car to the shop, the manager gets the customer's name, address, and telephone number. The manager then determines the make, model, and year of the car, and gives the customer a service quote. The service quote shows the estimated parts charges, estimated labor charges, sales tax, and total estimated charges.

### Identifying All of the Nouns

The next step is to identify all of the nouns and noun phrases in the problem description. (If the description contains pronouns, include them too.) Here's another look at the previous problem domain description that was written by Joe. This time the nouns and noun phrases appear in bold.

**Joe's Automotive Shop** services **foreign cars**, and specializes in servicing **cars** made by **Mercedes**, **Porsche**, and **BMW**. When a **customer** brings a **car** to the **shop**, the **manager** gets the **customer's name**, **address**, and **telephone number**. The **manager** then determines the **make**, **model**, and **year** of the **car**, and gives the **customer** a **service quote**. The **service quote** shows the **estimated parts charges**, **estimated labor charges**, **sales tax**, and **total estimated charges**.

Notice that some of the nouns are repeated. The following list shows all of the nouns without duplicates:

|                         |                         |
|-------------------------|-------------------------|
| address                 | Mercedes                |
| BMW                     | model                   |
| car                     | name                    |
| cars                    | Porsche                 |
| customer                | sales tax               |
| estimated labor charges | service quote           |
| estimated parts charges | shop                    |
| foreign cars            | telephone number        |
| Joe's Automotive Shop   | total estimated charges |
| make                    | year                    |
| manager                 |                         |

### Refining the List of Nouns

The nouns that appear in the problem description are merely candidates to become classes. It might not be necessary to make classes for all of them. The next step is to refine the list to include only the classes that are necessary to solve the particular problem at hand. We will look at the common reasons that a noun can be eliminated from the list of potential classes.

#### 1. Some of the nouns really mean the same thing.

In this example, the following sets of nouns refer to the same thing:

- **cars and foreign cars**
- Both of these refer to the general concept of a car.
- **Joe's Automotive Shop and shop**  
Both of these refer to the company “Joe’s Automotive Shop.”

We can settle on a single class for each of these. In this example, we will arbitrarily eliminate **foreign cars** from the list, and use the word **cars**. Likewise, we will eliminate **Joe’s Automotive Shop** from the list and use the word **shop**. The updated list of potential classes is as follows:

|                              |                         |
|------------------------------|-------------------------|
| address                      | Mercedes                |
| BMW                          | model                   |
| car                          | name                    |
| cars                         | Porsche                 |
| customer                     | sales tax               |
| estimated labor charges      | service quote           |
| estimated parts charges      | shop                    |
| <b>foreign cars</b>          | telephone number        |
| <b>Joe's Automotive Shop</b> | total estimated charges |
| make                         | year                    |
| manager                      |                         |

Because **cars** and **foreign cars** mean the same thing in this problem, we have eliminated **foreign cars**. Also, because **Joe’s Automotive Shop** and **shop** mean the same thing, we have eliminated **Joe’s Automotive Shop**.

## 2. Some nouns might represent items that we do not need to be concerned with in order to solve the problem.

A quick review of the problem description reminds us of what our application should do: print a service quote. In this example, we can eliminate two unnecessary classes from the list:

- We can cross **shop** off the list because our application only needs to be concerned with individual service quotes. It doesn’t need to work with or determine any company-wide information. If the problem description asked us to keep a total of all the service quotes, then it would make sense to have a class for the **shop**.
- We will not need a class for the **manager** because the problem statement does not direct us to process any information about the manager. If there were multiple shop managers, and the problem description had asked us to record which manager generated each service quote, then it would make sense to have a class for the **manager**.

The updated list of potential classes at this point is as follows:

|                         |                              |
|-------------------------|------------------------------|
| address                 | estimated parts charges      |
| BMW                     | <b>foreign cars</b>          |
| car                     | <b>Joe's Automotive Shop</b> |
| cars                    | make                         |
| customer                | <b>manager</b>               |
| estimated labor charges | Mercedes                     |

|               |                         |
|---------------|-------------------------|
| model         | shop                    |
| name          | telephone number        |
| Porsche       | total estimated charges |
| sales tax     | year                    |
| service quote |                         |

Our problem description does not direct us to process any information about the **shop**, or any information about the **manager**, so we have eliminated those from the list.

### 3. Some of the nouns might represent objects, not classes.

We can eliminate **Mercedes**, **Porsche**, and **BMW** as classes because, in this example, they all represent specific cars, and can be considered instances of the **cars** class. Also, we can eliminate the word **car** from the list. In the description, it refers to a specific car brought to the shop by a customer. Therefore, it would also represent an instance of the **cars** class. At this point the updated list of potential classes is as follows:

|                         |                         |
|-------------------------|-------------------------|
| address                 | Mercedes                |
| <b>BMW</b>              | model                   |
| ear                     | name                    |
| cars                    | Porsche                 |
| customer                | sales tax               |
| estimated labor charges | service quote           |
| estimated parts charges | <b>shop</b>             |
| <b>foreign cars</b>     | telephone number        |
| Joe's Automotive Shop   | total estimated charges |
| make                    | year                    |
| manager                 |                         |

We have eliminated **Mercedes**, **Porsche**, **BMW**, and **car** because they are all instances of the **cars** class. That means that these nouns identify objects, not classes.



**TIP:** Some object-oriented designers note whether a noun is plural or singular. Sometimes a plural noun will indicate a class and a singular noun will indicate an object.

### 4. Some of the nouns might represent simple values that can be stored in a regular variable and do not require a class.

Remember, a class contains fields and methods. Fields are related items that are stored within an object of the class, and define the object's state. Methods are actions or behaviors that may be performed by an object of the class. If a noun represents a type of item that would not have any identifiable fields or methods, then it can probably be eliminated from the list. To help determine whether a noun represents an item that would have fields and methods, ask the following questions:

- Would you use a group of related values to represent the item's state?
- Are there any obvious actions to be performed by the item?

If the answers to both of these questions are no, then the noun probably represents a value that can be stored in a regular variable. If we apply this test to each of the nouns that remain in our list, we can conclude that the following are probably not classes: **address**, **estimated labor charges**, **estimated parts charges**, **make**, **model**, **name**, **sales tax**, **telephone number**, **total estimated charges**, and **year**. These are all simple string or numeric values that can be stored in variables. The following is the updated list of potential classes:

|                         |                         |
|-------------------------|-------------------------|
| address                 | Mercedes                |
| BMW                     | model                   |
| car                     | name                    |
| cars                    | Porsche                 |
| customer                | sales tax               |
| estimated labor charges | service quote           |
| estimated parts charges | shop                    |
| foreign cars            | telephone number        |
| Joe's Automotive Shop   | total estimated charges |
| make                    | year                    |
| manager                 |                         |

We have eliminated address, estimated labor charges, estimated parts charges, make, model, name, sales tax, telephone number, total estimated charges, and year as classes because they represent simple values that can be stored in primitive variables.

As you can see from the list, we have eliminated everything except cars, customer, and service quote. This means that in our application, we will need classes to represent cars, customers, and service quotes. In the next *In the Spotlight* section, we will write a Car class, a Customer class, and a ServiceQuote class.

## In the Spotlight: Determining Class Responsibilities



In the previous *In the Spotlight* section, we examined the problem domain description for the Joe's Automotive Shop program. We also identified the classes that we will need, which are **Car**, **Customer**, and **ServiceQuote**. The next step is to determine those classes' *responsibilities*. A class's *responsibilities* are as follows:

- The things that the class is responsible for knowing
- The actions that the class is responsible for doing

When you have identified the things that a class is responsible for knowing, then you have identified the values that will be stored in fields. Likewise, when you have identified the actions that a class is responsible for doing, you have identified its methods.

It is often helpful to ask the questions “In this program, what must the class know? What must the class do?” The first place to look for the answers is in the description of the problem domain. Many of the things that a class must know and do will be mentioned. Some class responsibilities, however, might not be directly mentioned in the problem domain, so brainstorming is often required. Let’s apply this methodology to the classes we previously identified from our problem domain.

### The Customer Class

In this program, what must the `Customer` class know? The problem domain description directly mentions the following items:

- The customer’s name
- The customer’s address
- The customer’s telephone number

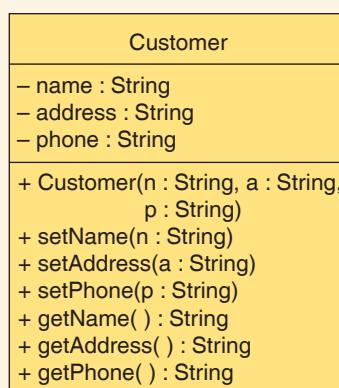
These are all values that can be represented as strings and stored in the class’s fields. The `Customer` class can potentially know many other things. One mistake that can be made at this point is to identify too many things that an object is responsible for knowing. In some programs, a `Customer` class might know the customer’s email address. This particular problem domain does not mention that the customer’s email address is used for any purpose, so we should not include it as a responsibility.

Now, let’s identify the class’s methods. In this program, what must the `Customer` class do? The following are the only obvious actions:

- Create an object of the `Customer` class
- Set and get the customer’s name
- Set and get the customer’s address
- Set and get the customer’s telephone number

From this list, we can see that the `Customer` class will have a constructor, as well as accessor and mutator methods, for each of its fields. Figure 14-13 shows a UML diagram for the `Customer` class. Class Listing 14-5 shows the pseudocode for a class definition.

**Figure 14-13** UML diagram for the `Customer` class



**Class Listing 14-5**

```
1 Class Customer
2 // Fields
3 Private String name
4 Private String address
5 Private String phone
6
7 // Constructor
8 Public Module Customer(String n, String a,
9 String p)
10 Set name = n
11 Set address = a
12 Set phone = p
13 End Module
14
15 // Mutators
16 Public Module setName(String n)
17 Set name = n
18 End Module
19
20 Public Module setAddress(String a)
21 Set address = a
22 End Module
23
24 Public Module setPhone(String p)
25 Set phone = p
26 End Module
27
28 // Accessors
29 Public Function String getName()
30 Return name
31 End Function
32
33 Public Function String getAddress()
34 Return address
35 End Function
36
37 Public Function String getPhone()
38 Return phone
39 End Function
40 End Class
```

**The Car Class**

In this program, what must an object of the Car class know? The following items are all attributes of a car, and are mentioned in the problem domain:

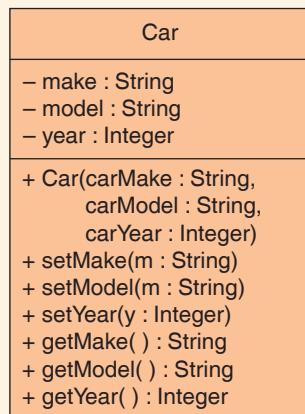
- the car's make
- the car's model
- the car's year

Now let's identify the class's methods. In this program, what must the `Car` class do? Once again, the only obvious actions are the standard set of methods that we will find in most classes (constructors, accessors, and mutators). Specifically, the actions are as follows:

- create an object of the `Car` class
- set and get the car's make
- set and get the car's model
- set and get the car's year

Figure 14-14 shows a UML diagram for the `Car` class, and Class Listing 14-6 shows the pseudocode for a class definition.

**Figure 14-14** UML diagram for the `Car` class



#### Class Listing 14-6

```

1 Class Car
2 // Fields
3 Private String make
4 Private String model
5 Private Integer year
6
7 // Constructor
8 Public Module Car(String carMake,
9 String carModel, Integer carYear)
10 Set make = carMake
11 Set model = carModel
12 Set year = carYear
13 End Module
14
15 // Mutators
16 Public Module setMake(String m)
17 Set make = m
18 End Module
19
20 Public Module setModel(String m)
21 Set model = m
22 End Module

```

```

23
24 Public Module setYear(Integer y)
25 Set year = y
26 End Module
27
28 // Accessors
29 Public Function String getMake()
30 Return make
31 End Function
32
33 Public Function String getModel()
34 Return model
35 End Function
36
37 Public Function Integer getYear()
38 Return year
39 End Function
40 End Class

```

### The ServiceQuote Class

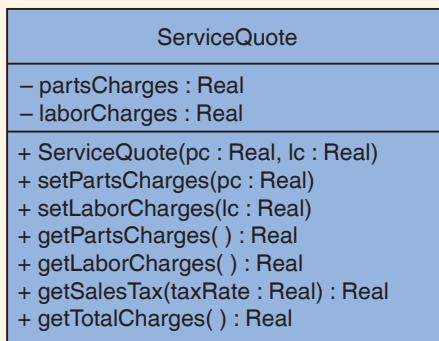
In this program, what must an object of the `ServiceQuote` class know? The problem domain mentions the following items:

- the estimated parts charges
- the estimated labor charges
- the sales tax
- the total estimated charges

Careful thought and a little brainstorming will reveal that two of these items are the results of calculations: sales tax and total estimated charges. These items are dependent on the values of the estimated parts and labor charges. Instead of storing these values in fields, we will provide methods that calculate these values and return them. (In a moment we will explain why we take this approach.)

The other methods that we will need for this class are a constructor and the accessors and mutators for the estimated parts charges and estimated labor charges fields. Figure 14-15 shows a UML diagram for the `ServiceQuote` class, and Class Listing 14-7 shows the pseudocode for a class definition.

**Figure 14-15** UML diagram for the `ServiceQuote` class



**Class Listing 14-7**

```

1 Class ServiceQuote
2 // Fields
3 Private Real partsCharges
4 Private Real laborCharges
5
6 // Constructor
7 Public Module ServiceQuote(Real pc, Real lc)
8 Set partsCharges = pc
9 Set laborCharges = lc
10 End Module
11
12 // Mutators
13 Public Module setPartsCharges(Real pc)
14 Set partsCharges = pc
15 End Module
16
17 Public Module setLaborCharges(Real lc)
18 Set laborCharges = lc
19 End Module
20
21 // Accessors
22 Public Function Real getPartsCharges()
23 Return partsCharges
24 End Function
25
26 Public Function Real getLaborCharges()
27 Return laborCharges
28 End Function
29
30 Public Function Real getSalesTax(Real taxRate)
31 // Sales tax is charged only on parts.
32 Return partsCharges * taxRate
33 End Function
34
35 Public Function Real getTotalCharges(Real taxRate)
36 Return partsCharges + laborCharges + getSalesTax(taxRate)
37 End Function
38 End Class

```

First, notice that the `getSalesTax` method, in lines 30 through 33, accepts a `Real` argument for the tax rate. The method returns the amount of sales tax in line 32, which is the result of a calculation.

The `getTotalCharges` method, in lines 35 through 37, returns the total charges estimate. The value that is returned by this method is the result of a calculation. The value that is returned in line 36 is the result of the expression `partsCharges + laborCharges + getSalesTax(taxRate)`. Notice that this expression calls one of the object's own methods: `getSalesTax`.

### Avoiding Stale Data

In the ServiceQuote class, the `getPartsCharges` and `getLaborCharges` methods return the values stored in fields, but the `getSalesTax` and `getTotalCharges` methods return the results of calculations. You might be wondering why the sales tax and the total charges are not stored in fields, like the parts charges and labor charges. These values are not stored in fields because they could potentially become *stale*. When the value of an item is dependent on other data and that item is not updated when the other data is changed, it is said that the item has become stale. If the sales tax and total charges were stored in fields, the values of those fields would become incorrect as soon as the `partsCharges` or `laborCharges` field changed.

When designing a class, you should take care not to store in a field any calculated data that can potentially become stale. Instead, provide a method that returns the result of the calculation.



### Checkpoint

- 14.17 What is a problem domain description?
- 14.18 What technique was described in this section for finding the classes in a particular problem?
- 14.19 What are classes' responsibilities?
- 14.20 What causes an item of data to become stale?

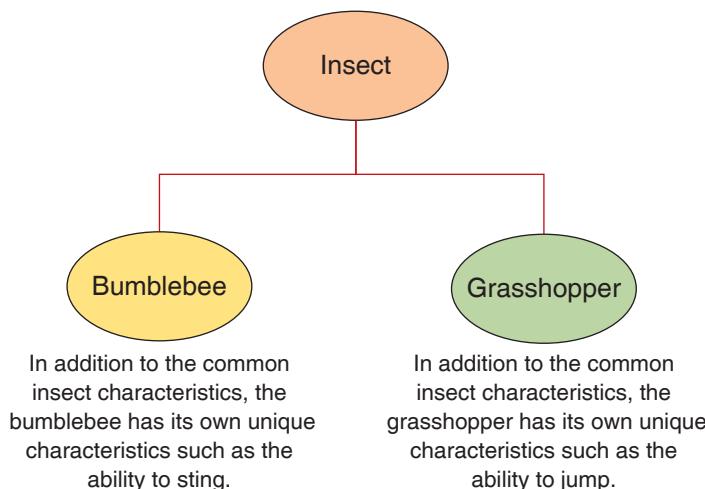
14.5

## Inheritance

**CONCEPT:** Inheritance allows a new class to extend an existing class. The new class inherits the members of the class it extends.

### Generalization and Specialization

In the real world, you can find many objects that are specialized versions of other more general objects. For example, the term *insect* describes a very general type of creature with numerous characteristics. Because grasshoppers and bumblebees are insects, they have all the general characteristics of an insect. In addition, they have special characteristics of their own. For example, the grasshopper has its jumping ability, and the bumblebee has its stinger. Grasshoppers and bumblebees are specialized versions of an insect. This is illustrated in Figure 14-16.

**Figure 14-16** Bumblebees and grasshoppers are specialized versions of an insect

## Inheritance and the “Is a” Relationship

When one object is a specialized version of another object, there is an “is a” relationship between them. For example, a grasshopper is an insect. Here are a few other examples of the “is a” relationship:

- A poodle is a dog.
- A car is a vehicle.
- A flower is a plant.
- A rectangle is a shape.
- A football player is an athlete.

When an “is a” relationship exists between objects, it means that the specialized object has all of the characteristics of the general object, plus additional characteristics that make it special. In object-oriented programming, inheritance is used to create an “is a” relationship among classes. This allows you to extend the capabilities of a class by creating another class that is a specialized version of it.

Inheritance involves a superclass and a subclass. The *superclass* is the general class and the *subclass* is the specialized class. You can think of the subclass as an extended version of the superclass. The subclass inherits fields and methods from the superclass without any of them having to be rewritten. Furthermore, new fields and methods may be added to the subclass, and that is what makes it a specialized version of the superclass.

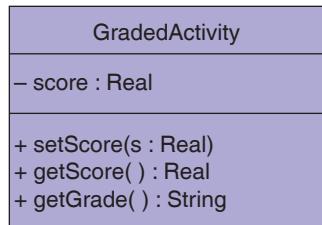


**NOTE:** Superclasses are also called *base classes*, and subclasses are also called *derived classes*. Either set of terms is correct. For consistency, this text will use the terms *superclass* and *subclass*.

Let’s look at an example of how inheritance can be used. Most teachers assign various graded activities for their students to complete. A graded activity can be given a numeric score such as 70, 85, 90, and so on, and a letter grade such as A, B, C, D, or F.

Figure 14-17 shows a UML diagram for the `GradedActivity` class, which is designed to hold the numeric score of a graded activity. The `setScore` method sets a numeric score, and the `getScore` method returns the numeric score. The `getGrade` method returns the letter grade that corresponds to the numeric score. Class Listing 14-8 shows the pseudocode for the class. The pseudocode in Program 14-4 demonstrates how the class works.

**Figure 14-17** UML diagram for the `GradedActivity` class



### Class Listing 14-8



```
1 Class GradedActivity
2 // The score field holds a numeric score.
3 Private Real score
4
5 // Mutator
6 Public Module setScore(Real s)
7 Set score = s
8 End Module
9
10 // Accessor
11 Public Function Real getScore()
12 Return score
13 End Function
14
15 // getGrade method
16 Public Function String getGrade()
17 // Local variable to hold a grade.
18 Declare String grade
19
20 // Determine the grade.
21 If score >= 90 Then
22 Set grade = "A"
23 Else If score >= 80 Then
24 Set grade = "B"
25 Else If score >= 70 Then
26 Set grade = "C"
27 Else If score >= 60 Then
28 Set grade = "D"
29 Else
30 Set grade = "F"
31 End If
32
```

```

33 // Return the grade.
34 Return grade
35 End Function
36 End Class

```

#### Program 14-4

```

1 Module main()
2 // A variable to hold a test score.
3 Declare Real testScore
4
5 // A class variable to reference a
6 // GradedActivity object.
7 Declare GradedActivity test
8
9 // Create a GradedActivity object.
10 Set test = New GradedActivity()
11
12 // Get a test score from the user.
13 Display "Enter a numeric test score."
14 Input testScore
15
16 // Store the test score in the object.
17 test.setScore(testScore)
18
19 // Display the grade for the object.
20 Display "The grade for that test is ",
21 test.getGrade()
22 End Module

```

#### Program Output (with Input Shown in Bold)

```

Enter a numeric test score.
89 [Enter]
The grade for that test is B

```

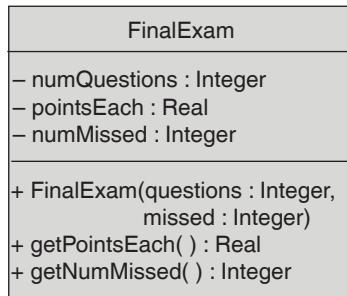
#### Program Output (with Input Shown in Bold)

```

Enter a numeric test score.
75 [Enter]
The grade for that test is C

```

The `GradedActivity` class represents the general characteristics of a student's graded activity. Many different types of graded activities exist, however, such as quizzes, mid-term exams, final exams, lab reports, essays, and so on. Because the numeric scores might be determined differently for each of these graded activities, we can create subclasses to handle each one. For example, we could create a `FinalExam` class that would be a subclass of the `GradedActivity` class. Figure 14-18 shows the UML diagram for such a class, and Class Listing 14-9 shows its definition in pseudocode. The class has fields for the number of questions on the exam (`numQuestions`), the number of points each question is worth (`pointsEach`), and the number of questions missed by the student (`numMissed`).

**Figure 14-18** UML diagram for the FinalExam class**Class Listing 14-9**

```
1 Class FinalExam Extends GradedActivity
2 // Fields
3 Private Integer numQuestions
4 Private Real pointsEach
5 Private Integer numMissed
6
7 // The constructor sets the number of
8 // questions on the exam and the number
9 // of questions missed.
10 Public Module FinalExam(Integer questions,
11 Integer missed)
12 // Local variable to hold the numeric score.
13 Declare Real numericScore
14
15 // Set the numQuestions and numMissed fields.
16 Set numQuestions = questions
17 Set numMissed = missed
18
19 // Calculate the points for each question
20 // and the numeric score for this exam.
21 Set pointsEach = 100.0 / questions
22 Set numericScore = 100.0 - (missed * pointsEach)
23
24 // Call the inherited setScore method to
25 // set the numeric score.
26 Call setScore(numericScore)
27 End Module
28
29 // Accessors
30 Public Function Real getPointsEach()
31 Return pointsEach
32 End Function
33
34 Public Function Integer getNumMissed()
35 Return numMissed
36 End Function
37 End Class
```

Notice that the first line of the `FinalExam` class declaration uses the `Extends` key word, which indicates that this class extends another class (a superclass). The name of the superclass is listed after the word `extends`. So, this line indicates that `FinalExam` is the name of the class being declared and `GradedActivity` is the name of the superclass it extends.

If we want to express the relationship between the two classes, we can say that a `FinalExam` is a `GradedActivity`. Because the `FinalExam` class extends the `GradedActivity` class, it inherits all of the public members of the `GradedActivity` class. Here is a list of the members of the `FinalExam` class:

#### Fields:

|                           |                                              |
|---------------------------|----------------------------------------------|
| <code>numQuestions</code> | Declared in the <code>FinalExam</code> class |
| <code>pointsEach</code>   | Declared in the <code>FinalExam</code> class |
| <code>numMissed</code>    | Declared in the <code>FinalExam</code> class |

#### Methods:

|                            |                                                      |
|----------------------------|------------------------------------------------------|
| <code>Constructor</code>   | Declared in the <code>FinalExam</code> class         |
| <code>getPointsEach</code> | Declared in the <code>FinalExam</code> class         |
| <code>getNumMissed</code>  | Declared in the <code>FinalExam</code> class         |
| <code>setScore</code>      | Inherited from the <code>GradedActivity</code> class |
| <code>getScore</code>      | Inherited from the <code>GradedActivity</code> class |
| <code>getGrade</code>      | Inherited from the <code>GradedActivity</code> class |

Notice that the `GradedActivity` class's `score` field is not listed among the members of the `FinalExam` class. That is because the `score` field is private. In most languages, private members of the superclass cannot be accessed by the subclass, so technically speaking, they are not inherited. When an object of the subclass is created, the private members of the superclass exist in memory, but only methods in the superclass can access them. They are truly private to the superclass.

To see how inheritance works in this example, let's take a closer look at the `FinalExam` constructor in lines 10 through 27. The constructor accepts two arguments: the number of test questions on the exam, and the number of questions missed by the student. In lines 16 and 17 these values are assigned to the `numQuestions` and `numMissed` fields. Then, in lines 21 and 22, the number of points for each question and the numeric test score are calculated. In line 26, the last statement in the constructor reads as follows:

Call `setScore(numericScore)`

This is a call to the `setScore` method, which is inherited from the `GradedActivity` class. Although the `FinalExam` constructor cannot directly access the `score` field (because it is declared private in the `GradedActivity` class), it can call the `setScore` method to store a value in the `score` field.

The pseudocode in Program 14-5 demonstrates the `FinalExam` class.

#### Program 14-5



```

1 Module main()
2 // Variables to hold user input.
3 Declare Integer questions, missed

```

```
4 // Class variable to reference a FinalExam object.
5 Declare FinalExam exam
6
7 // Prompt the user for the number of questions
8 // on the exam.
9 Display "Enter the number of questions on the exam."
10 Input questions
11
12 // Prompt the user for the number of questions
13 // missed by the student.
14 Display "Enter the number of questions that the ",
15 "student missed."
16 Input missed
17
18 // Create a FinalExam object.
19 Set exam = New FinalExam(questions, missed)
20
21 // Display the test results.
22 Display "Each question on the exam counts ",
23 exam.getPointsEach(), " points."
24 Display "The exam score is ", exam.getScore()
25 Display "The exam grade is ", exam.getGrade()
26
27 End Module
```

### Program Output (with Input Shown in Bold)

```
Enter the number of questions on the exam.
20 [Enter]
Enter the number of questions that the student missed.
3 [Enter]
Each question on the exam counts 5 points.
The exam score is 85
The exam grade is B
```

In line 20, the following statement creates an instance of the `FinalExam` class and assigns its address to the `exam` variable:

```
Set exam = New FinalExam(questions, missed)
```

When a `FinalExam` object is created in memory, not only does it have the members declared in the `FinalExam` class, but also it has the non-private members declared in the `GradedActivity` class. Notice in lines 25 and 26, shown here, that two public methods of the `GradedActivity` class, `getScore` and `getGrade`, are directly called with the `exam` object:

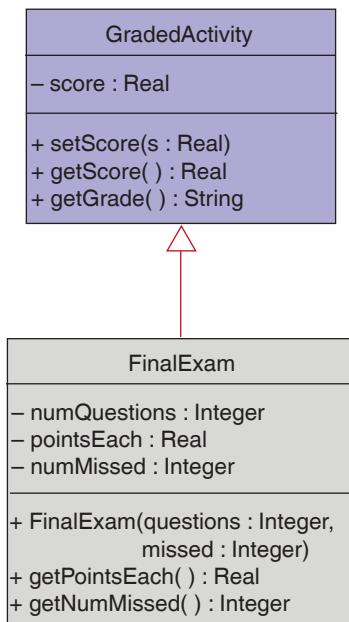
```
Display "The exam score is ", exam.getScore()
Display "The exam grade is ", exam.getGrade()
```

When a subclass extends a superclass, the public members of the superclass become public members of the subclass. In this program, the `getScore` and `getGrade` methods can be called with the `exam` object because they are public members of the object's superclass.

## Inheritance in UML Diagrams

You show inheritance in a UML diagram by connecting two classes with a line that has an open arrowhead at one end. The arrowhead points to the superclass. Figure 14-19 is a UML diagram showing the relationship between the `GradedActivity` and `FinalExam` classes.

**Figure 14-19** UML diagram showing inheritance



## Inheritance Does Not Work in Reverse

In an inheritance relationship, the subclass inherits members from the superclass, not the other way around. This means it is not possible for a superclass to call a subclass's methods. For example, if we create a `GradedActivity` object, it cannot call the `getPointsEach` and the `getNumMissed` methods because they are members of the `FinalExam` class.



### Checkpoint

- 14.21 In this section, we discussed superclasses and subclasses. Which is the general class and which is the specialized class?
- 14.22 What does it mean to say there is an “is a” relationship between two objects?
- 14.23 What does a subclass inherit from its superclass?
- 14.24 Look at the following pseudocode; which is the first line of a class definition? What is the name of the superclass? What is the name of the subclass?  
Class Canary Extends Bird

**14.6**

## Polymorphism

**CONCEPT:** Polymorphism allows you to create methods with the same name in different classes (that are related through inheritance) and gives you the ability to call the correct method depending on the type of object that is used to call it.

The term *polymorphism* refers to an object's ability to take different forms. It is a powerful feature of object-oriented programming. In this section, we will look at two essential ingredients of polymorphic behavior:

1. The ability to define a method in a superclass, and then define a method with the same name in a subclass. When a subclass method has the same name as a superclass method, it is often said that the subclass method *overrides* the superclass method.
2. The ability to declare a class variable of the superclass type, and then use that variable to reference objects of either the superclass or the subclass types.

The best way to describe polymorphism is to demonstrate it, so let's look at a simple example. Class Listing 14-10 shows pseudocode for a class named `Animal`.

**Class Listing 14-10**

```
1 Class Animal
2 // showSpecies method
3 Public Module showSpecies()
4 Display "I'm just a regular animal."
5 End Module
6
7 // makeSound method
8 Public Module makeSound()
9 Display "Grrrrr"
10 End Module
11 End Class
```

The class has two methods: `showSpecies` and `makeSound`. Here is an example of pseudocode that creates an instance of the class and calls the methods:

```
Declare Animal myAnimal
Set myAnimal = New Animal()
Call myAnimal.showSpecies()
Call myAnimal.makeSound()
```

If this were actual code, it would display the following:

```
I'm just a regular animal.
Grrrrr
```

Next, look at Class Listing 14-11, which shows the pseudocode for the `Dog` class. The `Dog` class is a subclass of the `Animal` class.

**Class Listing 14-11**

```

1 Class Dog Extends Animal
2 // showSpecies method
3 Public Module showSpecies()
4 Display "I'm a dog."
5 End Module
6
7 // makeSound method
8 Public Module makeSound()
9 Display "Woof! Woof!"
10 End Module
11 End Class

```

Even though the `Dog` class inherits the `showSpecies` and `makeSound` methods that are in the `Animal` class, those methods are not adequate for the `Dog` class. So, the `Dog` class has its own `showSpecies` and `makeSound` methods, which display messages that are more appropriate for a dog. We say that the `showSpecies` and `makeSound` methods in the `Dog` class override the `showSpecies` and `makeSound` methods in the `Animal` class. Here is an example of pseudocode that creates an instance of the `Dog` class and calls the methods:

```

Declare Dog myDog
Set myDog = New Dog()
Call myDog.showSpecies()
Call myDog.makeSound()

```

If this were actual code, it would display the following:

```

I'm a dog.
Woof! Woof!

```

Class Listing 14-12 shows pseudocode for the `Cat` class, which is also a subclass of the `Animal` class.

**Class Listing 14-12**

```

1 Class Cat Extends Animal
2 // showSpecies method
3 Public Module showSpecies()
4 Display "I'm a cat."
5 End Module
6
7 // makeSound method
8 Public Module makeSound()
9 Display "Meow"
10 End Module
11 End Class

```

The `Cat` class also has methods named `showSpecies` and `makeSound`. Here is an example of pseudocode that creates an instance of the `Cat` class and calls the methods:

```
Declare Cat myCat
Set myCat = New Cat()
Call myCat.showSpecies()
Call myCat.makeSound()
```

If this were actual code, it would display the following:

```
I'm a cat.
Meow
```

Because of the “is a” relationship between a superclass and a subclass, an object of the Dog class is not just a Dog object. It is also an Animal object. (A dog is an animal.) Because of this relationship, we can use an Animal class variable to reference a Dog object. For example, look at the following pseudocode:

```
Declare Animal myAnimal
Set myAnimal = New Dog()
Call myAnimal.showSpecies()
Call myAnimal.makeSound()
```

The first statement declares myAnimal as an Animal variable. The second statement creates a Dog object and stores the object’s address in the myAnimal variable. In most object-oriented languages this type of assignment is perfectly legal because a Dog object is also an Animal object. The third and fourth statements use the myAnimal object to call the showSpecies and makeSound methods. If this pseudocode were actual code, it would display the following in most programming languages:

```
I'm a dog.
Woof! Woof!
```

Similarly, we can use an Animal variable to reference a Cat object, as shown here:

```
Declare Animal myAnimal
Set myAnimal = New Cat()
Call myAnimal.showSpecies()
Call myAnimal.makeSound()
```

If this pseudocode were actual code, it would display the following in most programming languages:

```
I'm a cat.
Meow
```

This aspect of polymorphism gives us a great deal of flexibility when designing programs. For example, look at the following module:

```
Module showAnimalInfo(Animal creature)
 Call creature.showSpecies()
 Call creature.makeSound()
End Module
```

This module displays information about an animal. Because it has an Animal variable as its parameter, you can pass an Animal object to the module when you call it. The module then calls the object’s showSpecies method and makeSound method.

The showAnimalInfo module works with an Animal object, but what if you also need modules that display information about Dog objects and Cat objects? Do you need to write additional modules for each of these types? Because of polymorphism, the answer is *no*. In addition to Animal objects, you can also pass Dog objects or Cat objects

as arguments to the `showAnimalInfo` module previously shown. The pseudocode in Program 14-6 demonstrates this.

**Program 14-6**

```
1 Module main()
2 // Declare three class variables.
3 Declare Animal myAnimal
4 Declare Dog myDog
5 Declare Cat myCat
6
7 // Create an Animal object, a Dog object,
8 // and a Cat object.
9 Set myAnimal = New Animal()
10 Set myDog = New Dog()
11 Set myCat = New Cat()
12
13 // Show info about an animal.
14 Display "Here is info about an animal."
15 showAnimalInfo(myAnimal)
16 Display
17
18 // Show info about a dog.
19 Display "Here is info about a dog."
20 showAnimalInfo(myDog)
21 Display
22
23 // Show info about a cat.
24 Display "Here is info about a cat."
25 showAnimalInfo(myCat)
26 End Module
27
28 // The showAnimalInfo module accepts an Animal
29 // object as an argument and displays information
30 // about it.
31 Module showAnimalInfo(Animal creature)
32 Call creature.showSpecies()
33 Call creature.makeSound()
34 End Module
```

**Program Output**

```
Here is info about an animal.
I'm just a regular animal.
Grrrrr
```

```
Here is info about a dog.
I'm a dog.
Woof! Woof!
```

```
Here is info about a cat.
I'm a cat.
Meow
```

Although these examples are very simple, polymorphism has many practical uses. For example, a university's software processes a lot of data about students, so it might use a `Student` class. One of the methods in the `Student` class might be called `getFees`. This method would return the amount of a typical student's fees for a semester.

In addition, the software might have a `BiologyStudent` class as a subclass of the `Student` class (because a biology student *is a* student). Because of additional lab charges, a biology student's fees are usually more than those of the typical student. So, the `BiologyStudent` class would have its own `getFees` method that returns the fees for a biology student.



## Checkpoint

14.25 Look at the following pseudocode class definitions:

```
Class Vegetable
 Public Module message()
 Display "I'm a vegetable."
 End Module
End Class

Class Potato Extends Vegetable
 Public Module message()
 Display "I'm a potato."
 End Module
End Class
```

Given these class definitions, what will the following pseudocode display?

```
Declare Vegetable v
Declare Potato p
Set v = New Potato()
Set p = New Potato()
Call v.message()
Call p.message()
```

14.7

## Focus on Languages: Java, Python, and C++

This section discusses the ways that many of this chapter's topics are implemented in the Java, Python, and C++ programming languages. For a more detailed look at these languages, including several more example programs in each language, you can download the *Java Language Companion*, the *Python Language Companion*, and the *C++ Language Companion* from the publisher's website for this textbook. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

## Java

### Classes and Objects

#### Class Declarations in Java

The `CellPhone` class shown in Class Listing 14-13 is the Java version of Class Listing 14-3. Notice that each of the field declarations (lines 4 through 6) begin with the key word `private`. This is an access specifier that makes the fields private to the class. No code outside the class can directly access private class fields. Also, notice that each of the method headers begin with the `public` access specifier. This makes the methods public, which means that code outside the class can call the methods.

#### Class Listing 14-13 (CellPhone.java)

```
1 public class CellPhone
2 {
3 // Field declarations
4 private String manufacturer;
5 private String modelNumber;
6 private double retailPrice;
7
8 // Method Definitions
9 public void setManufacturer(String manufact)
10 {
11 manufacturer = manufact;
12 }
13
14 public void setModelNumber(String modNum)
15 {
16 modelNumber = modNum;
17 }
18
19 public void setRetailPrice(double retail)
20 {
21 retailPrice = retail;
22 }
23
24 public String getManufacturer()
25 {
26 return manufacturer;
27 }
28
29 public String getModelNumber()
30 {
31 return modelNumber;
32 }
33
34 public double getRetailPrice()
35 {
36 return retailPrice;
37 }
38 }
```

Notice that none of the field and method declarations contain the `static` key word. All of the fields and methods in this class are *non-static*. A non-static class field belongs to a specific object. For example, the `CellPhone` class has three fields: `manufacturer`, `modelNumber`, and `retailPrice`. Because these fields are non-static, they do not actually exist in memory until an instance of the `CellPhone` class is created. When an instance of the `CellPhone` class is created, its fields are created. Because non-static fields belong to a specific instance of the class, they are commonly referred to as *instance fields*.

Now let's discuss the difference between static and non-static methods. Static methods, such as the `main` method that you have written in every program so far, are general purpose methods that can simply be called in the program. They are defined in a class, but you do not have to create an instance of the class in order to use them. Non-static methods, however, are intended to work on an instance of the class in which they are defined. For this reason, non-static methods are usually referred to as *instance methods*. To call an instance method, an instance of the class in which the method is declared must exist.

For example, all of the methods that are declared in the `CellPhone` class are instance methods. They are meant to operate on the data that belongs to an instance of the `CellPhone` class. Before we can call any of the `CellPhone` class's methods, we must create an instance of the `CellPhone` class (in other words, we must create a `CellPhone` object). Then, we can call the `setManufacturer` method to set the manufacturer for that object. We can call the `setModelNumber` method to set the model number for that object. And, we can call the `setRetailPrice` method to set the retail price for that object. Likewise, we can call the `getManufacturer`, `getModelNumber`, and `getRetail` methods to get the manufacturer, model number, and retail price for that object.

The following code demonstrates how to create an instance of the `CellPhone` class, and use the class's methods to store data in the object:

```
// Declare a CellPhone reference variable.
CellPhone myPhone;

// Create a CellPhone object.
myPhone = new CellPhone();

// Store values in the object's fields.
myPhone.setManufacturer("Motorola");
myPhone.setModelNumber("M1000");
myPhone.setRetailPrice(199.99);

// Display the values stored in the object's fields.
System.out.println(myPhone.getManufacturer());
System.out.println(myPhone.getModelNumber());
System.out.println(myPhone.getRetailPrice());
```

### Constructors in Java

A class constructor in Java is a method that has the same name as the class. The following is a version of the `CellPhone` class that has a constructor. This is the Java version of Class Listing 14-14 in your textbook. The constructor appears in lines 9 through 14.

**Class Listing 14-14 (CellPhone.java)**

```
1 public class CellPhone
2 {
3 // Field declarations
4 private String manufacturer;
5 private String modelNumber;
6 private double retailPrice;
7
8 // Constructor
9 public CellPhone(String manufact, String modNum, double retail)
10 {
11 manufacturer = manufact;
12 modelNumber = modNum;
13 retailPrice = retail;
14 }
15
16 // Mutator methods
17 public void setManufacturer(String manufact)
18 {
19 manufacturer = manufact;
20 }
21
22 public void setModelNumber(String modNum)
23 {
24 modelNumber = modNum;
25 }
26
27 public void setRetailPrice(double retail)
28 {
29 retailPrice = retail;
30 }
31
32 // Accessor methods
33 public String getManufacturer()
34 {
35 return manufacturer;
36 }
37
38 public String getModelNumber()
39 {
40 return modelNumber;
41 }
42
43 public double getRetailPrice()
44 {
45 return retailPrice;
46 }
47 }
```

The following code demonstrates how to create an instance of the class, passing arguments to the constructor. This code creates an instance of the `CellPhone` class, passing the arguments "Motorola", "M1000", and 199.99 to the constructor:

```
CellPhone myPhone;
myPhone = new CellPhone("Motorola", "M1000", 199.99);
```

### Inheritance in Java

In Java, you use the `extends` key word to indicate that a class is a subclass of another class. For example, look at the following class declarations:

```
public class ClassA
{
 Field and method declarations
}

public class ClassB extends ClassA
{
 Field and method declarations
}
```

The header for `ClassB` indicates that `ClassB` extends `ClassA`. So, `ClassA` is the superclass, and `ClassB` is the subclass. `ClassB` inherits all of `ClassA`'s public members.

### Polymorphism in Java

Earlier in this chapter, you saw a polymorphism demonstration that uses the `Animal` class pseudocode shown in Class Listing 14-10 as a superclass. The Java version of that class is shown in Class Listing 14-15:

#### Class Listing 14-15 (Animal.java)

```
1 public class Animal
2 {
3 // showSpecies method
4 public void showSpecies()
5 {
6 System.out.println("I'm just a regular animal.");
7 }
8
9 // makeSound method
10 public void makeSound()
11 {
12 System.out.println("Grrrrrrr");
13 }
14 }
```

The pseudocode for the `Dog` class, which extends the `Animal` class, was shown in Class Listing 14-11. The Java version of the `Dog` class is shown in Class Listing 14-16:

**Class Listing 14-16 (Dog.java)**

```

1 public class Dog extends Animal
2 {
3 // showSpecies method
4 public void showSpecies()
5 {
6 System.out.println("I'm a dog.");
7 }
8
9 // makeSound method
10 public void makeSound()
11 {
12 System.out.println("Woof! Woof!");
13 }
14 }
```

The pseudocode for the Cat class, which also extends the Animal class, was shown in Class Listing 14-12 in your textbook. The Java version of the Cat class is shown in Class Listing 14-17:

**Class Listing 14-17 (Cat.java)**

```

1 public class Cat extends Animal
2 {
3 // showSpecies method
4 public void showSpecies()
5 {
6 System.out.println("I'm a cat.");
7 }
8
9 // makeSound method
10 public void makeSound()
11 {
12 System.out.println("Meow");
13 }
14 }
```

Program 14-7, shown here, demonstrates the polymorphic behavior of these classes, as discussed in your textbook. This is the Java version of pseudocode Program 14-6.

**Program 14-7 (PolymorphismDemo.java)**

```

1 public class PolymorphismDemo
2 {
3 public static void main(String[] args)
4 {
5 // Declare three class variables.
6 Animal myAnimal;
7 Dog myDog;
8 Cat myCat;
```

```
9
10 // Create an Animal object, a Dog object,
11 // and a Cat object.
12 myAnimal = new Animal();
13 myDog = new Dog();
14 myCat = new Cat();
15
16 // Show info about an animal.
17 System.out.println("Here is info about an animal.");
18 showAnimalInfo(myAnimal);
19 System.out.println();
20
21 // Show info about a dog.
22 System.out.println("Here is info about a dog.");
23 showAnimalInfo(myDog);
24 System.out.println();
25
26 // Show info about a cat.
27 System.out.println("Here is info about a cat.");
28 showAnimalInfo(myCat);
29 }
30
31 // The showAnimalInfo method accepts an Animal
32 // object as an argument and displays information
33 // about it.
34 public static void showAnimalInfo(Animal creature)
35 {
36 creature.showSpecies();
37 creature.makeSound();
38 }
39 }
```

### Program Output

```
Here is info about an animal.
I'm just a regular animal.
Grrrrrrr
```

```
Here is info about a dog.
I'm a dog.
Woof! Woof!
```

```
Here is info about a cat.
I'm a cat.
Meow
```

## Python

### Classes and Objects

#### Class Declarations in Python

Here is the general format of a class declaration in Python:

```
class ClassName:
 Method definitions go here...
```

The first line of a class declaration begins with the keyword `class`, followed by the name of the class, followed by a colon. The class's method definitions follow this line. Method definitions are written much like regular function definitions. Because they belong to the class, method definitions must be indented.

One difference that you will notice between Python class declarations and the pseudocode class declarations in the textbook is that there are no field declarations in a Python class. This is because an object's fields are created by assignment statements that appear inside the class's methods.

Another difference that you will notice is the absence of access specifiers such as `Private` and `Public`. In Python, we hide a field or method by starting its name with two underscores. This is similar to making the field or method private.

The Python program shown in Program 14-8 contains a `CellPhone` class like the pseudocode class shown in Class Listing 14-3. It also has a `main` method to demonstrate the class, like that shown in pseudocode Program 14-3.

### Program 14-8

```
1 class CellPhone:
2 def set_manufacturer(self, manufact):
3 self.__manufacturer = manufact
4
5 def set_model_number(self, model):
6 self.__model_number = model
7
8 def set_retail_price(self, retail):
9 self.__retail_price = retail
10
11 def get_manufacturer(self):
12 return self.__manufacturer
13
14 def get_model_number(self):
15 return self.__model_number
16
17 def get_retail_price(self):
18 return self.__retail_price
19
20 def main():
21 # Create a CellPhone object. The phone
22 # variable will reference the object.
23 phone = CellPhone()
24
25 # Store values in the object's fields.
26 phone.set_manufacturer("Motorola")
27 phone.set_model_number("M1000")
28 phone.set_retail_price(199.99)
29
30 # Display the values stored in the fields.
31 print('The manufacturer is', phone.get_manufacturer())
32 print('The model number is', phone.get_model_number())
33 print('The retail price is', phone.get_retail_price())
34
```

```
35 # Call the main function.
36 main()
```

### Program Output

```
The manufacturer is Motorola
The model number is M1000
The retail price is 199.99
```

Notice that each of the methods has a parameter named `self`. The `self` parameter is required in every method that a class has. A method operates on a specific object's data attributes. When a method executes, it must have a way of knowing which object's data attributes it is supposed to operate on. That's where the `self` parameter comes in. When a method is called, Python automatically makes its `self` parameter reference the specific object that the method is supposed to operate on.

Now let's look at the `set_manufacturer` method in lines 2 through 3. Notice that in addition to the `self` parameter, it also has a parameter named `manufact`. The statement in line 3 assigns `manufact` to `self.__manufacturer`. What is `self.__manufacturer`? Let's analyze it:

- `self` refers to a specific `CellPhone` object in memory.
- `__manufacturer` is the name of a field. The two underscores at the beginning of the field name make it private to code outside the `CellPhone` class.

So, the statement in line 3 assigns the value of the `manufact` parameter to a `CellPhone` object's `__manufacturer` field.

The `set_model_number` method, in lines 5 through 6 is similar. It has a `model` parameter that is assigned to the object's `__model_number` field.

The `set_retail_price` method, in lines 8 through 9 is also similar. It has a `retail` parameter that is assigned to the object's `__retail_price` field.

The `get_manufacturer` method, in lines 11 through 12, returns the value of the object's `__manufacturer` field. The `get_model_number` method, in lines 14 through 15, returns the value of the object's `model_number` field. The `get_retail_price` method, in lines 17 through 18, returns the object's `__retail_price` field.

Inside the `main` function, line 23 creates an instance of the `CellPhone` class in memory and assigns it to the `phone` variable. We say that the object is referenced by the `phone` variable. (Notice that Python does not require the `New` keyword, as discussed earlier in this chapter.) Lines 26 through 28 call the object's `set_manufacturer`, `set_model_number`, and `set_retail_price` methods, passing arguments to each.

Recall that in the `CellPhone` class, the `set_manufacturer`, `set_model_number`, and `set_retail_price` methods each have two parameters. However, when we call these methods in lines 26 through 28, we pass only one argument. The first parameter in each of these methods is the `self` parameter. When you call a method, you do not pass an argument for the `self` parameter because Python automatically passes a reference to the calling object into the method's first parameter. As a result, the `self` parameter will automatically reference the object that the method is to operate on. This means that:

- In line 26, the argument “Motorola” is being passed into the `set_manufacturer` method’s `manufact` parameter.
- In line 27 the argument “M1000” is being passed into the `set_model_number` method’s `model` parameter.
- In line 28 the 199.99 argument is being passed into the `set_retail_price` method’s `retail` parameter.

Lines 31 through 33 call the `print` function to display the values of the object’s fields.

### Constructors in Python

In Python, classes can have a method named `__init__` which is automatically executed when an instance of the class is created in memory. The `__init__` method is commonly known as an *initializer method* because it initializes the object’s data attributes. (The name of the method starts with two underscore characters, followed by the word `init`, followed by two more underscore characters.)

Program 14-9 shows a version of the `CellPhone` class that has an `__init__` method. This is the Python version of pseudocode Class Listing 14-4, combined with pseudocode Program 14-2.

#### Program 14-9

```

1 class CellPhone:
2 def __init__(self, manufact, model, retail):
3 self.__manufacturer = manufact
4 self.__model_number = model
5 self.__retail_price = retail
6
7 def set_manufacturer(self, manufact):
8 self.__manufacturer = manufact
9
10 def set_model_number(self, model):
11 self.__model_number = model
12
13 def set_retail_price(self, retail):
14 self.__retail_price = retail
15
16 def get_manufacturer(self):
17 return self.__manufacturer
18
19 def get_model_number(self):
20 return self.__model_number
21
22 def get_retail_price(self):
23 return self.__retail_price
24
25 def main():
26 # Create a CellPhone object and initialize its
27 # fields with values passed to the __init__ method.
28 phone = CellPhone("Motorola", "M1000", 199.99)
29
30 # Display the values stored in the fields.

```

```

31 print('The manufacturer is', phone.get_manufacturer())
32 print('The model number is', phone.get_model_number())
33 print('The retail price is', phone.get_retail_price())
34
35 # Call the main function.
36 main()

```

### Program Output

```

The manufacturer is Motorola
The model number is M1000
The retail price is 199.99

```

The statement in line 28 creates a `CellPhone` object in memory and assigns it to the `phone` variable. Notice that the values “Motorola,” “M1000,” and 199.99 appear inside the parentheses after the class name. These values are passed as arguments to the class’s `__init__` method.

### Inheritance in Python

Suppose we want to declare two classes: `ClassA` and `ClassB`. Furthermore, we want `ClassB` to be a subclass of `ClassA`. The general format of the declarations in Python is:

```

class ClassA:
 Field and method declarations

class ClassB(ClassA):
 Field and method declarations

```

Notice that in the class header for `ClassB`, we wrote `ClassA` inside parentheses. This indicates that `ClassB` extends `ClassA`. So, `ClassA` is the superclass, and `ClassB` is the subclass. `ClassB` inherits all of `ClassA`’s public members.

### Polymorphism in Python

This chapter presents a polymorphism demonstration that uses the `Animal` class (Class Listing 14-10) as a superclass, and the `Dog` class (Class Listing 14-11) and `Cat` class (Class Listing 14-12) as subclasses of `Animal`. The Python versions of those classes are shown here, in Program 14-10. The `main` function and the `show_animal_info` functions are the Python equivalent of pseudocode Program 14-6.

### Program 14-10 (polymorphism.py)

```

1 class Animal:
2 def show_species(self):
3 print('I am just a regular animal.')
4
5 def make_sound(self):
6 print('Grrrrrr')
7
8 class Dog(Animal):
9 def show_species(self):
10 print('I am a dog.')
11
12 def make_sound(self):

```

```
13 print('Woof! Woof!')
14
15 class Cat(Animal):
16 def show_species(self):
17 print('I am a cat.')
18
19 def make_sound(self):
20 print('Meow')
21
22 # Here is the main function.
23
24 def main():
25 # Create an animal object, a Dog object, and
26 # a Cat object.
27 my_animal = Animal()
28 my_dog = Dog()
29 my_cat = Cat()
30
31 # Show info about an animal.
32 print('Here is info about an animal.')
33 show_animal_info(my_animal)
34 print()
35
36 # Show info about a dog.
37 print('Here is info about a dog.')
38 show_animal_info(my_dog)
39 print()
40
41 # Show info about a cat.
42 print('Here is info about a cat.')
43 show_animal_info(my_cat)
44
45 # The show_animal_info function accepts an Animal
46 # object as an argument and displays information
47 # about it.
48
49 def show_animal_info(creature):
50 creature.show_species()
51 creature.make_sound()
52
53 # Call the main function.
54 main()
```

### Program Output

Here is info about an animal.

I am just a regular animal.

Grrrrrrr

Here is info about a dog.

I am a dog.

Woof! Woof!

Here is info about a cat.

I am a cat.

Meow

## C++

### Classes and Objects

#### Class Declarations in C++

Here is the general format of a class declaration in C++:

```
class ClassName
{
 Field declarations and member function definitions go here...
};
```

Notice that a class declaration in C++ ends with a semicolon.

The `CellPhone` class shown in Program 14-11 is the C++ version of pseudocode Class Listing 14-3. Notice that line 3 reads `private:`, and line 9 reads `public:`. These are *access specifiers*, and they control how class fields and member functions can be accessed by code outside the class. All the field declarations that appear after the `private:` access specifier in line 3 are private. They can be accessed only by code inside the class. All of the member functions that appear after the `public:` access specifier in line 9 are public, and can be called by code outside the class.

Program 14-11 also has a `main` function to demonstrate the class, like that shown in pseudocode Program 14-3.

#### Program 14-11 (CellPhoneDemo.cpp)

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 class CellPhone
6 {
7 private:
8 // Field declarations
9 string manufacturer;
10 string modelNumber;
11 double retailPrice;
12
13 public:
14 // Member functions
15 void setManufacturer(string manuf)
16 {
17 manufacturer = manuf;
18 }
19
20 void setModelNumber(string modNum)
21 {
22 modelNumber = modNum;
23 }
24
25 void setRetailPrice(double retail)
26 {
27 retailPrice = retail;
28 }
29
```

```

30 string getManufacturer()
31 {
32 return manufacturer;
33 }
34
35 string getModelNumber()
36 {
37 return modelNumber;
38 }
39
40 double getRetailPrice()
41 {
42 return retailPrice;
43 }
44 };
45
46 int main()
47 {
48 // Declare a variable that can reference
49 // a CellPhone object.
50 CellPhone myPhone;
51
52 // Store values in the object's fields.
53 myPhone.setManufacturer("Motorola");
54 myPhone.setModelNumber("M1000");
55 myPhone.setRetailPrice(199.99);
56
57 // Display the values stored in the fields.
58 cout << "The manufacturer is "
59 << myPhone.getManufacturer() << endl;
60 cout << "The model number is "
61 << myPhone.getModelNumber() << endl;
62 cout << "The retail price is "
63 << myPhone.getRetailPrice() << endl;
64
65 return 0;
66 }
```

### Program Output

```
The manufacturer is Motorola
The model number is M1000
The retail price is 199.99
```

Inside the `main` function, line 50 creates an instance of the `CellPhone` class in memory and assigns it to the `myPhone` variable. We say that the object is referenced by the `myPhone` variable. (Notice that C++ does not require the `New` keyword, as discussed previously in this chapter.) Lines 53 through 55 call the object's `setManufacturer`, `setModelNumber`, and `setRetailPrice` member functions, passing arguments to each.

### Constructors in C++

A class constructor in C++ is a member function that has the same name as the class. Program 14-12 shows a version of the `CellPhone` class that has a constructor. This is the C++ version of pseudocode Class Listing 14-4, combined with pseudocode Program 14-2 from your textbook. The constructor appears in lines 9 through 14.

**Program 14-12 (ConstructorDemo.cpp)**

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 class CellPhone
6 {
7 private:
8 // Field declarations
9 string manufacturer;
10 string modelNumber;
11 double retailPrice;
12
13 public:
14 // Constructor
15 CellPhone(string manufact, string modNum, double retail)
16 {
17 manufacturer = manufact;
18 modelNumber = modNum;
19 retailPrice = retail;
20 }
21
22 // Member functions
23 void setManufacturer(string manufact)
24 {
25 manufacturer = manufact;
26 }
27
28 void setModelNumber(string modNum)
29 {
30 modelNumber = modNum;
31 }
32
33 void setRetailPrice(double retail)
34 {
35 retailPrice = retail;
36 }
37
38 string getManufacturer()
39 {
40 return manufacturer;
41 }
42
43 string getModelNumber()
44 {
45 return modelNumber;
46 }
47
48 double getRetailPrice()
49 {
50 return retailPrice;
51 }
52 };
```

```

53
54 int main()
55 {
56 // Create a CellPhone object and initialize its
57 // fields with values passed to the constructor.
58 CellPhone myPhone("Motorola", "M1000", 199.99);
59
60 // Display the values stored in the fields.
61 cout << "The manufacturer is "
62 << myPhone.getManufacturer() << endl;
63 cout << "The model number is "
64 << myPhone.getModelNumber() << endl;
65 cout << "The retail price is "
66 << myPhone.getRetailPrice() << endl;
67
68 return 0;
69 }
```

### Program Output

The manufacturer is Motorola  
 The model number is M1000  
 The retail price is 199.99

### Inheritance in C++

Suppose we want to declare two classes: `ClassA` and `ClassB`. Furthermore, we want `ClassB` to be a subclass of `ClassA`. The general format of the declarations in C++ is:

```

class ClassA
{
 Member declarations
};

class ClassB : public ClassA
{
 Member declarations
};
```

Notice that the header for `ClassB` ends with the following clause:  
`: public ClassA`

This specifies that the `ClassB` class extends the `ClassA` class. So, `ClassA` is the superclass, and `ClassB` is the subclass. `ClassB` inherits all of `ClassA`'s public members.

### Polymorphism in C++

Earlier in this chapter, you saw a polymorphism demonstration that uses the `Animal` class (Class Listing 14-10) as a superclass, and the `Dog` class (Class Listing 14-11) and `Cat` class (Class Listing 14-12) as subclasses of `Animal`. The C++ versions of those classes are shown here, in Program 14-13. The `main` function and the `showAnimalInfo` functions are the C++ equivalent of Program 14-6 in your textbook.

Notice that the key word `virtual` appears in the function headers for the `showSpecies` and `makeSound` functions (lines 9, 15, 25, 31, 40, and 46). The `virtual` key word tells the compiler to expect the function to be redefined in a subclass.

Also, notice that in line 82, the `showAnimalInfo` function accepts an `Animal` object by reference. In C++, polymorphic behavior is possible only when an object is passed by reference.

### Program 14-13 (Polymorphism.cpp)

```
1 #include <iostream>
2 #include <string>
3 using namespace std;
4
5 class Animal
6 {
7 public:
8 // showSpecies function
9 virtual void showSpecies()
10 {
11 cout << "I'm just a regular animal." << endl;
12 }
13
14 // makeSound function
15 virtual void makeSound()
16 {
17 cout << "Grrrrrr" << endl;
18 }
19 };
20
21 class Dog : public Animal
22 {
23 public:
24 // showSpecies function
25 virtual void showSpecies()
26 {
27 cout << "I'm a dog." << endl;
28 }
29
30 // makeSound function
31 virtual void makeSound()
32 {
33 cout << "Woof! Woof!" << endl;
34 }
35 };
36
37 class Cat : public Animal
38 {
39 // showSpecies function
40 virtual void showSpecies()
41 {
42 cout << "I'm a cat." << endl;
43 }
44 }
```

```
45 // makeSound function
46 virtual void makeSound()
47 {
48 cout << "Meow" << endl;
49 }
50 };
51
52 // Function prototype
53 void showAnimalInfo(Animal &creature);
54
55 int main()
56 {
57 // Declare three class variables.
58 Animal myAnimal;
59 Dog myDog;
60 Cat myCat;
61
62 // Show info about an animal.
63 cout << "Here is info about an animal." << endl;
64 showAnimalInfo(myAnimal);
65 cout << endl;
66
67 // Show info about a dog.
68 cout << "Here is info about a dog." << endl;
69 showAnimalInfo(myDog);
70 cout << endl;
71
72 // Show info about a cat.
73 cout << "Here is info about a cat." << endl;
74 showAnimalInfo(myCat);
75
76 return 0;
77 }
78
79 // The showAnimalInfo function accepts an Animal
80 // object as an argument and displays information
81 // about it.
82 void showAnimalInfo(Animal &creature)
83 {
84 creature.showSpecies();
85 creature.makeSound();
86 }
```

### Program Output

Here is info about an animal.  
I am just a regular animal.  
Grrrrrrr

Here is info about a dog.  
I am a dog.  
Woof! Woof!

Here is info about a cat.  
I am a cat.  
Meow

## Review Questions

### Multiple Choice

1. A(n) \_\_\_\_\_ programming practice is centered on creating modules and functions that are separate from the data that they work on.
  - a. modular
  - b. procedural
  - c. functional
  - d. object-oriented
2. A(n) \_\_\_\_\_ programming practice is centered on creating objects.
  - a. object-centric
  - b. objective
  - c. procedural
  - d. object-oriented
3. A(n) \_\_\_\_\_ is a member of a class that holds data.
  - a. method
  - b. instance
  - c. field
  - d. constructor
4. The \_\_\_\_\_ specifies how a class's field or method may be accessed by code outside the class.
  - a. field declaration
  - b. New key word
  - c. access specifier
  - d. constructor
5. A class's fields are commonly declared with the \_\_\_\_\_ access specifier.
  - a. Private
  - b. Public
  - c. ReadOnly
  - d. Hidden
6. A \_\_\_\_\_ variable is a special type of variable that can reference an object in the computer's memory.
  - a. memory
  - b. procedural
  - c. class
  - d. dynamic
7. In many programming languages, the \_\_\_\_\_ key word creates an object in memory.
  - a. Create
  - b. New
  - c. Instantiate
  - d. Declare

8. A(n) \_\_\_\_\_ method gets a value from a class's field but does not change it.
  - a. retriever
  - b. constructor
  - c. mutator
  - d. accessor
9. A(n) \_\_\_\_\_ method stores a value in a field or changes the value of a field in some other way.
  - a. modifier
  - b. constructor
  - c. mutator
  - d. accessor
10. A(n) \_\_\_\_\_ method is automatically called when an object is created.
  - a. accessor
  - b. constructor
  - c. setter
  - d. mutator
11. A set of standard diagrams for graphically depicting object-oriented systems is provided by \_\_\_\_\_.
  - a. the Unified Modeling Language
  - b. flowcharts
  - c. pseudocode
  - d. the Object Hierarchy System
12. When the value of an item is dependent on other data, and that item is not updated when the other data is changed, we say that the value has become \_\_\_\_\_.
  - a. bitter
  - b. stale
  - c. asynchronous
  - d. moldy
13. A class's responsibilities are \_\_\_\_\_.
  - a. objects created from the class
  - b. things the class knows
  - c. actions the class performs
  - d. both b and c
14. In an inheritance relationship, the \_\_\_\_\_ is the general class.
  - a. subclass
  - b. superclass
  - c. prototype class
  - d. child class
15. In an inheritance relationship, the \_\_\_\_\_ is the specialized class.
  - a. superclass
  - b. prototype class
  - c. subclass
  - d. parent class

16. The \_\_\_\_\_ characteristic of object-oriented programming allows a superclass variable to reference a subclass object.
- polymorphism
  - inheritance
  - generalization
  - specialization

### True or False

- The practice of procedural programming is centered on the creation of objects.
- Object reusability has been a factor in the increased use of object-oriented programming.
- It is a common practice in object-oriented programming to make all of a class's fields public.
- One way to find the classes needed for an object-oriented program is to identify all of the verbs in a description of the problem domain.
- The superclass inherits fields and methods from the subclass.
- Polymorphism allows a class variable of the superclass type to reference objects of either the superclass or the subclass types.

### Short Answer

- What is encapsulation?
- Why is an object's internal data usually hidden from outside code?
- What is the difference between a class and an instance of a class?
- In many programming languages, what does the New key word do?
- The following pseudocode statement calls an object's method. What is the name of the method? What is the name of the variable that references the object?  
`Call wallet.getDollar()`
- What is stale data?
- What does a subclass inherit from its superclass?
- Look at the following pseudocode, which is the first line of a class definition. What is the name of the superclass? What is the name of the subclass?  
`Class Tiger Extends Felis`

### Algorithm Workbench

- Suppose myCar is the name of a class variable that references an object, and go is the name of a method. (The go method does not take any arguments.) Write a pseudocode statement that uses the myCar variable to call the method.

2. Look at this partial class definition, and then follow the subsequent instructions:

```
Class Book
 Private String title
 Private String author
 Private String publisher
 Private Integer copiesSold
End Class
```

- Write a constructor for this class. The constructor should accept an argument for each of the fields.
- Write accessor and mutator methods for each field.
- Draw a UML diagram for the class, including the methods you have written.

3. Look at the following description of a problem domain:

The bank offers the following types of accounts to its customers: savings accounts, checking accounts, and money market accounts. Customers are allowed to deposit money into an account (thereby increasing its balance), withdraw money from an account (thereby decreasing its balance), and earn interest on the account. Each account has an interest rate.

Assume that you are writing a program that will calculate the amount of interest earned for a bank account.

- Identify the potential classes in this problem domain.
- Refine the list to include only the necessary class or classes for this problem.
- Identify the responsibilities of the class or classes.

4. In pseudocode, write the first line of the definition for a Poodle class. The class should extend the Dog class.

5. Look at the following pseudocode class definitions:

```
Class Plant
 Public Module message()
 Display "I'm a plant."
 End Module
End Class
Class Tree Extends Plant
 Public Module message()
 Display "I'm a tree."
 End Module
End Class
```

Given these class definitions, what will the following pseudocode display?

```
Declare Plant p
Set p = New Tree()
Call p.message()
```



VideoNote  
The Pet Class Problem

## Programming Exercises

### 1. Pet Class

Design a class named Pet, which should have the following fields:

- **name:** The name field holds the name of a pet.
- **type:** The type field holds the type of animal that a pet is. Example values are "Dog", "Cat", and "Bird".
- **age:** The age field holds the pet's age.

The `Pet` class should also have the following methods:

- **setName**: The `setName` method stores a value in the `name` field.
- **setType**: The `setType` method stores a value in the `type` field.
- **setAge**: The `setAge` method stores a value in the `age` field.
- **getName**: The `getName` method returns the value of the `name` field.
- **getType**: The `getType` method returns the value of the `type` field.
- **getAge**: The `getAge` method returns the value of the `age` field.

Once you have designed the class, design a program that creates an object of the class and prompts the user to enter the name, type, and age of his or her pet. This data should be stored in the object. Use the object's accessor methods to retrieve the pet's name, type, and age and display this data on the screen.

## 2. Car Class

Design a class named `Car` that has the following fields:

- **yearModel**: The `yearModel` field is an `Integer` that holds the car's year model.
- **make**: The `make` field references a `String` that holds the make of the car.
- **speed**: The `speed` field is an `Integer` that holds the car's current speed.

In addition, the class should have the following constructor and other methods:

- **Constructor**: The constructor should accept the car's year model and make as arguments. These values should be assigned to the object's `yearModel` and `make` fields. The constructor should also assign 0 to the `speed` field.
- **Accessors**: Design appropriate accessor methods to get the values stored in an object's `yearModel`, `make`, and `speed` fields.
- **accelerate**: The `accelerate` method should add 5 to the `speed` field each time it is called.
- **brake**: The `brake` method should subtract 5 from the `speed` field each time it is called.

Next, design a program that creates a `Car` object, and then calls the `accelerate` method five times. After each call to the `accelerate` method, get the current speed of the car and display it. Then call the `brake` method five times. After each call to the `brake` method, get the current speed of the car and display it.

## 3. Personal Information Class

Design a class that holds the following personal data: name, address, age, and phone number. Write appropriate accessor and mutator methods. Also, design a program that creates three instances of the class. One instance should hold your information, and the other two should hold your friends' or family members' information.

## 4. Employee and ProductionWorker Classes

Design an `Employee` class that has fields for the following pieces of information:

- Employee name
- Employee number

Next, design a class named `ProductionWorker` that extends the `Employee` class. The `ProductionWorker` class should have fields to hold the following information:

- Shift number (an integer, such as 1, 2, or 3)
- Hourly pay rate

The workday is divided into two shifts: day and night. The shift field will hold an integer value representing the shift that the employee works. The day shift is shift 1 and the night shift is shift 2. Design the appropriate accessor and mutator methods for each class.

Once you have designed the classes, design a program that creates an object of the `ProductionWorker` class and prompts the user to enter data for each of the object's fields. Store the data in the object and then use the object's accessor methods to retrieve it and display it on the screen.

### 5. Essay Class

Design an `Essay` class that extends the `GradedActivity` class presented in this chapter. The `Essay` class should determine the grade a student receives for an essay. The student's essay score can be up to 100 and is determined in the following manner:

- Grammar: up to 30 points
- Spelling: up to 20 points
- Correct length: up to 20 points
- Content: up to 30 points

Once you have designed the class, design a program that prompts the user to enter the number of points that a student has earned for grammar, spelling, length, and content. Create an `Essay` object and store this data in the object. Use the object's methods to get the student's overall score and grade, and display this data on the screen.

### 6. Patient Charges

Design a class named `Patient` that has fields for the following data:

- First name, middle name, last name
- Address, city, state, and ZIP code
- Phone number
- Name and phone number of emergency contact

The `Patient` class should have a constructor that accepts an argument for each field. The `Patient` class should also have accessor and mutator methods for each field.

Next, write a class named `Procedure` that represents a medical procedure that has been performed on a patient. The `Procedure` class should have fields for the following data:

- Name of the procedure
- Date of the procedure
- Name of the practitioner who performed the procedure
- Charges for the procedure

The `Procedure` class should have a constructor that accepts an argument for each field. The `Procedure` class should also have accessor and mutator methods for each field.

Next, design a program that creates an instance of the `Patient` class, initialized with sample data. Then, create three instances of the `Procedure` class, initialized with the following data:

| Procedure #1:                 | Procedure #2:             | Procedure #3:              |
|-------------------------------|---------------------------|----------------------------|
| Procedure name: Physical Exam | Procedure name: X-ray     | Procedure name: Blood test |
| Date: Today's date            | Date: Today's date        | Date: Today's date         |
| Practitioner: Dr. Irvine      | Practitioner: Dr. Jamison | Practitioner: Dr. Smith    |
| Charge: 250.00                | Charge: 500.00            | Charge: 200.00             |

The program should display the patient's information, information about all three of the procedures, and the total charges of the three procedures.

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# GUI Applications and Event-Driven Programming

## TOPICS

- |                                                     |                                                |
|-----------------------------------------------------|------------------------------------------------|
| 15.1 Graphical User Interfaces                      | 15.4 Designing Apps for Mobile Devices         |
| 15.2 Designing the User Interface for a GUI Program | 15.5 Focus on Languages: Java, Python, and C++ |
| 15.3 Writing Event Handlers                         |                                                |

### 15.1

## Graphical User Interfaces

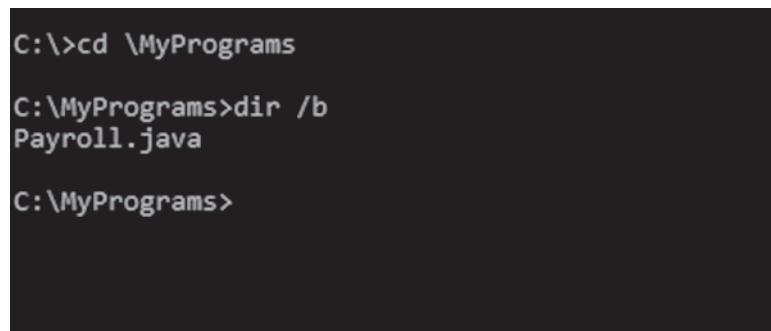
**CONCEPT:** A graphical user interface allows the user to interact with the operating system and other programs using graphical elements such as icons, buttons, and dialog boxes.



VideoNote  
Graphical User Interfaces

A computer's *user interface* is the part of the computer that the user interacts with. One part of the user interface consists of hardware devices, such as the keyboard and the video display. Another part of the user interface lies in the way that the computer's operating system accepts commands from the user. For many years, the only way that the user could interact with an operating system was through a *command line interface*, such as the one shown in Figure 15-1. A command line interface typically displays a prompt, and the user types a command, which is then executed.

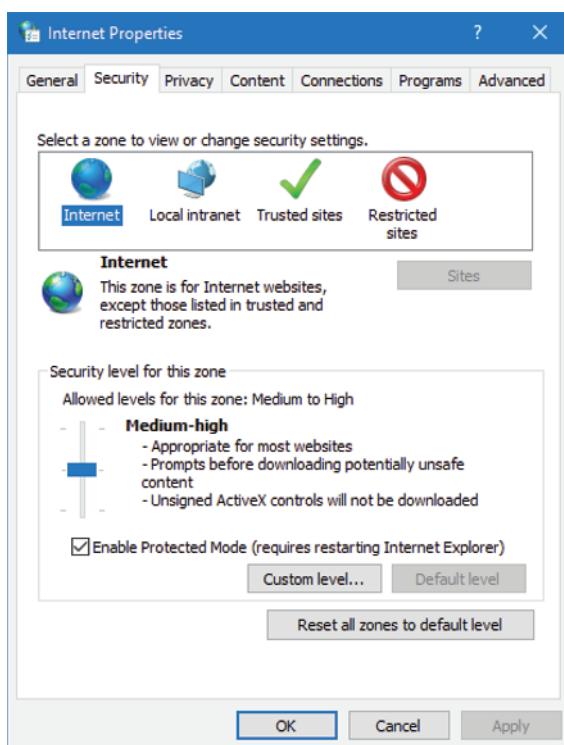
Many computer users, especially beginners, find command line interfaces difficult to use. This is because there are many commands to be learned, and each command has its own syntax, much like a programming statement. If a command isn't entered correctly, it will not work.

**Figure 15-1** A command line interface (courtesy of Microsoft Corporation)

```
C:\>cd \MyPrograms
C:\MyPrograms>dir /b
Payroll.java
C:\MyPrograms>
```

In the 1980s, a new type of interface known as a graphical user interface came into use in commercial operating systems. A *graphical user interface (GUI)* (pronounced “gooey”) allows the user to interact with the operating system through graphical elements on the screen. GUIs also popularized the use of the mouse as an input device. Instead of requiring the user to type commands on the keyboard, GUIs allow the user to point at graphical elements and click the mouse button to activate them.

Much of the interaction with a GUI is done through *dialog boxes*, which are small windows that display information and allow the user to perform actions. Figure 15-2 shows an example of a dialog box that allows the user to change their Internet settings in the Windows operating system. Instead of typing cryptic commands, the user interacts with graphical elements such as icons, buttons, and slider bars.

**Figure 15-2** A dialog box (courtesy of Microsoft Corporation)

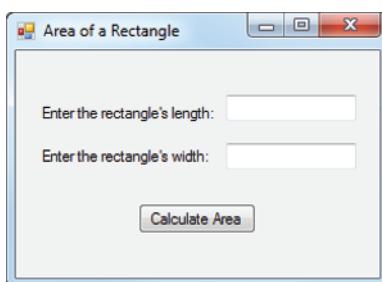
If you are developing software in an operating system that uses a GUI, such as Windows, macOS, or Linux, you can also use the GUI in the programs that you write. This allows you to incorporate standard GUI elements such as dialog boxes with icons, buttons, and so on into your programs.

## GUI Programs Are Event-Driven

In a text-based environment, such as a command line interface, programs determine the order in which things happen. For example, consider a program that calculates the area of a rectangle. First, the program prompts the user to enter the rectangle's width. The user enters the width and then the program prompts the user to enter the rectangle's length. The user enters the length and then the program calculates the area. The user has no choice but to enter the data in the order that it is requested.

In a GUI environment, however, the user determines the order in which things happen. For example, Figure 15-3 shows a GUI program that calculates the area of a rectangle. The user can enter the length and the width in any order. If a mistake is made, the user can erase the data that was entered and retype it. To calculate the area, the user clicks the *Calculate Area* button and the program performs the calculation. Because GUI programs must respond to the actions of the user, it is said that they are *event-driven*. The user causes events to take place, such as the clicking of a button, and the program must respond to the events.

**Figure 15-3** A GUI program (courtesy of Microsoft Corporation)



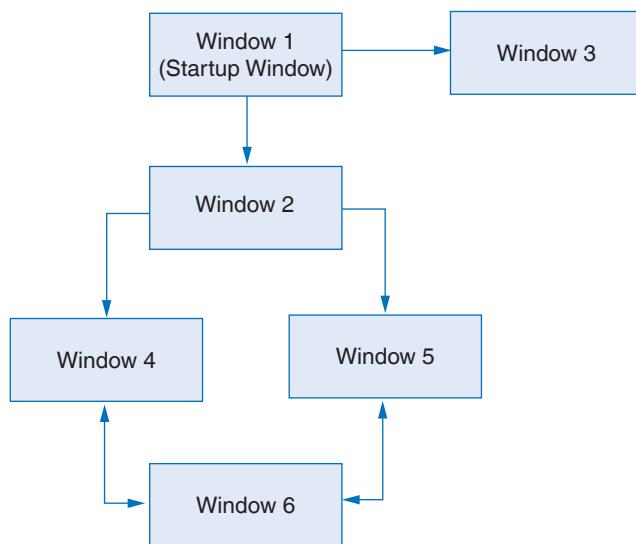
## Creating a GUI Program

Many of the steps involved in creating a GUI program are the same as those that you have used to create text-based programs throughout this book. For example, you must understand the task that the program is to perform and determine the steps that must be taken to perform the task.

In addition, you must design the on-screen GUI elements that make up each window in the program's user interface. You must also determine how the program will flow from one window to the next as the user interacts with it. Some programmers find it helpful to draw a *user interface flow diagram*. Figure 15-4 shows an example of such a diagram. Each box represents a window that is displayed by the program. If actions performed in one window can cause another window to open, then an arrow appears between the two windows in the diagram. In the diagram, notice that an arrow points away from Window 1 to Window 2. This means that actions in Window 1 can cause

Window 2 to open. When a double-headed arrow appears between two windows, then either window can open the other.

**Figure 15-4** A user interface flow diagram



### Checkpoint

- 15.1 What is a user interface?
- 15.2 How does a command line interface work?
- 15.3 When the user runs a program in a text-based environment, such as the command line, what determines the order in which things happen?
- 15.4 What is an event-driven program?
- 15.5 What is a user interface flow diagram?

## 15.2

### Designing the User Interface for a GUI Program

**CONCEPT:** When creating a GUI program you must design the program's windows and all of the graphical components that appear in them.

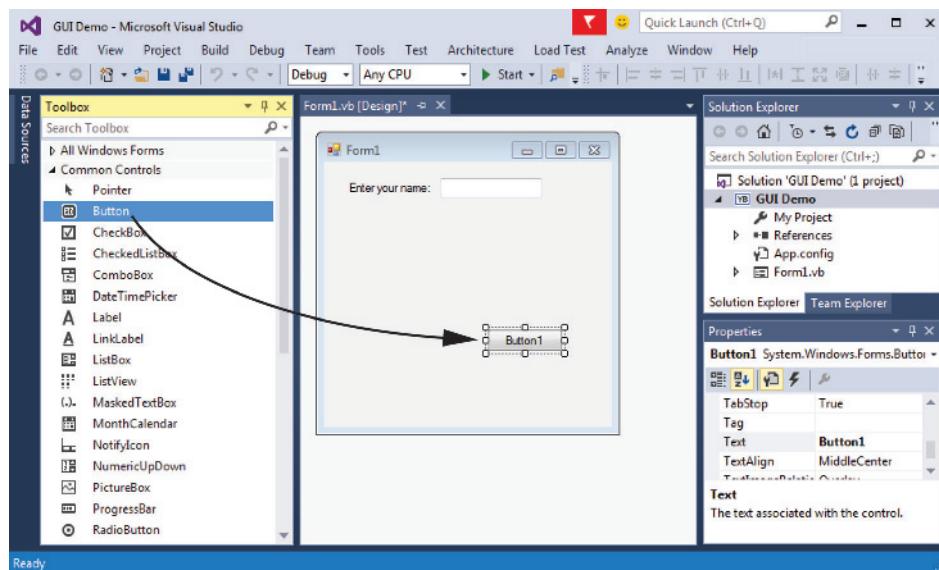
A GUI program's user interface consists of one or more windows that appear on the screen when the program is running. While creating a GUI program, one of your tasks is to design the windows and all of the graphical elements that appear in them.

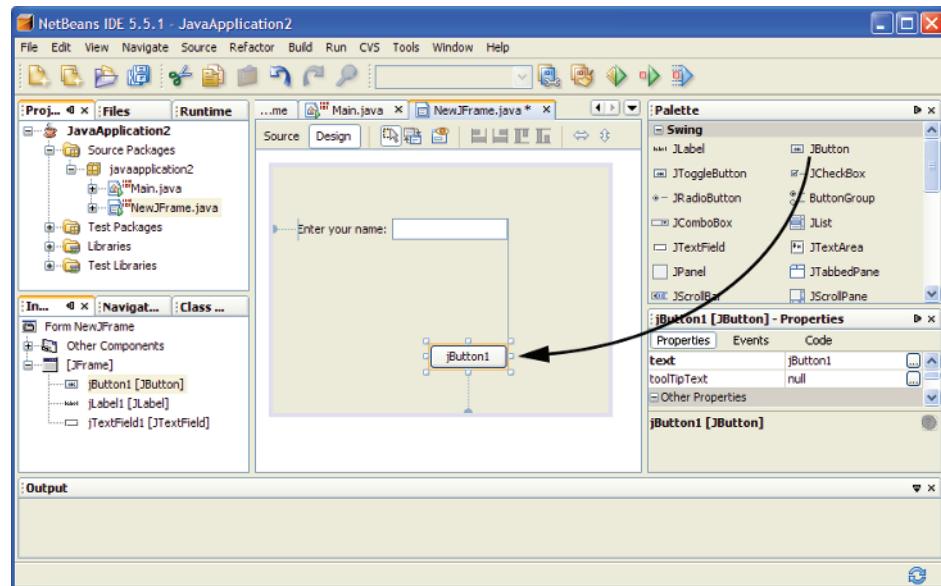
In the early days of GUI programming, creating a set of graphical windows for a program was a complex and time-consuming endeavor. Programmers had to write code that constructed the windows, create graphical elements such as icons and buttons, and set each element's color, position, size, and other properties. Even a simple GUI program that displayed a message such as "Hello world" required the programmer to write a hundred or more lines of code. Furthermore, the programmer could not actually see the program's user interface until the program was compiled and executed.

Today, there are several integrated development environments (IDEs) that allow you to construct a program's windows and its graphical elements visually without writing a single line of code. For example, Microsoft Visual Studio allows you to create GUI programs using the Visual Basic, C++, and C# programming languages. There are several other IDEs as well.

Most IDEs display a window editor that allows you to create windows, and a "toolbox" that displays all of the items that you can place in a window. You construct a window by dragging the desired items from the toolbox to the window editor. This is shown in Figures 15-5 and 15-6. The screen in Figure 15-5 is from Visual Basic, and the screen in Figure 15-6 is from NetBeans. As you visually construct the user interface in the window editor, the IDE automatically generates the code needed to display it.

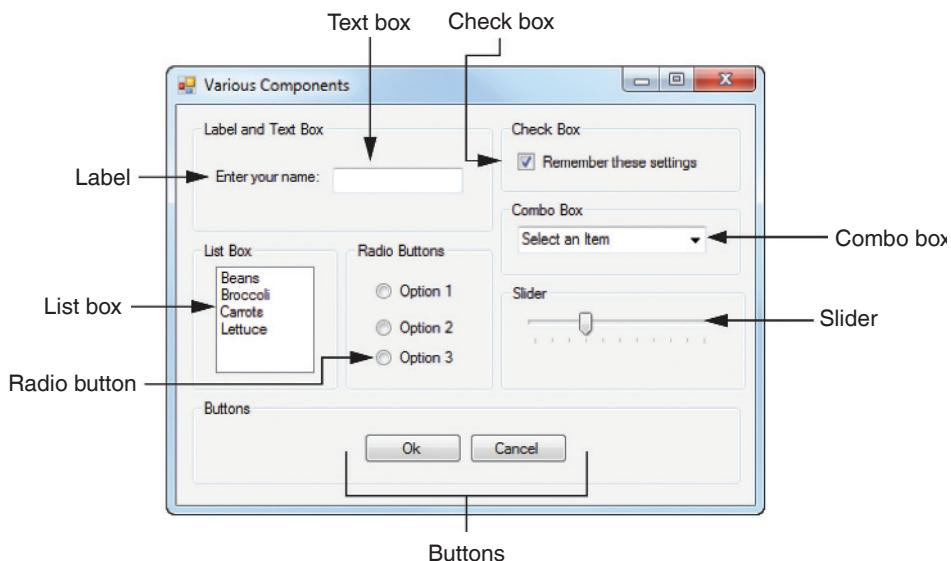
**Figure 15-5** Visually constructing a window in Visual Basic (courtesy of Microsoft Corporation)



**Figure 15-6** Visually constructing a window in NetBeans (courtesy of Microsoft Corporation)

## Components

The items that appear in a program's graphical user interface are known as *components*. Some of the common GUI components are buttons, labels, text boxes, check boxes, and radio buttons. Figure 15-7 shows an example of a window with a variety of components. Table 15-1 describes the components that appear in the window.

**Figure 15-7** Various components in a GUI window (courtesy of Microsoft Corporation)

**Table 15-1** Common GUI components

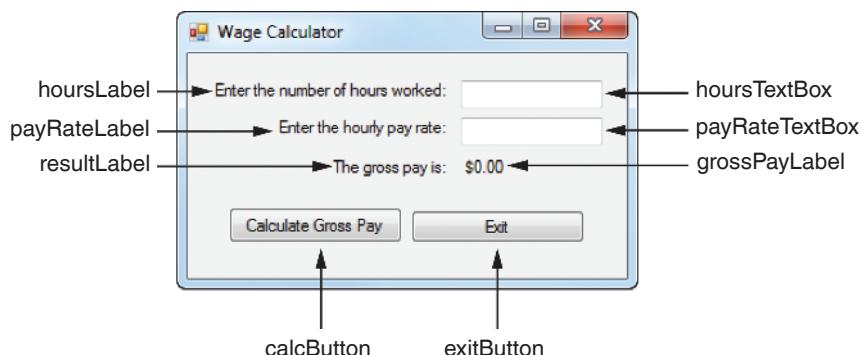
| Component    | Description                                                                                                                                                                     |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Button       | A component that causes an action to occur when it is clicked                                                                                                                   |
| Label        | An area that can display text                                                                                                                                                   |
| Text box     | An area in which the user may type a single line of input from the keyboard                                                                                                     |
| Check box    | A component that has a box that may be checked or unchecked                                                                                                                     |
| Radio button | A component that can be either selected or deselected; usually appears in groups and allows the user to select one of several options                                           |
| Combo box    | A component (combination of a list and a text box) that displays a drop-down list of items from which the user may select; provides a text box in which the user may type input |
| List box     | A list from which the user may select an item                                                                                                                                   |
| Slider       | A component that allows the user to select a value by moving a slider along a track                                                                                             |



**NOTE:** GUI components are also known as *controls* and *widgets*.

## Component Names

In most IDEs, you must assign unique names to the components that you place in a window. A component's name identifies the component in the program, in the same way that a variable's name identifies the variable. For example, Figure 15-8 shows a window from a program that calculates gross pay. The figure also shows the names that the programmer assigned to each component in the window. Notice that each component's name describes the component's purpose in the program. For example, the text box that the user enters the number of hours worked into is named `hoursTextBox`, and the button that calculates the gross pay is named `calcButton`. Additionally, in most programming languages, the rules for naming components are the same as the rules for naming variables.

**Figure 15-8** Components and their names (courtesy of Microsoft Corporation)



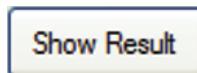
**NOTE:** In most IDEs, if you look at the code that is generated to display a window, you will see that each component in the window is an object, and the name that you have assigned to the component is used as the name of the object.

## Properties

Most GUI components have a set of *properties* that determines how the component appears on the screen. Typically, components have properties that specify the component's color, size, and position. Like variables, properties can be set to values. When you set a property to a value, it changes some aspect of the component that it belongs to.

Let's look at an example from Visual Basic. Suppose you have placed a button in a window and you want to display the text "Show Result" on the button. In Visual Basic, the `Text` property controls the text that is displayed on a component, so you change the value of the button's `Text` property to "Show Result." This causes the text "Show Result" to be displayed on the button, as shown in Figure 15-9.

**Figure 15-9** A button with its `Text` property set to "Show Result"



Most components in Visual Basic also have a property named `BackColor` that specifies the component's color, and another property named `ForeColor` that specifies the color of any text that is displayed on the component. For example, if you want to change the color of the text that is displayed on a button to blue, you set its `ForeColor` property to the value `Blue`.

Most IDEs allow you to set a component's properties while you are constructing the window. Typically, IDEs provide a *property window* that displays all of a component's properties, and allows you to change the properties to the desired values.

## Constructing a Window—A Summary

Now that you have an idea of how GUI windows are created in an IDE, let's look at a simple set of steps that you can follow to construct a window.

1. Sketch the window.

You should draw a sketch of the window before you start constructing it in the IDE. By doing this you will determine the components that are needed. At this point, it is often helpful to make a list of the necessary components.

2. Create the necessary components and name them.

After sketching the window and determining the components you will need, you can start constructing it in the IDE. As you place each component in the window, you should assign it a unique and meaningful name.

### 3. Set the components' properties to the desired values.

A component's properties control its visual characteristics, such as color, size, position, and any text that is displayed on the component. To get the visual appearance that you want, set each component's properties to the desired values. In most IDEs, you will use a property window to set the starting values for the properties of each component.

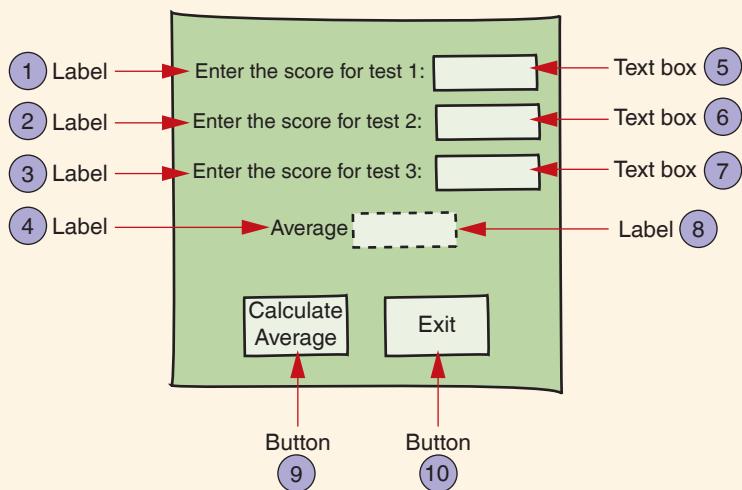
## In the Spotlight: Designing a Window



Kathryn teaches a science class. In Chapter 3, we stepped through the development of a program that her students can use to calculate the average of three test scores. The program prompts the student to enter each score, and then it displays the average. She has asked you to design a GUI program that performs a similar operation. She would like the program to have three text boxes that the test scores can be entered into, and a button that causes the average to be displayed when clicked.

First, we need to draw a sketch of the program's window, as shown in Figure 15-10. The sketch also shows the type of each component. (The numbers that appear in the sketch will help us when we make a list of all the components.)

**Figure 15-10** A sketch of the window



By examining the sketch we can make a list of all the components that we need. As we make the list, we will include a brief description of each component and a name that we will assign to each component when we construct it.

| Component Number in the Sketch | Component Type | Description                                                                                                                  | Name         |
|--------------------------------|----------------|------------------------------------------------------------------------------------------------------------------------------|--------------|
| 1                              | Label          | Instructs the user to enter the score for test 1.                                                                            | test1Label   |
| 2                              | Label          | Instructs the user to enter the score for test 2.                                                                            | test2Label   |
| 3                              | Label          | Instructs the user to enter the score for test 3.                                                                            | test3Label   |
| 4                              | Label          | Identifies the average, which will be displayed next to this label.                                                          | resultLabel  |
| 5                              | Text box       | This is where the user will enter the score for test 1.                                                                      | test1TextBox |
| 6                              | Text box       | This is where the user will enter the score for test 2.                                                                      | test2TextBox |
| 7                              | Text box       | This is where the user will enter the score for test 3.                                                                      | test3TextBox |
| 8                              | Label          | The program will display the average test score in this label.                                                               | averageLabel |
| 9                              | Button         | When this button is clicked, the program will calculate the average test score and display it in the averageLabel component. | calcButton   |
| 10                             | Button         | When this button is clicked the program will end.                                                                            | exitButton   |

Now that we have a sketch of the window and a list of the components we will need, we can use our IDE to construct it. As we place the components, we will set the appropriate properties to make the components look the way we want them to. Assuming we are constructing the window in Visual Basic, we will set the following properties:

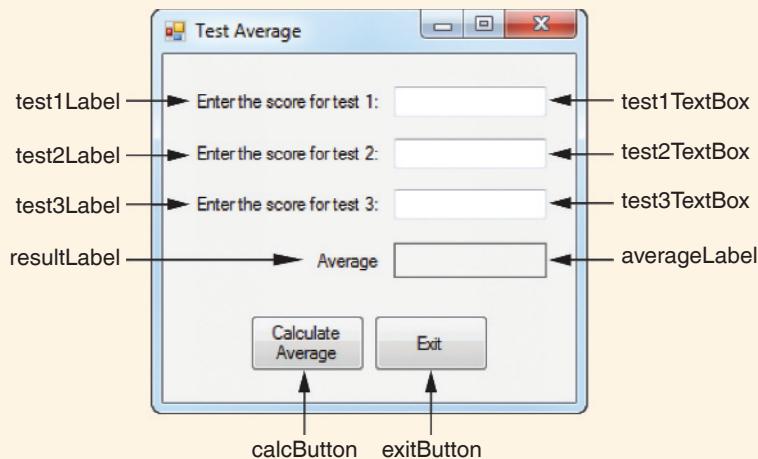
- The `test1Label` component's `Text` property will be set to "Enter the score for test 1:"
- The `test2Label` component's `Text` property will be set to "Enter the score for test 2:"
- The `test3Label` component's `Text` property will be set to "Enter the score for test 3:"
- The `resultLabel` component's `Text` property will be set to "Average"
- The `calcButton` component's `Text` property will be set to "Calculate Average"
- The `exitButton` component's `Text` property will be set to "Exit"
- The `averageLabel` component's `BorderStyle` property will be set to `FixedSingle`. This will cause a thin border to appear around the label, as shown in the sketch.



**TIP:** Although the properties listed here are specific to Visual Basic, other languages have similar properties. The names, however, may be different.

Figure 15-11 shows an example of how the window will appear. The figure shows the name of each component.

**Figure 15-11** The completed window (courtesy of Microsoft Corporation)



In the next *In the Spotlight* section we will continue developing this program by writing pseudocode that responds to the user's actions.



## Checkpoint

- 15.6 Why was GUI programming complex and time consuming in the early days of GUI technology?
- 15.7 In an IDE that allows you to visually construct a window, how do you place an item such as a button in the window?
- 15.8 What is a component?
- 15.9 Why must components be assigned names?
- 15.10 What do a component's properties do?

### 15.3

## Writing Event Handlers

**CONCEPT:** If you want a GUI program to perform an action when an event occurs, you must write code, known as an event handler, which responds to that event.

After you create a GUI program's user interface, you can write the code that responds to events. As previously mentioned, an *event* is an action that takes place within a program, such as the clicking of a button. Part of writing a GUI application is creating event handlers. An *event handler* is a module that automatically executes when a specific event occurs. If you want a program to perform an operation when a particular event

occurs, you must create an event handler that responds when that event takes place. In pseudocode, our event handlers will be written in the following general format:

```
Module ComponentName_EventName()
 The statements that appear here
 are executed when the event occurs.
End Module
```

In the general format, *ComponentName* is the name of the component that generated the event, and *EventName* is the name of the event that occurred. For example, suppose a window contains a button component named `showResultButton`, and we want to write an event handler that executes when the user clicks it. The event handler would be written in the following format:

```
Module showResultButton_Click()
 statement
 statement
 etc.
End Module
```

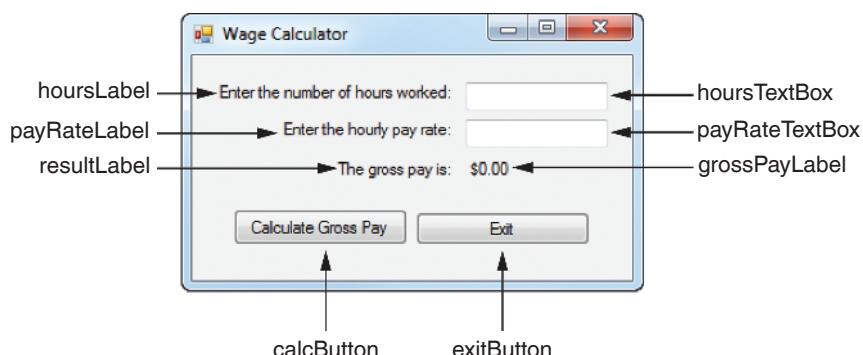
Predefined names are given to all of the events that can be generated in a GUI system. In this example, you saw that a `Click` event occurs when the user clicks a component. There are many other events that can be generated as well. For example, an event with a name such as `MouseEnter` will be generated when the mouse cursor is moved over a component, and an event with a name such as `MouseLeave` will be generated when the mouse cursor is moved off of a component.



**NOTE:** If an event occurs and there is no event handler to respond to that event, the event is ignored.

Let's look at an example of how we can write an event handler in pseudocode. Previously in this chapter, you saw a GUI window for a program that calculates an employee's gross pay. For your convenience the window is shown again, in Figure 15-12. The figure also shows the names of the components.

**Figure 15-12** A GUI window (courtesy of Microsoft Corporation)



When this program runs, there are two possible events that we want it to respond to: the user clicking the `calcButton` component and the user clicking the `exitButton` component. If the user clicks the `calcButton` component, we want the program to calculate the gross pay and display it in the `grossPayLabel` component. If the user clicks the `exitButton` component, we want the program to end.

To handle the event that occurs when the user clicks the `calcButton`, we would write the following event handler in pseudocode:

```
1 Module calcButton_Click()
2 // Local variables to hold the hours worked, the
3 // pay rate, and the gross pay.
4 Declare Real hours, payRate, grossPay
5
6 // Get the number of hours worked from the
7 // hoursTextBox component.
8 Set hours = stringToReal(hoursTextBox.Text)
9
10 // Get the pay rate from the payRateTextBox
11 // component.
12 Set payRate = stringToReal(payRateTextBox.Text)
13
14 // Calculate the gross pay.
15 Set grossPay = hours * payRate
16
17 // Display the gross pay in the grossPayLabel
18 // component.
19 Set grossPayLabel.Text = realToString(grossPay)
20 End Module
```

Let's take a closer look at each statement in this event handler.

- Line 4 declares three local variables: `hours`, `payRate`, and `grossPay`.
- Line 8 gets the value that has been typed into the `hoursTextBox` component and assigns it to the `hours` variable. A lot of things are happening in this line, so it deserves a thorough explanation.

When the user types a value into a text box component, the value is stored in the component's `Text` property. In pseudocode, we use dot notation to refer to a component's `Text` property. For example, to refer to the `hoursTextBox` component's `Text` property, we write `hoursTextBox.Text`.

In many languages, you cannot assign the value of a component's `Text` property directly to a numeric variable. For example, if line 8 were written as follows, an error would occur:

```
Set hours = hoursTextBox.Text
```

This logic will cause an error because the `Text` property holds strings, and strings cannot be assigned to numeric variables. So, we need to convert the value in the `Text` property to a real number. This can be done with the `stringToReal` function, as follows:

```
Set hours = stringToReal(hoursTextBox.Text)
```

(We discussed the `stringToReal` function in Chapter 6.)

- Line 12 gets the value that has been typed into the `payRateTextBox` component, converts it to a real number, and assigns it to the `payRate` variable.
- Line 15 multiplies `hours` by `payRate` and assigns the result to the `grossPay` variable.
- Line 19 displays the gross pay. It does this by assigning the value of the `grossPay` variable to the `grossPayLabel` component's `Text` property. Notice that a function, `realToString`, is used to convert the `grossPay` variable to a string. This is

necessary because in many languages an error will occur if we try to assign a `Real` number directly to a `Text` property. When we assign a value to a label component's `Text` property, that value will be displayed in the label.

To handle the event that occurs when the user clicks the `exitButton`, we would write the following event handler:

```
1 Module exitButton_Click()
2 Close
3 End Module
```

This event handler executes the `Close` statement. In pseudocode, the `Close` statement causes the window that is currently open to close. If the current window is the only one open, closing it causes the program to end.

## The Init Module

Quite often, you need to perform some actions when a GUI application starts executing. For example, you might need to display some initial data in one or more Label components. In our pseudocode, you can perform these actions in the `Init` module. If a GUI application has an `Init` module, it executes automatically when the application begins running. For example, we might want to add the following `Init` module to the Wage Calculator program:

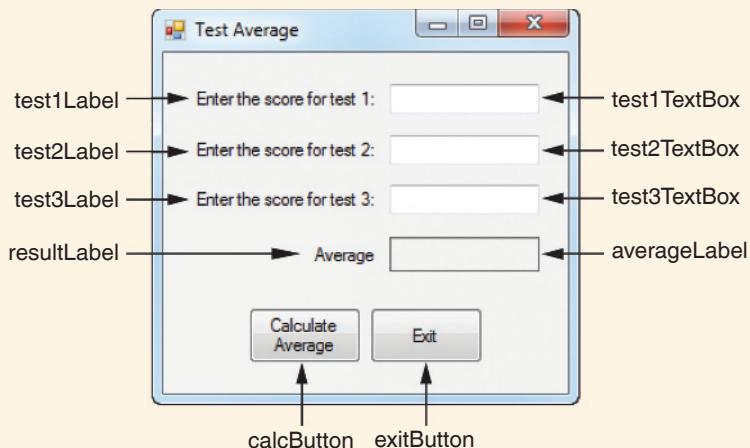
```
Module Init()
 Set grossPayLabel.Text = "$0.00"
End Module
```

This module initializes the `grossPayLabel` component's `Text` property with the string `"$0.00"`. As a result, the label will display `$0.00` when the application starts running.

## In the Spotlight: Designing an Event Handler

In the previous *In the Spotlight* section, we designed the window shown in Figure 15-13 for Kathryn's test score averaging program.

**Figure 15-13** The window for the test score averaging program (courtesy of Microsoft Corporation)



Now, we will design the program's event handlers. When the user clicks the `calcButton` component, the program should calculate the average of the three test scores and display it in the `averageLabel` component. When the user clicks the `exitButton` component, the program should end. The pseudocode in Program 15-1 shows both event handlers, as well as an `Init` module that displays an initial value in the `averageLabel` component.

### Program 15-1

```
1 Module Init()
2 Set averageLabel.Text = "0"
3 End Module
4
5 Module calcButton_Click()
6 // Declare local variables to hold the test
7 // scores and the average.
8 Declare Real test1, test2, test3, average
9
10 // Get the first test score.
11 Set test1 = stringToReal(test1TextBox.Text)
12
13 // Get the second test score.
14 Set test2 = stringToReal(test2TextBox.Text)
15
16 // Get the third test score.
17 Set test3 = stringToReal(test3TextBox.Text)
18
19 // Calculate the average test score.
20 Set average = (test1 + test2 + test3) / 3
21
22 // Display the average test score in the
23 // averageLabel component.
24 Set averageLabel.Text = realToString(average)
25 End Module
26
27 Module exitButton_Click()
28 Close
29 End Module
```

The `Init` Module initializes the `averageLabel` component's `Text` property with the value “0”. This causes 0 to be initially displayed in the label. Here is a description of each statement in the `calcButton_Click` module:

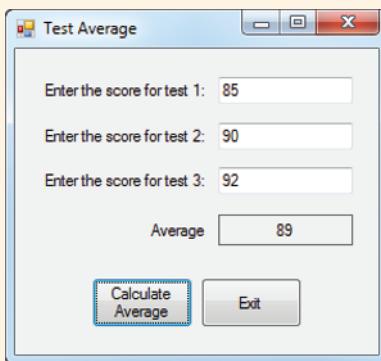
- Line 8 declares local variables to hold the three test scores and the average of the test scores.
- Line 11 gets the value that has been entered into the `test1TextBox` component, converts it to a real number, and stores it in the `test1` variable.
- Line 14 gets the value that has been entered into the `test2TextBox` component, converts it to a real number, and stores it in the `test2` variable.
- Line 17 gets the value that has been entered into the `test3TextBox` component, converts it to a real number, and stores it in the `test3` variable.
- Line 20 calculates the average of the three test scores and stores the result in the `average` variable.

- Line 24 converts the value in the `average` variable to a string and stores it in the `averageLabel` component's `Text` property. Doing this displays the value in the label component.

The `exitButton_Click` module executes the `Close` statement to close the window and subsequently end the program.

Figure 15-14 shows an example of how the program's window will appear after the user has entered values into the text boxes and clicked the `calcButton` component.

**Figure 15-14** The window with an average displayed (courtesy of Microsoft Corporation)



## Checkpoint

- 15.11 What is an event?
- 15.12 What is an event handler?
- 15.13 Look at the following pseudocode and then answer the questions that follow it:

```
Module showValuesButton_Click()
 statement
 statement
 etc.
End Module
```

  - a. What event does this module respond to?
  - b. What is the name of the component that generates the event?
- 15.14 We introduced a module named `Init` in our pseudocode. What is the purpose of this module? When does it execute?

**15.4**

## Designing Apps for Mobile Devices

**CONCEPT:** Smaller screen size and special hardware capabilities typically require special consideration from developers creating mobile applications.

GUIs are used in applications, or *apps*, that are developed for mobile devices such as smartphones and tablets. However, the physical screens on mobile devices are much smaller than those used with desktop and laptop computers. As a result, the GUI for a mobile app is usually designed differently than the GUI for an application that is intended for a desktop or laptop computer. Also, mobile users typically interact with apps via a touchscreen, not a mouse and a physical keyboard. These are important considerations that programmers must keep in mind when developing apps for mobile devices. Here are a few guidelines that mobile developers must follow:

- **Present less information at once**—Mobile apps must present less information per screen than traditional applications that are viewed on desktop and laptop computers. The content that will easily fit in one window in a desktop application must sometimes be separated into multiple screens in a mobile app.
- **Use larger font sizes for easier reading**—To reduce eye strain and make mobile screens easier to read, a larger font size is typically required.
- **Arrange components in a way that works for the smaller screen size**—Quite often, the user of a mobile device must scroll the screens in an app to see all their content. Because of this, the more important and the most often used components should be placed near the top of the screen.
- **Use components that work well with touchscreens**—Mobile apps need to use GUI components that work well in a touch environment, and are arranged in such a way that the user can easily interact with them. For example, you might discover that on a touchscreen it is difficult to click buttons that are placed near the edges of the screen. You might also discover that list boxes work better than combo boxes in a touch environment.

### Utilizing the Unique Hardware Capabilities of Mobile Devices

Mobile devices typically have capabilities that are not available on laptop and desktop computers. For example, smartphones can typically do the following:

- make and receive phone calls
- send and receive text messages
- determine the device's location
- detect the device's physical orientation in 3D space
- determine when the device is moving

These capabilities are possible because of specialized hardware components that most mobile devices are equipped with. A program, or app, that is running on a mobile

device can interact with these hardware components. The program can obtain data from the components and, in many cases, cause the components to perform actions. In this section, we will look at some pseudocode and flowchart algorithms that interact with the specialized hardware components that are typically found in mobile devices.



**NOTE:** In our pseudocode, we will use generic programming techniques for interacting with a simulated mobile device. When you start learning to program for a specific type of mobile device, the syntax will be different. Much of the logic, however, will be the same.

## Making Phone Calls

A smartphone's most fundamental hardware component is the one that makes and receives phone calls. In our algorithms, we will refer to this component as the PhoneCall component. Our PhoneCall component has a method named `makeCall` that makes a call to a specified phone number. (Recall from Chapter 14 that a method is a module or function that an object can execute.) Here is an example of how we call the `makeCall` method:

```
PhoneCall.makeCall("919-555-1212")
```

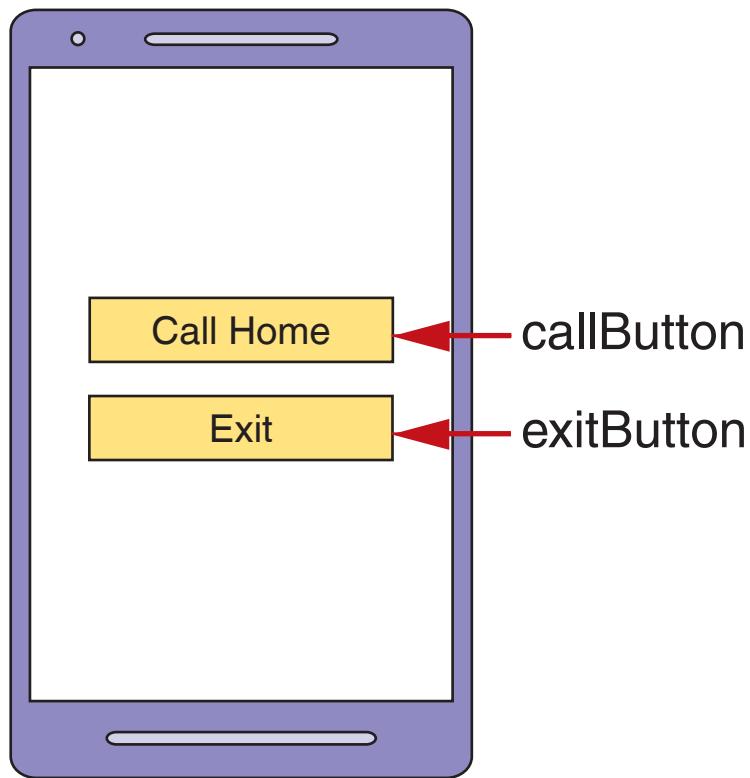
This statement causes the device to make a phone call to the phone number 919-555-1212. Note that the phone number is a string, and it is passed as an argument to the method.



**NOTE:** The PhoneCall component is a *non-visual component*. This means it does not visually appear in the app's GUI, like a Button or a Label. Non-visual components are objects that you cannot see in a GUI, but provide special capabilities to your programs.

Let's look at the design for a very simple app that uses this method. Figure 15-15 shows a simulated smartphone displaying the app's GUI. The app's GUI has a Button component named `callButton`, and another Button component named `exitButton`. When the user presses the `callButton` component, the app dials a predefined phone number and initiates a phone call. When the user presses the `exitButton` component, the app closes. Program 15-2 shows the pseudocode for the app's event handlers.

**Figure 15-15** Screen for the Call Home Mobile App



### Program 15-2

```
1 Module callButton_Click()
2 PhoneCall.makeCall("919-555-1212")
3 End Module
4
5 Module exitButton_Click()
6 Close
7 End Module
```

In the `callButton_Click` module, the statement in line 2 calls the `PhoneCall` component's `makeCall` method, passing the string "919-555-1212" as an argument. This causes the device to dial the specified phone number. In the `exitButton_Click` module, the `Close` statement in line 6 causes the app to end execution.

## Sending Text Messages

Another important smartphone component is the one that sends and receives text messages. In our algorithms, we will refer to this component as the `TextMessage` component. Like the `PhoneCall` component, our `TextMessage` component is a non-visual

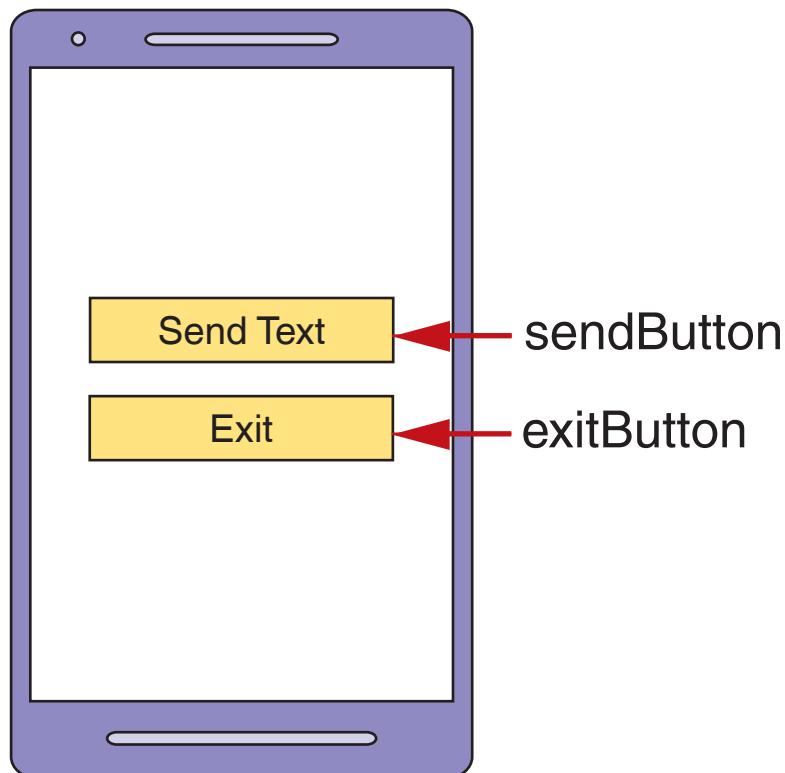
component. The `TextMessage` component has a method named `sendText` that sends a text message to a specified phone number. Here is an example of how we call the `sendText` method:

```
Declare String phoneNumber = "919-555-1212"
Declare String message = "What time are you coming over?"
TextMessage.sendText(phoneNumber, message)
```

Notice that we pass two string arguments to the `sendText` method: the first is the phone number that the message will be sent to, and the second is the text that you want to send. This statement causes the device to send the text message *What time are you coming over?* to the phone number 919-555-1212.

Let's look at the design for a simple app that uses this method. Figure 15-16 shows the app's GUI on a simulated mobile smartphone screen. It has a Button component named `sendButton`, and another Button component named `exitButton`. When the user presses the `sendButton` component, the app sends a text message to a predefined phone number. When the user presses the `exitButton` component, the app closes. Program 15-3 shows the pseudocode for the app's event handlers.

**Figure 15-16** Screen for the Send Text Mobile App



**Program 15-3**

```
1 Module sendButton_Click()
2 Declare String phoneNumber = "919-555-1212"
3 Declare String message = "I'm on my way home."
4 TextMessage.sendText(phoneNumber, message)
5 End Module
6
7 Module exitButton_Click()
8 Close
9 End Module
```

In the `sendButton_Click` module, the statement in line 2 declares a `String` variable named `phoneNumber`, initialized with "919-555-1212". Line 3 declares a `String` variable named `message`, initialized with "I'm on my way home." Line 4 calls the `TextMessage` component's `sendText` method, passing the `phoneNumber` and `message` variables as arguments. This causes the device to send the text message *I'm on my way home* to the phone number 919-555-1212. In the `exitButton_Click` module, the `Close` statement in line 8 causes the app to end execution.

## Receiving Phone Calls

In pseudocode, the `PhoneCall` component in our simulated mobile device generates an `IncomingCall` event when the device receives an incoming phone call. If you want your app to perform an action when the device receives an incoming phone call, you have to write an event handler in the following general format:

```
Module PhoneCall_IncomingCall()
 statement
 statement
 etc.
End Module
```

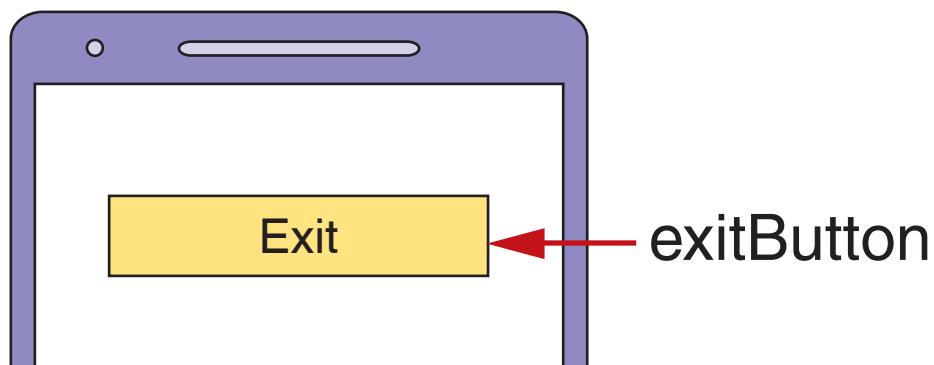
The statements that appear inside the `PhoneCall_IncomingCall` module will be executed each time the device receives an incoming phone call.

The `PhoneCall` component also has a property named `IncomingNumber` that holds the phone number, as a string, of the last incoming call. The following code shows an example of how to get the phone number from this property:

```
Declare String phoneNumber
phoneNumber = PhoneCall.IncomingNumber
```

After this code executes, the `phoneNumber` variable will hold the phone number of the last incoming phone call.

Let's look at an example app design that responds to an incoming phone call. Suppose you are going to be away from your smartphone for a while, and each time the phone receives a call, you want it to automatically send a text message to the caller indicating that you are away from your phone. Figure 15-17 shows the app's GUI on a simulated smartphone screen. It has one `Button` component, named `exitButton`. Program 15-4 shows the pseudocode for the app's event handlers.

**Figure 15-17** Screen for the Call Auto Responder Mobile App**Program 15-4**

```

1 Module PhoneCall_IncomingCall()
2 Declare String phoneNumber
3 Declare String message = "I'll call you back later."
4
5 phoneNumber = PhoneCall.IncomingNumber
6 TextMessage.sendText(phoneNumber, message)
7 End Module
8
9 Module exitButton_Click()
10 Close
11 End Module

```

In a nutshell, we can describe the app like this: When the app runs, it waits for incoming phone calls. When an incoming phone call occurs, it sends the caller a text message saying *I'll call you back later*. To close the app, the user presses the *Exit* button.

## Receiving Text Messages

In pseudocode, the `TextMessage` component in our simulated mobile device generates an `IncomingText` event when the device receives an incoming text message. If you want your app to perform an action when the device receives an incoming text message, you have to write an event handler in the following general format:

```

Module TextMessage_IncomingText()
 statement
 statement
 etc.
End Module

```

The statements that appear inside the `TextMessage_IncomingText` module will be executed each time the device receives an incoming text message.

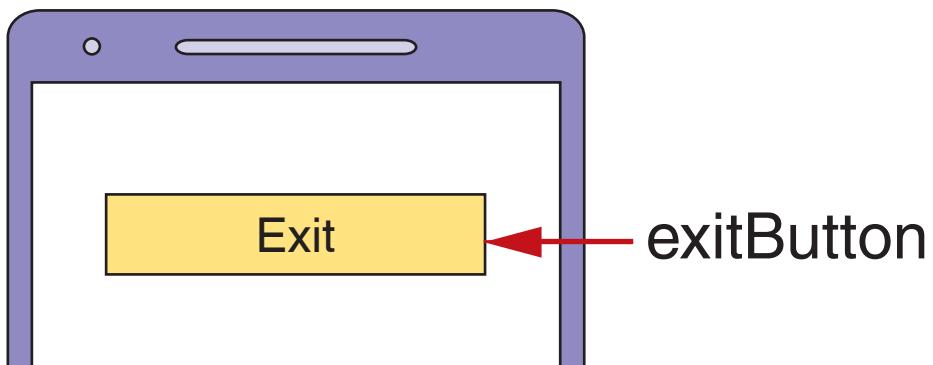
The TextMessage component also has a property named IncomingNumber that holds the phone number, as a string, of the device that sent the last incoming text message. The following code shows an example of how to get the phone number from this property:

```
Declare String phoneNumber
phoneNumber = TextMessage.IncomingNumber
```

After this code executes, the phoneNumber variable will hold the phone number of the device that sent the last incoming text message.

Let's look at an example app design that responds to an incoming text message. Suppose you are driving, and each time the phone receives a text message, you want it to automatically send a text message back to the sender indicating that you can't respond to the message. Figure 15-18 shows the app's GUI on a simulated smartphone screen. It has one Button component, named exitButton. Program 15-5 shows the pseudocode for the app's event handlers.

**Figure 15-18** Screen for the Text Auto Responder Mobile App



### Program 15-5

```
1 Module TextMessage_IncomingMessage()
2 Declare String phoneNumber
3 Declare String message = "I'm driving, so I'll reply later."
4
5 phoneNumber = TextMessage.IncomingNumber
6 TextMessage.sendText(phoneNumber, message)
7 End Module
8
9 Module exitButton_Click()
10 Close
11 End Module
```

When the app runs, it waits for incoming text messages. When text message arrives, the app sends back a text message saying *I'm driving, so I'll reply later*. When the user is finished using the app, the *Exit* button can be pressed to close it.

## Detecting the Device's Location

Most mobile devices are equipped with a location sensor. A *location sensor* is a component that can determine the device's latitude, longitude, and nearest street address. In our pseudocode, we will refer to this component as the Location component. Our Location component has the following three methods that we can use to get the device's location:

- `getLatitude()`—returns the device's latitude as a Real number
- `getLongitude()`—returns the device's longitude as a Real number
- `getAddress()`—returns a string containing the street address that is nearest to the device

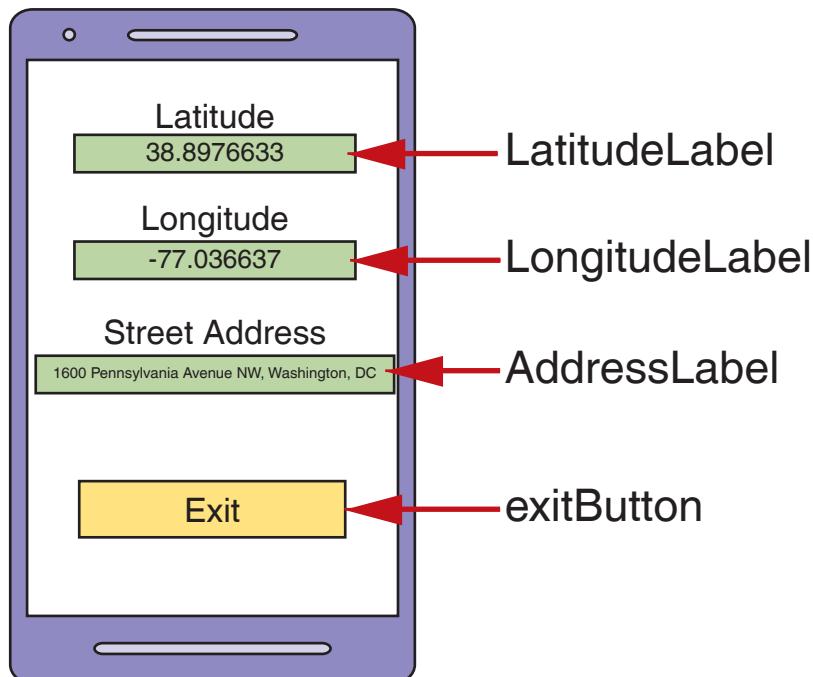
Our Location component also generates a `LocationChanged` event each time the device's location changes. If you want your app to perform an action when the device's location changes, you have to write an event handler in the following general format:

```
Module Location_LocationChanged()
 statement
 statement
 etc.
End Module
```

The statements that appear inside the `Location_LocationChanged` module will be executed each time the device's location changes.

Let's look at an example app design that uses the location sensor. The app's GUI is shown in Figure 15-19, on a simulated smartphone screen. When the app starts, it

**Figure 15-19** Screen for the Get Location Mobile App



displays the device's current latitude, longitude, and nearest street address in Label components. Each time the device's location changes, the app gets the new latitude, longitude, and street address, and updates the Label components with the new information. Program 15-6 shows the app's pseudocode.

### Program 15-6

```
1 Module Init()
2 // Initialize the Labels with the device's
3 // current location.
4 LatitudeLabel.Text = realToString(Location.getLatitude())
5 LongitudeLabel.Text = realToString(Location.getLongitude())
6 AddressLabel.Text = Location.getAddress()
7 End Module
8
9 Module Location_LocationChanged()
10 // Update the Labels when the device's
11 // location changes.
12 LatitudeLabel.Text = realToString(Location.getLatitude())
13 LongitudeLabel.Text = realToString(Location.getLongitude())
14 AddressLabel.Text = Location.getAddress()
15 End Module
16
17 Module exitButton_Click()
18 Close
19 End Module
```

Let's take a closer look at the pseudocode. The `Init` module, shown in lines 1 through 7, executes when the app starts. It performs the following steps to display the device's initial location:

- Line 4 gets the device's current latitude, converts it to a string, and assigns the string to the `LatitudeLabel` component's `Text` property. Doing this displays the latitude in the Label component.
- Line 5 gets the device's current longitude, converts it to a string, and assigns the string to the `LongitudeLabel` component's `Text` property. Doing this displays the longitude in the Label component.
- Line 6 gets the street address nearest to the device's current location and assigns it to the `AddressLabel` component's `Text` property. Doing this displays the address in the Label component.

The `Location_LocationChanged` module is shown in lines 9 through 15. This module is an event handler that executes each time the device's location changes. The code in lines 12 through 14 get the device's latitude, longitude, and nearest street address, and displays this new information in the Label components.

The `exitButton_Clicked` module, shown in lines 17 through 19, closes the app when the user clicks the *Exit* button.



## Checkpoint

- 15.15 Do mobile devices allow you to show more information on a screen, or less?
- 15.16 Do mobile device screens typically require a larger font or a smaller font compared to desktop screens?
- 15.17 Name at least three unique capabilities that mobile devices usually have, compared to desktop computers.
- 15.18 What is a non-visual component? Give two examples that we discussed in this section.
- 15.19 Suppose you are writing pseudocode for an app that performs an action each time the smartphone receives an incoming call. How does the app know that a call is coming in?
- 15.20 Suppose you are writing pseudocode for an app that performs an action each time the smartphone receives an incoming text message. How does the app know that a message is coming in?
- 15.21 Suppose you are writing pseudocode for a mobile app that performs an action each time the device's location changes. How does the app know that the device's location has changed?

15.5

## Focus on Languages: Java, Python, and C++

### Java

This chapter discusses how GUI components can be created in an integrated development environment (IDE), and how event handlers can be written to respond to the user's interactions. The Java language does not come with an IDE, but Oracle provides a free IDE known as NetBeans. You can download NetBeans for free from [www.netbeans.org/downloads](http://www.netbeans.org/downloads). Be sure to download the Java SE version. Once you have downloaded and installed NetBeans, refer to Chapter 15 of the *Java Language Companion* that is available from the publisher's website for this textbook. (You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).) The *Java Language Companion* provides a simple, step-by-step tutorial that leads you through the process of creating a simple Java GUI application in NetBeans.

### Python

Python does not have GUI programming features built into the language itself. However, it comes with a module named Tkinter that allows you to create simple GUI programs. The name "Tkinter" is short for "Tk interface." It is named this because it provides a way for Python programmers to use a GUI library named Tk. Many other programming languages use the Tk library as well.

Chapter 15 of the *Python Language Companion*, which is available from the publisher's website for this textbook, will give you a brief introduction to GUI programming using Python and Tkinter. You can access the website by visiting [www.pearson.com/gaddis](http://www.pearson.com/gaddis).

## C++

C++ does not have GUI programming features built into the language itself. However, there are many third-party libraries and programming tools available that you can use to write GUI applications in C++. For example, Microsoft Visual C++ is very popular. You can use the Microsoft Visual Studio IDE to develop Visual C++ applications.

## Review Questions

### Multiple Choice

1. The \_\_\_\_\_ is the part of a computer with which the user interacts.
  - a. central processing unit
  - b. user interface
  - c. control system
  - d. interactivity system
2. Before GUIs became popular, the \_\_\_\_\_ interface was the most commonly used.
  - a. command line
  - b. remote terminal
  - c. sensory
  - d. event-driven
3. A \_\_\_\_\_ is a small window that displays information and allows the user to perform actions.
  - a. menu
  - b. confirmation window
  - c. startup screen
  - d. dialog box
4. A type of program that is typically event-driven is the \_\_\_\_\_ program.
  - a. command line
  - b. text-based
  - c. GUI
  - d. procedural
5. An item that appears in a program's graphical user interface is known as a \_\_\_\_\_.
  - a. gadget
  - b. component
  - c. tool
  - d. graphic object

6. By specifying characteristics such as color, size, and location, \_\_\_\_\_ determine how a GUI element appears on the screen.
  - a. properties
  - b. attributes
  - c. methods
  - d. event handlers
7. An \_\_\_\_\_ is an action that takes place within a program, such as the clicking of a button.
  - a. event handler
  - b. anomaly
  - c. event
  - d. exception
8. A(n) \_\_\_\_\_ is a module that automatically executes when a specific event occurs.
  - a. event handler
  - b. auto module
  - c. startup module
  - d. exception
9. In our pseudocode, the \_\_\_\_\_ module executes automatically when the GUI application starts executing.
  - a. StartUp
  - b. Init
  - c. Auto
  - d. Main
10. The \_\_\_\_\_ component that we discussed in this chapter is an example of a non-visual component.
  - a. Button
  - b. Label
  - c. TextMessage
  - d. Text box

### True or False

1. Many computer users, especially beginners, find command line interfaces difficult to use.
2. Writing a GUI program today is complex and time consuming because you have to write all of the code that constructs the program's windows without seeing it on the screen.
3. A component's `Text` property typically holds string values.
4. Predefined names are given to all of the events that can be generated in a GUI system.
5. A user interface flow diagram shows how a GUI program flows from one window to the next as the user interacts with it.

6. In our pseudocode, the `Init` module automatically executes when the application starts.
7. When developing GUIs for mobile devices and desktop computers, you typically use a smaller font with the mobile device than with the desktop computer.

### Short Answer

1. When a program runs in a text-based environment, such as a command line interface, what determines the order in which things happen?
2. What determines how a component appears on the screen?
3. Describe how you typically change the color of a component.
4. Why must components be assigned names?
5. What happens if an event occurs and there is no event handler to respond to the event?
6. What is a non-visual component? Give an example of a non-visual component that we discussed in this chapter.

### Algorithm Workbench

1. Design an event handler that will execute when the `showNameButton` component is clicked. The event handler should perform the following:
  - Store your first name in a label component named `firstNameLabel1`.
  - Store your middle name in a label component named `middleNameLabel1`.
  - Store your last name in a label component named `lastNameLabel1`.(Remember, to store a value in a label component, you must store the value in the component's `Text` property.)
2. Design an event handler that will execute when the `calcAvailableCreditButton` component is clicked. The event handler should perform the following:
  - Declare the following `Real` variables: `maxCredit`, `usedCredit`, and `availableCredit`.
  - Get a value from a text box named `maxCreditTextBox` and assign it to the `maxCredit` variable.
  - Get a value from a text box named `usedCreditTextBox` and assign it to the `usedCredit` variable.
  - Subtract the value in `usedCredit` from `maxCredit` and assign the result to `availableCredit`.
  - Store the value in the `availableCredit` variable in a label component named `availableCreditLabel1`.
3. The GUI for a mobile app has a Label component named `phoneNumberLabel1`. Write an event handler that executes when the device receives an incoming phone call. The event handler should display the phone number of the incoming call in the `phoneNumberLabel` component.
4. The GUI for a mobile app has a Label component named `addressLabel1`. Write an `Init` module that gets the street address nearest to the device and displays it in the `addressLabel` component.



VideoNote

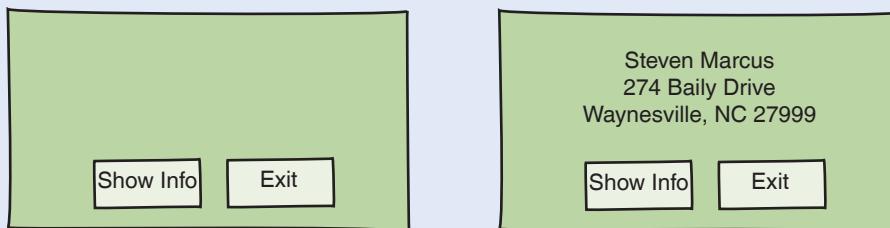
The Name and Address Problem

## Programming Exercises

### 1. Name and Address

Design a GUI program that displays your name and address when a button is clicked. The program's window should appear as the sketch on the left side of Figure 15-20 when it runs. When the user clicks the *Show Info* button, the program should display your name and address, as shown in the sketch on the right side of the figure.

**Figure 15-20** Name and address program



### 2. Latin Translator

Look at the following list of Latin words and their meanings:

| Latin     | English |
|-----------|---------|
| autem     | up      |
| descendit | down    |
| medium    | center  |

Design a GUI program that translates the Latin words to English. The window should have three buttons, one for each Latin word. When the user clicks a button, the program displays the English translation in a label component.

### 3. Miles-per-Gallon Calculator

Design a GUI program that calculates a car's gas mileage. The program's window should have text boxes that let the user enter the number of gallons of gas the car holds, and the number of miles it can be driven on a full tank. When a *Calculate MPG* button is clicked, the program should display the number of miles that the car may be driven per gallon of gas. Use the following formula to calculate miles-per-gallon:

$$MPG = \frac{Miles}{Gallons}$$

### 4. Celsius to Fahrenheit

Design a GUI program that converts Celsius temperatures to Fahrenheit temperatures. The user should be able to enter a Celsius temperature, click a button, and

then see the equivalent Fahrenheit temperature. Use the following formula to make the conversion:

$$F = \frac{9}{5}C + 32$$

*F* is the Fahrenheit temperature and *C* is the Celsius temperature.

### 5. Property Tax

A county collects property taxes on the assessment value of property, which is 60 percent of the property's actual value. If an acre of land is valued at \$10,000, its assessment value is \$6,000. The property tax is then \$0.64 for each \$100 of the assessment value. The tax for the acre assessed at \$6,000 will be \$38.40. Design a GUI program that displays the assessment value and property tax when a user enters the actual value of a property.

### 6. Location Texting Mobile App

Sometimes it is helpful to update another person with your current location via a text message. Design a mobile app that does the following:

- Allows the user to enter the phone number of the person that you wish to send the text message to.
- Provides a button that sends a text message to the last specified phone number. The text message should contain the street address nearest the mobile device.

Note that the user should not have to enter a phone number each time the text message is sent. When the text message is sent, it should go to the last phone number that was specified. If the user attempts to send a text message before a phone number is entered, the app should display an error message.

### 7. Track Your Route

Design a mobile app that will write the device's latitude and longitude to a file each time the device's location changes. Use the techniques discussed in Chapter 10 to write the latitude and longitude to the file as a record.

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# A

# ASCII/Unicode Characters

The following table lists the ASCII (American Standard Code for Information Interchange) character set, which is the same as the first 127 Unicode character codes. This group of character codes is known as the *Latin Subset of Unicode*. The code columns show character codes and the character columns show the corresponding characters. For example, the code 65 represents the letter A. Note that the first 31 codes and code 127 represent control characters that are not printable.

| Code | Character | Code | Character | Code | Character | Code | Character |
|------|-----------|------|-----------|------|-----------|------|-----------|
| 0    | NUL       | 26   | SUB       | 52   | 4         | 78   | N         |
| 1    | SOH       | 27   | Escape    | 53   | 5         | 79   | O         |
| 2    | STX       | 28   | FS        | 54   | 6         | 80   | P         |
| 3    | ETX       | 29   | GS        | 55   | 7         | 81   | Q         |
| 4    | EOT       | 30   | RS        | 56   | 8         | 82   | R         |
| 5    | ENQ       | 31   | US        | 57   | 9         | 83   | S         |
| 6    | ACK       | 32   | (Space)   | 58   | :         | 84   | T         |
| 7    | BEL       | 33   | !         | 59   | ;         | 85   | U         |
| 8    | Backspace | 34   | "         | 60   | <         | 86   | V         |
| 9    | HTab      | 35   | #         | 61   | =         | 87   | W         |
| 10   | Line Feed | 36   | \$        | 62   | >         | 88   | X         |
| 11   | VTAB      | 37   | %         | 63   | ?         | 89   | Y         |
| 12   | Form Feed | 38   | &         | 64   | @         | 90   | Z         |
| 13   | CR        | 39   | '         | 65   | A         | 91   | [         |
| 14   | SO        | 40   | (         | 66   | B         | 92   | \         |
| 15   | SI        | 41   | )         | 67   | C         | 93   | ]         |
| 16   | DLE       | 42   | *         | 68   | D         | 94   | ^         |
| 17   | DC1       | 43   | +         | 69   | E         | 95   | _         |
| 18   | DC2       | 44   | ,         | 70   | F         | 96   | `         |
| 19   | DC3       | 45   | -         | 71   | G         | 97   | a         |
| 20   | DC4       | 46   | .         | 72   | H         | 98   | b         |
| 21   | NAK       | 47   | /         | 73   | I         | 99   | c         |
| 22   | SYN       | 48   | 0         | 74   | J         | 100  | d         |
| 23   | ETB       | 49   | 1         | 75   | K         | 101  | e         |
| 24   | CAN       | 50   | 2         | 76   | L         | 102  | f         |
| 25   | EM        | 51   | 3         | 77   | M         | 103  | g         |
|      |           |      |           |      |           |      | DEL       |

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**B**

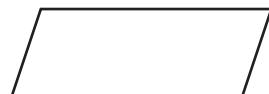
# Flowchart Symbols

This page shows the flowchart symbols that are used in this book.

Terminal Symbols



Input/Output Symbol



Processing Symbol



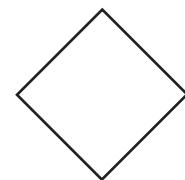
Connector



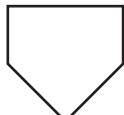
Module Call Symbol



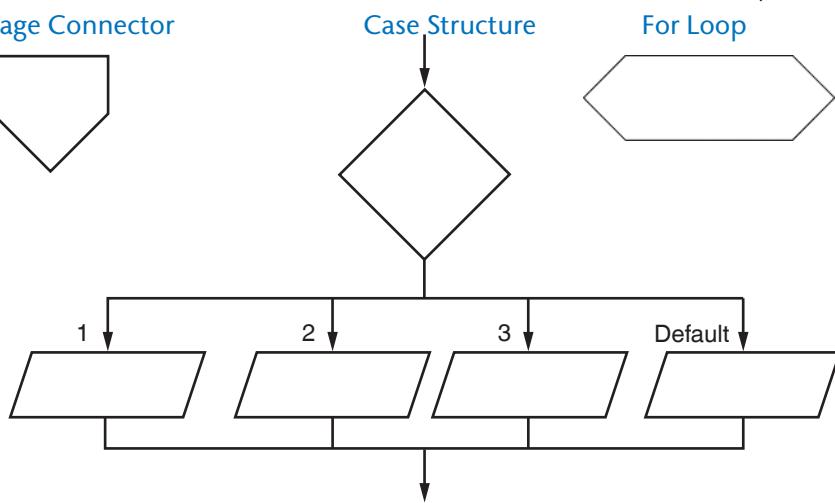
Decision Symbol



Off-Page Connector



Case Structure



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# Pseudocode Reference

This appendix serves as a quick reference for the pseudocode that is used in this book. This reference concisely covers the book's statements and operators. (It does not cover the library functions, however. See the index to locate a specific library function in the main text.)

| Data Types | Description                                                       |
|------------|-------------------------------------------------------------------|
| Integer    | Used for variables that will store whole numbers                  |
| Real       | Used for variables that will store numbers with a fractional part |
| String     | Used for variables that will store strings                        |
| Character  | Used for variables that will store a single character             |

## Variables

To declare a variable, you use the `Declare` statement. Here is the general format:

`Declare DataType VariableName`

In the general format, `DataType` is the variable's data type and `VariableName` is the variable's name. Here are some examples:

```
Declare Integer distance
Declare Real grossPay
Declare String name
Declare Character letter
```

You can optionally initialize a variable with a starting value when you declare it. Here is an example:

`Declare Real price = 49.95`

## Named Constants

You create a named constant by using the `Constant` statement instead of the `Declare` statement. Here is the general format:

`Constant DataType Name = Value`

In the general format, `DataType` is the constant's data type, `Name` is the constant's name, and `Value` is the constant's value. Here is an example:

`Constant Real INTEREST_RATE = 0.072`

## Arrays

Here is the general format of an array declaration:

```
Declare DataType ArrayName[Size]
```

In the general format, *DataType* is the array's data type, *ArrayName* is the array's name, and *Size* is the number of elements in the array. Here is an example:

```
Declare Integer units[10]
```

This statement declares an array of Integer values. The array's name is *units*, and it has 10 elements.

## Two-Dimensional Arrays

Here is the general format of a two-dimensional array declaration:

```
Declare DataType ArrayName[Rows] [Cols]
```

In the general format, *DataType* is the array's data type, *ArrayName* is the array's name, *Rows* is the number of rows in the array, and *Cols* is the number of columns. Here is an example:

```
Declare Integer values[10][20]
```

This statement declares an array of Integer values. The array's name is *values*, and it has 10 rows and 20 columns.

## Displaying Output

To display output you use the *Display* statement. The *Display* statement displays a line of output on the screen. Here is the general format to use when you are displaying one item of data:

```
Display Item
```

To display multiple items, you separate the items with commas, as shown in the following general format:

```
Display Item, Item, Item . . .
```

Here are some examples:

```
Display "Hello world"
Display grossPay
Display "My name is ", name
```

You can use the word *Tab* to indent screen output to the next tab position. Here is an example:

```
Display amount1, Tab, amount2, Tab, amount3
```

## Reading Input

You use the *Input* statement to read keyboard input. Here is the general format:

```
Input VariableName
```

In the general format, *VariableName* is the name of the variable that will receive the input. Here is an example:

```
Input hours
```

## Comments

In this book, we begin a comment with two forward slashes. Everything appearing on the line after the slashes is a comment. Here is an example:

```
// Get the number of hours worked.
```

## Math Operators

| Symbol | Operator       | Description                                           |
|--------|----------------|-------------------------------------------------------|
| +      | Addition       | Adds two numbers                                      |
| -      | Subtraction    | Subtracts one number from another                     |
| *      | Multiplication | Multiplies one number by another                      |
| /      | Division       | Divides one number by another and gives the quotient  |
| MOD    | Modulus        | Divides one number by another and gives the remainder |
| ^      | Exponent       | Raises a number to a power                            |

## Relational Operators

| Operator | Meaning                  |
|----------|--------------------------|
| >        | Greater than             |
| <        | Less than                |
| >=       | Greater than or equal to |
| <=       | Less than or equal to    |
| ==       | Equal to                 |
| !=       | Not equal to             |

## Logical Operators

| Operator | Meaning                                                                                                                                                                                                                                                                                                                             |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AND      | The AND operator connects two Boolean expressions into one compound expression. Both subexpressions must be true for the compound expression to be true.                                                                                                                                                                            |
| OR       | The OR operator connects two Boolean expressions into one compound expression. One or both subexpressions must be true for the compound expression to be true. It is only necessary for one of the subexpressions to be true, and it does not matter which.                                                                         |
| NOT      | The NOT operator is a unary operator, meaning it works with only one operand. The operand must be a Boolean expression. The NOT operator reverses the truth of its operand. If it is applied to an expression that is true, the operator returns false. If it is applied to an expression that is false, the operator returns true. |

## The If-Then Statement

General format:

```
If condition Then
 statement
 statement
 etc.
End If
```

} These statements are conditionally executed.

In the general format, the *condition* is a Boolean expression. If the expression is true, the statements appearing between the If clause and the End If clause are executed. Otherwise, the statements are skipped. Here is an example:

```
If sales > 50000 Then
 Set bonus = 500.0
 Set commissionRate = 0.12
 Display "You've met your sales quota!"
End If
```

## The If-Then-Else Statement

General format:

```
If condition Then
 statement
 statement
 etc.
Else
 statement
 statement
 etc.
End If
```

} These statements are executed if the condition is true.

} These statements are executed if the condition is false.

In the general format, the *condition* is a Boolean expression. If the expression is true, the statements appearing between the If clause and the Else clause are executed. Otherwise, the statements between the Else clause and the End If clause are executed. Here is an example:

```
If temperature < 40 Then
 Display "A little cold, isn't it?"
Else
 Display "Nice weather we're having."
End If
```

## The Select Case Statement

General format:

```
Select testExpression ← This is a variable or an expression.
Case value_1:
 statement
 statement
 etc.
```

} These statements are executed if the *testExpression* is equal to *value\_1*.

```

Case value_2:
 statement
 statement
 etc.

 } These statements are executed if the
 testExpression is equal to value_2.

Insert as many Case sections as necessary

Case value_N:
 statement
 statement
 etc.

 } These statements are executed if the
 testExpression is equal to value_N.

Default:
 statement
 statement
 etc.

 } These statements are executed if the
 testExpression is not equal to any of the
 values listed after the Case statements.

End Select ← This is the end of the structure.

```

The first line of the structure starts with the word `Select`, followed by a `testExpression`. Inside the structure there is one or more blocks of statements that begin with a `Case` statement. Notice that the word `Case` is followed by a value.

When the `Select Case` statement executes, it compares the value of the `testExpression` with the values that follow each of the `Case` statements (from top to bottom). When it finds a `Case` value that matches the `testExpression`'s value, the program branches to the `Case` statement. The statements that immediately follow the `Case` statement are executed, and then the program jumps out of the structure. If the `testExpression` does not match any of the `Case` values, the program branches to the `Default` statement and executes the statements that immediately follow it. Here is an example:

```

Select month
Case 1:
 Display "January"
Case 2:
 Display "February"
Case 3:
 Display "March"
Default:
 Display "Error: Invalid month"
End Select

```

## The While Loop

General format:

```

While condition
 statement
 statement
 etc.

 } These statements are the body of the loop. They are
 repeated while the condition is true.

End While

```

In the general format, the `condition` is a Boolean expression, and the statements that appear on the lines between the `While` and the `End While` clauses are the body of the loop. When the loop executes, the `condition` is tested. If it is true, the statements that appear in the body of the loop are executed, and then the loop starts over. If the

*condition* is false, the program exits the loop. The following pseudocode shows an example:

```
Set count = 0
While count < 10
 Display count
 Set count = count + 1
End While
```

## The Do-While Loop

General format:

```
Do
 statement
 statement
 etc.
 While condition
```

} These statements are the body of the loop. They are always performed once, and then repeated while the condition is true.

In the general format, the statements that appear in the lines between the `Do` and the `While` clauses are the body of the loop. The *condition* that appears after the `While` clause is a Boolean expression. When the loop executes, the statements in the body of the loop are executed, and then the *condition* is tested. If the *condition* is true, the loop starts over and the statements in the body are executed again. If the *condition* is false, however, the program exits the loop. Here is an example:

```
Set count = 10
Do
 Display count
 Set count = count - 1
 While count > 0
```

## The Do-Until Loop

General format:

```
Do
 statement
 statement
 etc.
 Until condition
```

} These statements are the body of the loop. They are always performed once, and then repeated until the condition is true.

In the general format, the statements that appear in the lines between the `Do` and the `Until` clauses are the body of the loop. The *condition* that appears after the `While` clause is a Boolean expression. When the loop executes, the statements in the body of the loop are executed, and then the *condition* is tested. If the *condition* is true, the program exits the loop. If the *condition* is false, the loop starts over and the statements in the body are executed again. Here is an example:

```
Set count = 10
Do
 Display count
 Set count = count - 1
 Until count == 0
```

## The For Loop

General format:

```
For counterVariable = startingValue To maxValue
 statement
 statement
 statement
 etc.
End For
```

These statements are the body of the loop.

In the general format, *counterVariable* is the name of a variable that is used as a counter, *startingValue* is the value that the counter will be initially set to, and *maxValue* is the maximum value that the counter can contain. When the loop executes, the following actions are performed:

1. The *counterVariable* is set to the *startingValue*.
2. The *counterVariable* is compared to the *maxValue*. If the *counterVariable* is greater than *maxValue*, the loop stops. Otherwise:
  - a. The statements that appear in the body of the loop are executed.
  - b. The *counterVariable* is incremented.
  - c. The loop starts over again at step 2.

Here is an example:

```
For counter = 1 To 10
 Display "Hello world"
End For
```

## The For Each Loop

General format:

```
For Each var In array
 statement
 statement
 statement
 etc.
End For
```

In the general format, *var* is the name of a variable and *array* is the name of an array. The loop will iterate once for every element in the *array*. Each time the loop iterates, it copies an array element to the *var* variable. For example, the first time the loop iterates, *var* will contain the value of *array[0]*, the second time the loop iterates *var* will contain the value of *array[1]*, and so forth. This continues until the loop has stepped through all of the elements in the array. The following pseudocode shows an example:

```
Constant Integer SIZE = 5
Declare Integer numbers[SIZE] = 5, 10, 15, 20, 25
Declare Integer num
For Each num In numbers
 Display num
End For
```

## Defining a Module

To create a module you write its definition, which has two parts: a header and a body. The header indicates the starting point of the module, and the body is a list of statements that belong to the module. Here is the general format used in this book to write a module definition in pseudocode:

```
Module name()
 statement
 statement
 etc.
} These statements are the body of the module.
End Module
```

## Calling a Module

To call a module you use the `Call` statement. Here is the general format:

```
Call ModuleName()
```

In the general format, `ModuleName` is the name of the module being called. In the following example, a module named `showMessage` is being called:

```
Call showMessage()
```

## Parameter Variables

If you want a module or function to receive arguments when it is called, you must equip the module or function with one or more parameter variables. Parameter variables are declared inside the parentheses of the module definition. Here is an example of a pseudocode module that has an `Integer` parameter variable:

```
Module doubleNumber(Integer value)
 Declare Integer result
 Set result = value * 2
 Display result
End Module
```

When this module is called, an `Integer` argument will be passed to it by value. To pass an argument by reference, the word `Ref` is used in the parameter variable declaration, and shown here:

```
Module setToZero(Integer Ref value)
 value = 0
End Module
```

## Defining a Function

A function definition is similar to a module definition. Here is the general format:

```
Function DataType FunctionName(ParameterList)
 statement
 statement
 etc.
 Return value ← A function must have a Return statement. This causes a
 value to be sent back to the part of the program that called
 the function.
End Function
```

The first line is the function header. It begins with the word **Function**, followed by these items:

- *Data Type* is the data type of the value that the function returns.
- *Function Name* is the name of the function.
- An optional parameter list appears inside a set of parentheses. If the function does not accept arguments, then an empty set of parentheses will appear.

Beginning at the line after the function header, one or more statements will appear. These statements are the function's body, and are performed any time the function is executed. One of the statements in the body must be a **Return** statement, which takes the following form:

```
Return value
```

The *value* that follows the word **Return** is the value that the function will send back to the part of the program that called the function. Here is an example:

```
Function Integer sum(Integer num1, Integer num2)
 Declare Integer result
 Set result = num1 + num2
 Return result
End Function
```

## Opening an Output File and Writing Data to It

In our pseudocode, we first declare an **OutputFile** variable, and then we use the **Open** statement to open the file. Here is an example:

```
Declare outputFile customerFile
Open customerFile "customers.dat"
```

We then use the **Write** statement to write data to the file. Here is an example:

```
Write customerFile "Charles Pace"
```

When finished writing to the file, we use the **Close** statement to close the file. Here is an example:

```
Close customerFile
```

## Opening an Input File and Reading Data from It

In our pseudocode, we first declare an **InputFile** variable, and then we use the **Open** statement to open the file. Here is an example:

```
Declare inputFile inventoryFile
Open inventoryFile "inventory.dat"
```

We then use the **Read** statement to read data from the file. Here is an example:

```
Read inventoryFile itemName
```

This statement reads an item from the file and stores it in the **itemName** variable. When finished reading the file, we use the **Close** statement to close the file. Here is an example:

```
Close inventoryFile
```

## Detecting the End of an Input File

In our pseudocode we use the `eof` function to determine whether we have reached the end of an input file. Here is the function's general format:

```
eof(internalFileName)
```

The `eof` function accepts a file's internal name as an argument, and returns true if the end of the file has been reached, or false if the end of the file has not been reached. The following pseudocode shows an example:

```
// Declare an input file
Declare InputFile salesFile
// A variable to hold a sales amount
// that is read from the file
Declare Real sales
// Open the sales.dat file.
Open salesFile "sales.dat"
// Read all of the items in the file
// and display them.
While NOT eof(salesFile)
 Read salesFile sales
 Display currencyFormat(sales)
End While
// Close the file.
Close salesFile
```

## Deleting a File

To delete a file we use the `Delete` statement. Here is the general format:

```
Delete Filename
```

In the general format, `Filename` is the name of the file on the system's disk. Here is an example:

```
Delete "customers.dat"
```

## Renaming a File

To rename a file we use the `Rename` statement. Here is the general format:

```
Rename ExistingName, NewName
```

In the general format, `ExistingName` is the file's existing name (on the system's disk), and `NewName` is the file's new name. Here is an example:

```
Rename "temp.dat", "customers.dat"
```

## Defining a Class

General format:

```
Class ClassName
 Field declarations and method definitions go here . . .
End Class
```

The first line starts with the word `Class`, followed by the name of the class. Next you write the declarations for the class's fields and the definitions of the class's methods. The words `End Class` appear at the end of the class definition. Here is the `CellPhone` example that is shown in Chapter 14:

```
Class CellPhone
 // Field declarations
 Private String manufacturer
 Private String modelNumber
 Private Real retailPrice
 // Method definitions
 Public Module setManufacturer(String manufact)
 Set manufacturer = manufact
 End Module
 Public Module setModelNumber(String modNum)
 Set modelNumber = modNum
 End Module
 Public Module setRetailPrice(Real retail)
 Set retailPrice = retail
 End Module
 Public Function String getManufacturer()
 Return manufacturer
 End Function
 Public Function String getModelNumber()
 Return modelNumber
 End Function
 Public Function Real getRetailPrice()
 Return retailPrice
 End Function
End Class
```

## Creating an Instance of a Class

To create an instance of a class (in other words, an object), you declare a variable to reference the object, and then you use the `New` operator to create the instance. Here is an example that creates an instance of the `CellPhone` class previously shown:

```
Declare CellPhone myPhone
Set myPhone = New CellPhone()
```

The first statement declares a variable named `myPhone`. The second statement creates an instance of the `CellPhone` class and assigns its memory address to the `myPhone` variable.

## The Init Module in a GUI Application

If a GUI application has an `Init` module, it executes automatically when the application begins running. The `Init` module is written in the following general format:

```
Module Init()
 The statements that appear here are executed
 when the application begins running.
End Module
```

## GUI Components

Several GUI components are listed in Table 15-1. However, our examples use the following components:

- Button—A component that causes an action to occur when it is clicked. The Button component has a Text property that specifies the text that is displayed on the Button.
- Label—An area that can display text. The Label component has a Text property that specifies the text that is displayed on the Label.
- Text box—An area in which the user may type a single line of input from the keyboard. The Text box component has a Text property that holds the input that the user entered into the component.

## Mobile Device Components

The following components are discussed in Chapter 15 as being specific to mobile devices:

- PhoneCall—A non-visual component that is responsible for making and receiving phone calls.
- TextMessage—A non-visual component that is responsible for sending and receiving text messages.
- Location—A non-visual component that can determine the device’s latitude, longitude, and nearest street address.

## Making a Phone Call on a Mobile Device

To make a phone call on a mobile device, we call the PhoneCall component’s `makeCall` method. The `makeCall` method takes a string argument that contains the phone number to call. Here is an example:

```
PhoneCall.makeCall("919-555-1212")
```

## Sending a Text Message from a Mobile Device

To send a text message from a mobile device, we call the TextMessage component’s `sendText` method. The `sendText` method takes two arguments: (1) a string that contains the phone number to send the message to, and (2) a string containing the message. Here is the general format:

```
TextMessage.sendText(PhoneNumber, Message)
```

## Getting a Mobile Device’s Current Location

The Location component has the following methods that we can use to get the device’s location:

- `getLatitude()`—returns the device’s latitude as a Real number
- `getLongitude()`—returns the device’s longitude as a Real number
- `getAddress()`—returns a string containing the street address that is nearest to the device

## Handling GUI Events

Our pseudocode event handlers are written in the following general format:

```
Module ComponentName_EventName()
 The statements that appear here
 are executed when the event occurs.
End Module
```

In the general format, *ComponentName* is the name of the component that generated the event, and *EventName* is the name of the event that occurred. The GUI events that we discussed in this book are:

- **Click**—an event that occurs when a Button component is clicked
- **IncomingCall**—an event that occurs in a smartphone when the device receives an incoming phone call
- **Incoming\_Text**—an event that occurs in a smartphone when the device receives an incoming text message
- **LocationChanged**—an event that occurs in a mobile device when the device's location changes

For example, suppose a GUI application has a Button component named `calculateButton`. The Click event handler for the component would be written in the following general format:

```
Module calculateButton_Click()
 The statements that appear here
 are executed when the event occurs.
End Module
```

In a mobile app, the IncomingCall event handler would be written in the following general format:

```
Module PhoneCall_IncomingCall ()
 The statements that appear here
 are executed when the event occurs.
End Module
```

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# Converting Decimal Numbers to Binary

You can convert a decimal number to binary by drawing a simple chart, and then performing repeated subtraction. The following steps show how to convert the decimal number 162 to binary.

1. Make a two-row chart. The top row should list all of the numbers that are powers of two, up to but not greater than the number you are trying to convert. (Powers of two are  $2^0 = 1$ ,  $2^1 = 2$ ,  $2^2 = 4$ ,  $2^3 = 8$ , and so forth.) The numbers should be listed from right to left.

To convert the decimal number 162 to binary, you would make the following chart. (The chart stops at 128 because the next power of two would be 256, which is greater than the number we are trying to convert.)

|     |    |    |    |   |   |   |   |
|-----|----|----|----|---|---|---|---|
| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|     |    |    |    |   |   |   |   |

2. Find the greatest number in the chart (in this case it is 128), and write a 1 below it in the second row. Then, subtract that number from the number you are trying to convert. In this problem, the result is 34. This is your new number. Your workspace should look something like this:

|     |    |    |    |   |   |   |   |
|-----|----|----|----|---|---|---|---|
| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
| 1   |    |    |    |   |   |   |   |

$$\begin{array}{r} 162 \\ -128 \\ \hline 34 \end{array}$$

3. Find the greatest number in the chart that is not greater than the new number you calculated in Step 2. In this problem, we are looking for the greatest number that is not greater than 34. The number we are looking for is 32. Write a 1 below that number in the second row. Then, subtract that number from the number you are

currently working with. In this problem, the result is 2. This is your new number. Your workspace should look something like this:

|     |    |    |    |   |   |   |   |
|-----|----|----|----|---|---|---|---|
| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
| 1   |    | 1  |    |   |   |   |   |

$$\begin{array}{r} 162 \\ -128 \\ \hline 34 \\ -32 \\ \hline 2 \end{array}$$

4. Find the greatest number in the chart that is not greater than the new number you calculated in Step 3. In this problem, we are looking for the greatest number that is not greater than 2. The number we are looking for is 2. Write a 1 below that number in the second row. Then, subtract that number from the number you are currently working with. In this problem, the result is 0. This is your new number. Your workspace should look something like this:

|     |    |    |    |   |   |   |   |
|-----|----|----|----|---|---|---|---|
| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
| 1   |    | 1  |    |   |   | 1 |   |

$$\begin{array}{r} 162 \\ -128 \\ \hline 34 \\ -32 \\ \hline 2 \\ -2 \\ \hline 0 \end{array}$$

5. When you reach 0 as your new value, you have converted the number. Go back to the chart and write a 0 in each empty slot in the second row. Your chart should look like this:

|     |    |    |    |   |   |   |   |
|-----|----|----|----|---|---|---|---|
| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
| 1   | 0  | 1  | 0  | 0 | 0 | 1 | 0 |

The second row now shows the binary number that is equivalent to 162: 10100010

# Answers to Checkpoint Questions

## Chapter 1

- 1.1 A program is a set of instructions that a computer follows to perform a task.
- 1.2 Hardware is all of the physical devices, or components, that a computer is made of.
- 1.3 The central processing unit (CPU), main memory, secondary storage devices, input devices, and output devices.
- 1.4 The CPU
- 1.5 Main memory
- 1.6 Secondary storage
- 1.7 Input device
- 1.8 Output device
- 1.9 One byte
- 1.10 A bit
- 1.11 The binary numbering system.
- 1.12 It is an encoding scheme that uses a set of 128 numeric codes to represent the English letters, various punctuation marks, and other characters. These numeric codes are used to store characters in a computer's memory. (ASCII stands for the American Standard Code for Information Interchange.)
- 1.13 Unicode
- 1.14 Digital data is data that is stored in binary, and a digital device is any device that works with binary data.
- 1.15 Machine language
- 1.16 Main memory, or RAM
- 1.17 The fetch-decode-execute cycle.
- 1.18 It is an alternative to machine language. Instead of using binary numbers for instructions, assembly language uses short words that are known as mnemonics.
- 1.19 A high-level language

- 1.20 Syntax
- 1.21 A compiler
- 1.22 An interpreter
- 1.23 A syntax error
- 1.24 The operating system
- 1.25 A utility program
- 1.26 Application software

## Chapter 2

- 2.1 Any person, group, or organization that is asking you to write a program.
- 2.2 A single function that the program must perform in order to satisfy the customer.
- 2.3 A set of well-defined logical steps that must be taken to perform a task.
- 2.4 An informal language that has no syntax rules, and is not meant to be compiled or executed. Instead, programmers use pseudocode to create models, or “mock-ups” of programs.
- 2.5 A diagram that graphically depicts the steps that take place in a program.
- 2.6 Ovals are terminal symbols. Parallelograms are either output or input symbols. Rectangles are processing symbols.
- 2.7 Input, processing, and output.
- 2.8 A chart, or table, that describes a program’s input, processing, and output.
- 2.9 A set of statements that execute in the order that they appear.
- 2.10 A string is a sequence of characters that is used as data. A string literal is a string that appears in the actual code of a program.
- 2.11 Quotation marks
- 2.12 A storage location in memory that is represented by a name.
- 2.13
  - Variable names must be one word. They cannot contain spaces.
  - In most languages, punctuation characters cannot be used in variable names. It is usually a good idea to use only alphabetic letters and numbers in variable names.
  - In most languages, the first character of a variable name cannot be a number.
- 2.14 camelCase
- 2.15
  - The program pauses and waits for the user to type something on the keyboard, and then press the `Enter` key.
  - When the `Enter` key is pressed, the data that was typed is stored in the `temperature` variable.
- 2.16 Any hypothetical person that is using a program and providing input for it.
- 2.17 A message that tells (or asks) the user to enter a specific value.
- 2.18
  1. Display a prompt on the screen.
  2. Read a value from the keyboard.

- 2.19 The term *user-friendly* is commonly used in the software business to describe programs that are easy to use.
- 2.20 A statement that sets a variable to a specified value.
- 2.21 It is replaced.
- 2.22 1. Perform any operations that are enclosed in parentheses.  
2. Perform any operations that use the exponent operator to raise a number to a power.  
3. Perform any multiplications, divisions, or modulus operations as they appear from left to right.  
4. Perform any additions or subtractions as they appear from left to right.
- 2.23 It raises a number to a power.
- 2.24 It performs division, but instead of returning the quotient it returns the remainder.
- 2.25 The variable's name and data type.
- 2.26 Yes, you must write a variable declaration before any other statement that uses the variable.
- 2.27 The assignment of a value to a variable at the time the variable is declared.
- 2.28 Yes, they are a common cause of errors. If an uninitialized variable is used in an operation such as a calculation, a logic error will occur.
- 2.29 A variable that has been declared, but has not been initialized or assigned a value.
- 2.30 External documentation is typically designed for the user. It consists of documents such as a reference guide that describes the program's features, and tutorials that teach the user how to operate the program.
- 2.31 Internal documentation appears as comments in a program's code. Comments are short notes placed in different parts of a program, explaining how those parts of the program work.
- 2.32 Programmers generally write block comments and line comments. Block comments take up several lines and are used when lengthy explanations are required. Line comments are comments that occupy a single line, and explain a short section of the program.

## Chapter 3

- 3.1 A logical design that controls the order in which a set of statements executes.
- 3.2 It is a program structure that can execute a set of statements only under certain circumstances.
- 3.3 A decision structure that provides a single alternative path of execution. If the condition that is being tested is true, the program takes the alternative path.
- 3.4 An expression that can be evaluated as either true or false.
- 3.5 You can determine whether one value is greater than, less than, greater than or equal to, less than or equal to, equal to, or not equal to another value.

- 3.6 If  $y == 20$  Then  
    Set  $x = 0$   
End If
- 3.7 If  $\text{sales} \geq 10000$  Then  
    Set  $\text{commission} = 0.2$   
End If
- 3.8 A dual alternative decision structure has two possible paths of execution—one path is taken if a condition is true, and the other path is taken if the condition is false.
- 3.9 If-Then-Else
- 3.10 When the condition is false.
- 3.11  $z$  is not less than  $a$ .
- 3.12 Boston  
    New York
- 3.13 A dual alternative decision structure has two possible paths of execution—one path is taken if a condition is true, and the other path is taken if the condition is false.
- 3.14 If-Then-Else
- 3.15 If the condition is false.
- 3.16 If  $\text{number} == 1$  Then  
    Display "One"  
Else If  $\text{number} == 2$  Then  
    Display "Two"  
Else If  $\text{number} == 3$  Then  
    Display "Three"  
Else  
    Display "Unknown"  
End If
- 3.17 A structure that tests the value of a variable or an expression and then uses that value to determine which statement or set of statements to execute.
- 3.18 With a Select Case statement.
- 3.19 A variable or an expression.
- 3.20 In such an event, you can use the If-Then-Else If statement, or a nested decision structure.
- 3.21 It is an expression that is created by using a logical operator to combine two Boolean subexpressions.
- 3.22 F  
T  
F  
F  
T  
T  
T  
F  
F  
T

3.23 T  
F  
T  
T  
T

3.24 The AND operator: If the expression on the left side of the AND operator is false, the expression on the right side will not be checked.

The OR operator: If the expression on the left side of the OR operator is true, the expression on the right side will not be checked.

3.25 `If speed >= 0 AND speed <= 200 Then`  
    `Display "The number is valid"`  
    `End If`

3.26 `If speed < 0 OR speed > 200 Then`  
    `Display "The number is not valid"`  
    `End If`

3.27 True or false

3.28 A variable that signals when some condition exists in the program.

## Chapter 4

- 4.1 A structure that causes a section of code to repeat.
- 4.2 A loop that uses a true/false condition to control the number of times that it repeats.
- 4.3 A loop that repeats a specific number of times.
- 4.4 An execution of the statements in the body of the loop.
- 4.5 A pretest loop tests its condition before it performs an iteration. A posttest loop tests its condition after it performs an iteration.
- 4.6 Before
- 4.7 After
- 4.8 A loop that has no way of stopping, and repeats until the program is interrupted.
- 4.9 A Do-While loop iterates while a condition is true. When the condition is false, the Do-While loop stops. A Do-Until loop iterates until a condition is true. When the condition is true, the Do-Until loop stops.
- 4.10 A variable that is used to store the number of iterations that it has performed.
- 4.11 Initialization, test, and increment.
- 4.12 Incrementing a variable means increasing its value. Decrementing a variable means decreasing its value.
- 4.13 6
- 4.14 1  
2  
3  
4  
5

4.15 0  
100  
200  
300  
400  
500

4.16 1  
2  
3  
4  
5  
6  
7  
8

4.17 1  
3  
5  
7

4.18 5  
4  
3  
2  
1

4.19 1. A loop that reads each number in the series.  
2. A variable that accumulates the total of the numbers as they are read.

4.20 A variable that is used to accumulate the total of a series of numbers.

4.21 Yes, it should be initialized with the value 0. This is because values are added to the accumulator by a loop. If the accumulator does not start at the value 0, it will not contain the correct total of the numbers that were added to it when the loop ends.

4.22 15

4.23 5

4.24 A sentinel is a special value that marks the end of a list of values.

4.25 A sentinel value must be unique enough that it will not be mistaken as a regular value in the list.

## Chapter 5

- 5.1 A module is a group of statements that exist within a program for the purpose of performing a specific task.
- 5.2 A large task is divided into several smaller tasks that are easily performed.
- 5.3 If a specific operation is performed in several places in a program, a module can be written once to perform that operation, and then be executed any time it is needed.

- 5.4 Modules can be written for the common tasks that are needed by the different programs. Those modules can then be incorporated into each program that needs them.
- 5.5 When a program is developed as a set of modules that each perform an individual task, then different programmers can be assigned the job of writing different modules.
- 5.6 In most languages, a module definition has two parts: a header and a body. The header indicates the starting point of the module, and the body is a list of statements that belong to the module.
- 5.7 To call a module means to execute the module.
- 5.8 When the end of the module is reached, the computer jumps back to the part of the program that called the module, and the program resumes execution at that point.
- 5.9 • The overall task that the program is to perform is broken down into a series of sub-tasks.  
• Each of the subtasks is examined to determine whether it can be further broken down into more subtasks. This step is repeated until no more subtasks can be identified.  
• Once all of the subtasks have been identified, they are written in code.
- 5.10 A local variable is a variable that is declared inside a module. It belongs to the module in which it is declared, and only statements inside the same module can access it.
- 5.11 The part of a program in which a variable may be accessed.
- 5.12 No, it is not permissible. The compiler or interpreter would not know which variable to use when a statement tries to access one of them.
- 5.13 Yes, it is permissible.
- 5.14 Arguments
- 5.15 Parameters
- 5.16 Yes, an error will usually occur if an argument's data type is different from the data type of the parameter it is being passed to.
- 5.17 A parameter variable's scope is usually the entire module in which the parameter is declared.
- 5.18 Passing an argument by value means that only a copy of the argument's value is passed into the parameter variable. If the contents of the parameter variable are changed inside the module, it has no effect on the argument in the calling part of the program. Passing an argument by reference means that the argument is passed into a special type of parameter known as a reference variable. When a reference variable is used as a parameter in a module, it allows the module to modify the argument in the calling part of the program.
- 5.19 The entire program
- 5.20 Here are three:
- Global variables make debugging difficult. Any statement in a program can change the value of a global variable. If you find that the wrong value is being stored in a global variable, you have to track down every statement that accesses it to determine where the bad value is coming from. In a program with thousands of lines of code, this can be difficult.

- Modules that use global variables are usually dependent on those variables. If you want to use such a module in a different program, you will most likely have to redesign it so it does not rely on the global variable.
  - Global variables make a program hard to understand. A global variable can be modified by any statement in the program. If you are to understand any part of the program that uses a global variable, you have to be aware of all the other parts of the program that access the global variable.
- 5.21 A global constant is a named constant that is available to every module in the program. It is permissible to use global constants. Because a global constant's value cannot be changed during the program's execution, you do not have to worry about its value being altered.

## Chapter 6

- 6.1 When a module finishes, the program merely returns back to the part of the program that called the module, and execution resumes at that point. When a function finishes, it returns a value back to the part of the program that called it.
- 6.2 A prewritten function that comes with a programming language.
- 6.3 The term *black box* is used to describe any mechanism that accepts input, performs some operation that cannot be seen on the input, and produces output. A library function can be regarded as a black box because you cannot see the code inside the function. The function accepts input, performs an operation on the input, and produces output.
- 6.4 It assigns a random number in the range of 1 through 100 to the `x` variable.
- 6.5 It displays a random number in the range of 1 through 20.
- 6.6 The `Return` statement specifies the value that the function returns to the part of the program that called the function. When the `Return` statement is executed, it causes the function to terminate and return the specified value.
- 6.7 a. `doSomething`  
b. `Integer`  
c. 10
- 6.8 A function that returns either true or false.

## Chapter 7

- 7.1 It means that if bad data (garbage) is provided as input to a program, the program will produce bad data (garbage) as output.
- 7.2 When input is given to a program, it should be inspected before it is processed. If the input is invalid, then it should be discarded and the user should be prompted to enter the correct data.
- 7.3 The input is read, and then a pretest loop is executed. If the input data is invalid, the body of the loop executes. In the body of the loop, an error message is displayed so the user will know that the input was invalid, and then the new input is read. The loop repeats as long as the input is invalid.

7.4 It is the input operation that takes place just before an input validation loop. The purpose of the priming read is to get the first input value.

7.5 None

## Chapter 8

8.1 No, you cannot. All of the items in an array must be of the same data type.

8.2 A nonnegative integer that specifies the size of an array.

8.3 No

8.4 An individual storage location in an array.

8.5 A number that identifies a specific element in an array.

8.6 0

8.7 a. numbers

b. 7

c. Real

d. 6

8.8 Many languages support array bounds checking, which means they do not allow a program to use an invalid array subscript.

8.9 An off-by-one error occurs when a loop iterates one time too many or one time too few.

8.10 An algorithm developed for the purpose of locating a specific item in a larger collection of data, such as an array.

8.11 The first element in the array.

8.12 The loop sequentially steps through each element in the array, comparing the elements to the value being searched for. When the value is found, the loop stops.

8.13 It looks at every element in the array.

8.14 You use a function similar to the `contains` function described in this chapter. The `contains` function returns true if a string is found inside another string, or false otherwise.

8.15 To calculate the total of the values in an array, you use a loop with an accumulator variable. The loop steps through the array, adding the value of each array element to the accumulator.

8.16 The first step in calculating the average of the values in an array is to get the sum of the values. You use the algorithm for totaling the values in an array to perform this. The second step is to divide the sum by the number of elements in the array.

8.17 You create a variable to hold the highest value. In the examples shown in this book, the variable is named `highest`. Then, you assign the value at element 0 to the `highest` variable. Next, you use a loop to step through the rest of the array elements, beginning at element 1. Each time the loop iterates, it compares an array element to the `highest`

variable. If the array element is greater than the `highest` variable, then the value in the array element is assigned to the `highest` variable. When the loop finishes, the `highest` variable will contain the highest value in the array.

- 8.18 You create a variable to hold the lowest value. In the examples shown in this book, the variable is named `lowest`. Then, you assign the value at element 0 to the `lowest` variable. Next, you use a loop to step through the rest of the array elements, beginning at element 1. Each time the loop iterates, it compares an array element to the `lowest` variable. If the array element is less than the `lowest` variable, then the value in the array element is assigned to the `lowest` variable. When the loop finishes, the `lowest` variable will contain the lowest value in the array.
- 8.19 You assign the individual elements of the array that you are copying to the elements of the other array. This is usually best done with a loop.
- 8.20 You use the same subscript to access data items in the two arrays.
- 8.21 It would be stored in `creditScore[82]`
- 8.22 88 rows and 100 columns
- 8.23 Set `points[87][99] = 100`
- 8.24 Constant Integer ROWS = 3  
 Constant Integer COLS = 5  
 Declare Integer table[ROWS][COLS] = 12, 24, 32, 21, 42,  
                                   14, 67, 87, 65, 90,  
                                   19, 1, 24, 12, 8
- 8.25 Declare Integer row  
 Declare Integer col  
 For `row` = 0 To ROWS - 1  
     For `col` = 0 to COLS - 1  
         Set `info[row][col]` = 99  
     End For  
 End For
- 8.26 Constant Integer RACKS = 50  
 Constant Integer SHELVES = 10  
 Constant Integer BOOKS = 25  
 Declare String books[RACKS][SHELVES][BOOKS]

## Chapter 9

- 9.1 The bubble sort
- 9.2 The insertion sort algorithm
- 9.3 The selection sort algorithm
- 9.4 The sequential search algorithm simply uses a loop to step through each element of an array, comparing each element's value with the value being searched for. The binary search algorithm, which requires the values in the array to be sorted in order, starts searching at the element in the middle of the array. If the middle element's value is greater than the value being searched for, the algorithm next tests the element in the

middle of the first half of the array. If the middle element's value is less than the value being searched for, the algorithm next tests the element in the middle of the last half of the array. Each time the array tests an array element and does not find the value being searched for, it eliminates half of the remaining portion of the array. This method continues until the value is found, or there are no more elements to test. The binary search is more efficient than the sequential search.

9.5 500

9.6 10

## Chapter 10

- 10.1 On the computer's disk.
- 10.2 A file that a program writes data to. It is called an output file because the program sends output to it.
- 10.3 A file that a program reads data from. It is called an input file because the program receives input from it.
- 10.4 1. Open the file.  
2. Process the file.  
3. Close the file.
- 10.5 Text and binary. A text file contains data that has been encoded as text, using a scheme such as Unicode. Even if the file contains numbers, those numbers are stored in the file as a series of characters. As a result, the file may be opened and viewed in a text editor such as Notepad. A binary file contains data that has not been converted to text. As a consequence, you cannot view the contents of a binary file with a text editor.
- 10.6 Sequential and direct access. When you work with a sequential access file, you access data from the beginning of the file to the end of the file. When you work with a direct access file, you can jump directly to any piece of data in the file without reading the data that comes before it.
- 10.7 The file's external name and internal name. The external name is the file name that identifies the file on the disk. The internal name is like a variable name. It identifies the file in your program code.
- 10.8 The file's contents are erased.
- 10.9 Opening a file creates a connection between the file and the program. It also creates an association between the file and its internal name.
- 10.10 Closing a file disconnects the file from the program.
- 10.11 A predefined character or set of characters that marks the end of piece of data. In many languages, a delimiter is written after each item that is stored in a file.
- 10.12 A special character, or set of characters, known as the end-of-file marker.
- 10.13 A file's read position marks the location of the next item that will be read from the file. When an input file is opened, its read position is initially set to the first item in the file.
- 10.14 You open the file in append mode. When you write data to a file in append mode, the data is written at the end of the file's existing contents.

10.15 Declare Integer counter  
Declare OutputFile myFile  
Open myFile "myfile.dat"  
For counter = 1 To 10  
    Write myFile, counter  
End For  
Close myFile

- 10.16 The `eof` function determines whether the end of a file has been reached.
- 10.17 No, this usually causes an error.
- 10.18 It would mean that the program had reached the end of the file associated with the name `myFile`.
- 10.19 b
- 10.20 A record is a complete set of data that describes one item, and a field is a single piece of data within a record.
- 10.21 You copy all of the original file's records to the temporary file, but when you get to the record that is to be modified, you do not write its old contents to the temporary file. Instead, you write its new, modified values to the temporary file. Then, you finish copying any remaining records from the original file to the temporary file.
- 10.22 You copy all of the original file's records to the temporary file, except for the record that is to be deleted. The temporary file then takes the place of the original file. You delete the original file and rename the temporary file, giving it the name that the original file had on the computer's disk.

## Chapter 11

- 11.1 A menu-driven program displays a list of operations that it can perform on the screen, and allows the user to select the operation they want the program to perform. The list of operations that is displayed on the screen is called a *menu*.
- 11.2 The user types the character that corresponds to the desired menu item.
- 11.3 You use a decision structure of some type. You might choose a case structure, nested If-Then-Else statements, or an If-Then-Else If statement.
- 11.4 Without a loop, the program would end after the selected action is performed. This would be an inconvenience because it would require the user to rerun the program to perform another action.
- 11.5 Ending the program should be an item that the user can select from the menu. When the user selects this item, the loop stops and the program ends.
- 11.6 In a program that uses a single-level menu, all of the menu selections fit nicely in a single menu. When the user selects an operation from the menu, the program immediately performs that operation and then the program redisplays the menu.
- 11.7 A program that uses a multiple-level menu typically displays a *main menu* when the program starts, showing only a few items, and then displays smaller *submenus* when the user makes a selection.
- 11.8 Users often have trouble sorting through the items in a menu when given too many choices.

## Chapter 12

- 12.1 y
- 12.2 Set str[0] = "L"
- 12.3 If isDigit(str[0]) Then  
    delete(str, 0, 0)  
End If
- 12.4 If isUpperCase(str[0]) Then  
    Set str[0] = "0"  
End If
- 12.5 insert(str, 0, "Hello ")
- 12.6 delete(city, 0, 2)

## Chapter 13

- 13.1 A recursive algorithm requires multiple method calls. Each method call requires several actions to be performed by the computer. These actions include allocating memory for parameters and local variables, and storing the address of the program location where control returns after the method terminates. All of these actions are known as overhead. In an iterative algorithm, which uses a loop, such overhead is unnecessary.
- 13.2 A case in which the problem can be solved without recursion.
- 13.3 A case in which the problem is solved using recursion.
- 13.4 When it reaches the base case.
- 13.5 In direct recursion, a recursive method calls itself. In indirect recursion, method A calls method B, which in turn calls method A.

## Chapter 14

- 14.1 An object is a software entity that contains both data and procedures.
- 14.2 Encapsulation is the combining of data and code into a single object.
- 14.3 When an object's internal data is hidden from outside code and access to that data is restricted to the object's methods, the data is protected from accidental corruption. In addition, the programming code outside the object does not need to know about the format or internal structure of the object's data.
- 14.4 Public methods can be accessed by entities outside the object. Private methods cannot be accessed by entities outside the object. They are designed to be accessed internally.
- 14.5 The metaphor of a blueprint represents a class.
- 14.6 Objects are the cookies.
- 14.7 A key word that specifies how code outside a class can access a field or method.
- 14.8 **Private**
- 14.9 The memory address of the object that it references.

- 14.10 It creates an object in the computer's memory.
- 14.11 An accessor is a method that gets a value from a class's field but does not change it. A mutator is a method that stores a value in a field or changes the value of a field in some other way.
- 14.12 A constructor is a method that typically initializes an object's fields. A constructor executes when an object is created.
- 14.13 If you do not write a constructor in a class, most languages automatically provide one when the class is compiled. The constructor that is automatically provided is usually known as the default constructor. Typically, the default constructor assigns default starting values to the object's fields.
- 14.14 The top section is where you write the name of the class. The middle section holds a list of the class's fields. The bottom section holds a list of the class's methods.
- 14.15 By writing a colon followed by `String` after the name of the field. Here is an example:  
`description : String`
- 14.16 You use a minus sign (−) to indicate private specification, and a plus sign (+) to indicate public specification.
- 14.17 A written description of the real-world objects, parties, and major events related to the problem.
- 14.18 First, identify the nouns, pronouns, and noun phrases in the problem domain description. Then, refine the list to eliminate duplicates, items that you do not need to be concerned with in order to solve the problem, items that represent objects instead of classes, and items that represent simple values that can be stored in variables.
- 14.19 The things that the class is responsible for knowing, and the actions that the class is responsible for doing.
- 14.20 When the value of an item is dependent on other data and that item is not updated when the other data is changed, it is said that the item has become stale.
- 14.21 The superclass is the general class and the subclass is the specialized class.
- 14.22 When an "is a" relationship exists between objects, it means that the specialized object has all of the characteristics of the general object, plus additional characteristics that make it special.
- 14.23 The superclass's fields and methods, except those that are private.
- 14.24 Bird is the superclass and Canary is the subclass.
- 14.25 I'm a potato.  
I'm a potato.

## Chapter 15

- 15.1 The part of a computer and its operating system that the user interacts with.
- 15.2 A command line interface typically displays a prompt, and the user types a command, which is then executed.
- 15.3 The program.

- 15.4 A program that responds to events that take place, such as the user clicking a button.
- 15.5 A diagram that shows how the program flows from one window to the next as the user interacts with it.
- 15.6 Because programmers had to write code that constructed the windows, create graphical elements such as icons and buttons, and set each element's color, position, size, and other properties. Even a simple GUI program that displayed a message such as "Hello world" required the programmer to write a hundred or more lines of code. Furthermore, the programmer could not actually see the program's user interface until the program was compiled and executed.
- 15.7 You drag the item from a "toolbox" to the window editor.
- 15.8 An item that appears in a program's graphical user interface.
- 15.9 A component's name identifies the component in the program, in the same way that a variable's name identifies the variable.
- 15.10 A component's properties determine how the component appears on the screen.
- 15.11 An action that takes place within a program, such as the clicking of a button.
- 15.12 A module that automatically executes when a specific event occurs.
- 15.13 a. It responds to a `Click` event.  
b. The component's name is `showValuesButton`.
- 15.14 It executes automatically when a GUI application (or mobile app) starts running.
- 15.15 Less
- 15.16 Larger
- 15.17 Here are five unique capabilities that mobile devices usually have, compared to desktop computers:
- make and receive phone calls
  - send and receive text messages
  - determine the device's location
  - detect the device's physical orientation in 3D space
  - determine when the device is moving
- 15.18 Non-visual components are objects that you cannot see in a GUI, but provide special capabilities to your programs. Examples that we discussed are the `PhoneCall` component, the `TextMessage` component, and the `Location` component.
- 15.19 An `IncomingCall` event is generated.
- 15.20 An `IncomingText` event is generated.
- 15.21 A `LocationChanged` event is generated.

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