CSCI 1301 Book

https://csci-1301.github.io/about#authors

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Contents

1 Introduction to Computers and Programming

1.1 Principles of Computer Programming

- Computer hardware changes frequently - from room-filling machines with punch cards and tapes to modern laptops and tablets
- With these changes - the capabilities of computers increase rapidly (storage, speed, graphics, etc.)
- Computer programming languages also change
  - Better programming language theory leads to new programming techniques
  - Improved programming language implementations
  - New languages are created - old ones updated
- There are hundreds of programming languages, why?
  - Different tools for different jobs
    - Some languages are better suited for certain jobs
    - Python for scripting, Javascript for web pages
  - Personnel preference and popularity
- This class is about "principles" of computer programming
  - Common principles behind all languages won't change, even though hardware and languages do
  - How to organize and structure data
  - How to express logical conditions and relations
  - How to solve problems with programs

1.2 Programming Language Concepts

We begin by discussing three categories of languages manipulated by computers. We will be studying and writing programs in *high-level languages*, but understanding their differences and relationships to other languages[1] is of importance to become familiar with them.

[1] That will be studied in the course of your study if you continue as a CS major.

- Machine language
  - Computers are made of electronic circuits
    - Circuits are components connected by wires
    - Some wires carry data - e.g. numbers
    - Some carry control signals - e.g. do an add or a subtract operation
  - Instructions are settings on these control signals
    - A setting is represented as a 0 or 1
    - A machine language instruction is a group of settings - For example: 1000100111011000
  - Most CPUs use one of two languages: x86 or ARM
- Assembly language
  - Easier way for humans to write machine-language instructions
  - Instead of 1s and 0s, it uses letters and "words" to represent an instruction.
    - Example x86 instruction: `MOV BX, AX` which makes a copy of data stored in a component called AX and places it in one called BX
  - **Assembler**: Translates assembly language instructions to machine language instructions
    - For example: `MOV BX, AX` translates into `1000100111011000`
    - One assembly instruction = one machine-language instruction
    - x86 assembly produces x86 machine code
  - Computers can only execute the machine code
- High-level language
  - Hundreds including C#, C++, Java, Python, etc.
  - Most programs are written in a high-level language since:
    - More human-readable than assembly language
    - High-level concepts such as processing a collection of items are easier to write and understand
    - Takes less code since each statement might be translated into several assembly instructions
  - **Compiler**: Translates high-level language to machine code
    - Finds "spelling" errors but not problem-solving errors
    - Incorporates code libraries – commonly used pieces of code previously written such as Math.Sqrt(9)
    - Optimizes high-level instructions – your code may look very different after it has been optimized
    - Compiler is specific to both the source language and the target computer
  - Compile high-level instructions into machine code then run since computers can only execute machine code

A more subtle difference exist between high-level languages. Some (like C) are *compiled* (as we discussed above), some (like python) are *interpreted*, and some (like C#) are in an in-between called *managed*.

- Compiled vs. Interpreted languages
  - Not all high-level languages use a compiler - some use an interpreter
  - **Interpreter**: Lets a computer "execute" high-level code by translating one statement at a time to machine code
  - Advantage: Less waiting time before you can run the program (no separate "compile" step)
  - Disadvantage: Program runs slower since you wait for the high-level statements to be translated then the program is run
- Managed high-level languages (like C#)
  - Combine features of compiled and interpreted languages
  - Compiler translates high-level statements to **intermediate language** instructions, not machine code

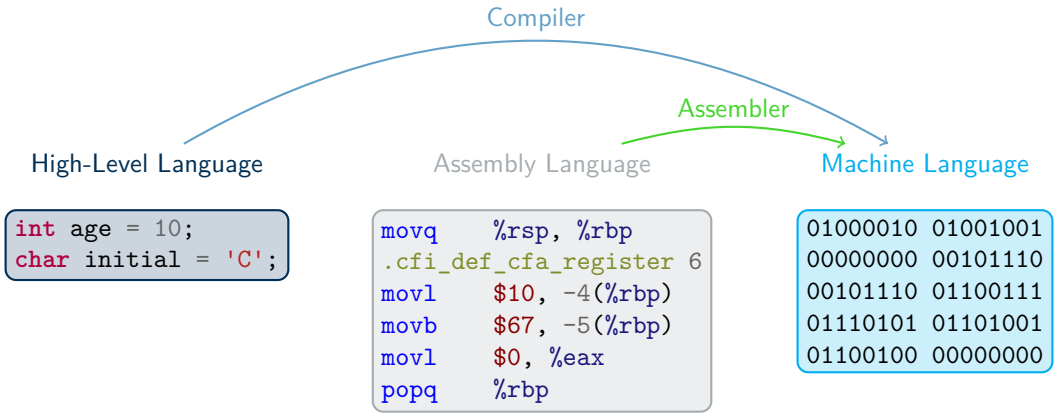


Figure 1: "A Visual Representation of the Relationships Between Languages"

    - Intermediate language: Looks like assembly language, but not specific to any CPU
  - **Runtime** executes by *interpreting* the intermediate language instructions - translates one at a time to machine code
    - faster since translation step is partially done and only its last step is done when running the program

  - Advantages of managed languages:
    - In a "non-managed" language, a compiled program only works on one OS + CPU combination (**platform**) because it is machine code
    - Managed-language programs can be reused on a different platform without recompiling - intermediate language is not machine code and not CPU-specific
    - Still need to write an intermediate language interpreter for each platform (so it produces the right machine code), but, for a non-managed language, you must write a compiler for each platform
    - Writing a compiler is more complicated and more work than writing an interpreter thus an interpreter is a quicker (and cheaper) way to put your language on different platforms
    - Intermediate-language interpreter is much faster than a high-level language interpreter, so programs run faster than an "interpreted language" like Python
  - This still runs slower than a non-managed language (due to the interpreter), so performance-minded programmers use non-managed compiled languages (e.g. for video games)

1.3 Software Concepts

- Flow of execution in a program
  - Program receives input from some source, e.g. keyboard, mouse, data in files
  - Program uses input to make decisions
  - Program produces output for the outside world to see, e.g. by displaying images on screen, writing text to console, or saving data in files
- Program interfaces
  - **GUI** or Graphical User Interface: Input is from clicking mouse in visual elements on screen (buttons, menus, etc.), output is by drawing onto the screen

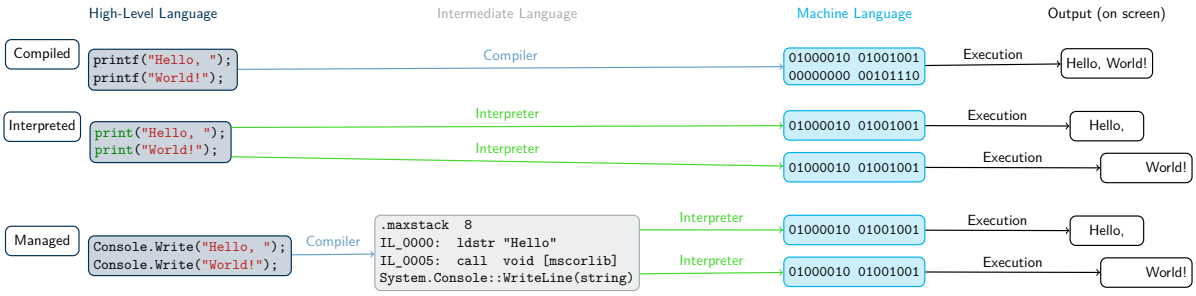


Figure 2: "A Visual Representation of the Differences Between High-Level Languages"

- **CLI** or Command Line Interface: Input is from text typed into "command prompt" or "terminal window," output is text printed at same terminal window
- This class will use CLI because it's simple, portable, easy to work with – no need to learn how to draw images, just read and write text

1.4 Programming Concepts

- Programming workflow (see flowchart)
  - Writing down specifications
  - Creating the source code
  - Running the compiler
  - Reading the compiler's output, warning and error messages
  - Fixing compile errors, if necessary
  - Running and testing the program
  - Debugging the program, if necessary
- Interpreted language workflow (see flowchart)
  - Writing down specifications
  - Creating the source code
  - Running the program in the interpreter
  - Reading the interpreter's output, determining if there is a syntax (language) error or the program finished executing
  - Editing the program to fix syntax errors
  - Testing the program (once it can run with no errors)
  - Debugging the program, if necessary
  - **Advantages**: Fewer steps between writing and executing, can be a faster cycle
  - **Disadvantages**: All errors happen when you run the program, no distinction between syntax errors (compile errors) and logic errors (bugs in running program)

1.4.0.1 Programming workflow

- Integrated Development Environment (IDE)
  - Combines a text editor, compiler, file browser, debugger, and other tools
  - Helps you organize a programming project
  - Helps you write, compile, and test code in one place
  - Visual Studio terms:
    - Solution: An entire software project, including source code, metadata, input data files, etc.

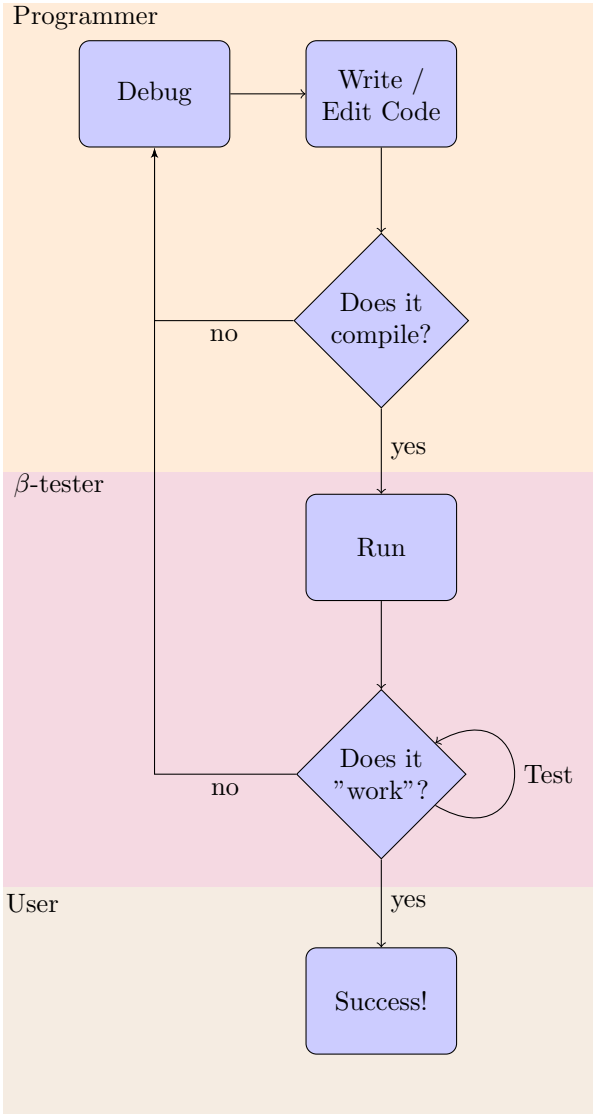


Figure 3: "Flowchart demonstrating roles and tasks of a programmer, beta tester and user in the creation of programs."

    - "Build solution": Compile all of your code
    - "Start without debugging": Run the compiled code
    - Solution location: The folder (on your computer's file system) that contains the solution, meaning all your code and the information needed to compile and run it

2 C# Fundamentals

2.1 Introduction to the C# Language

- C# is a managed language (as introduced in previous lecture)
  - Write in a high-level language, compile to intermediate language, run intermediate language in interpreter
  - Intermediate language is called CIL (Common Intermediate Language)
  - Interpreter is called .NET Runtime
  - Standard library is called .NET Framework, comes with the compiler and runtime
- It is widespread and popular
  - 8th most "loved" language on StackOverflow[2]
  - .NET is the 2nd most used "other" library/framework[3]
  - More insights on its evolution can be found in this blog post[4].

2.2 The Object-Oriented Paradigm

- C# is called an "object-oriented" language
  - Programming languages have different *paradigms*: philosophies for organizing code, expressing ideas
  - Object-oriented is one such paradigm, C# uses it
  - Meaning of object-oriented: Program mostly consists of *objects*, which are reusable modules of code
  - Each object contains some data (*attributes*) and some functions related to that data (*methods*)
- Object-oriented terms
  - **Class**: A blueprint or template for an object. Code that defines what kind of data the object will contain and what operations (functions) you will be able to do with that data
  - **Object**: A single instance of a class, containing running code with specific values for the data. Each object is a separate "copy" based on the template given by the class.
    Analogy: A *class* is like a floorplan while an *object* is the house build from the floorplan. Plus, you can make as many houses as you would like from a single floorplan.
  - **Attribute**: A piece of data stored in an object
    Example: A *House* class has a spot for a color property while an house object has a color(e.g. "Green").
  - **Method**: A function that modifies an object. This code is part of the class, but when it runs, it modifies only a specific object and not the class.
    Example: A *House* class with a method to change the house color. Using this method changes the color a single house object but doesn't change the *House* class or the color on any other house objects.
- Examples:

[2]https://insights.stackoverflow.com/survey/2020#technology-most-loved-dreaded-and-wanted-languages-loved
[3]https://insights.stackoverflow.com/survey/2020#technology-other-frameworks-libraries-and-tools
[4]https://dottutorials.net/stats-surveys-about-net-core-future-2020/#stackoverflow-surveys

- A Car *Class*
  - Attributes: Color, engine status (on/off), gear position
  - Methods: Press gas or brake pedal, turn key on/off, shift transmission
- A Car *Object*
  Example: A *Porsche911* object that is Red, Engine On, and in 1st gear
- An "Audio File" *Class* represents a song being played in a music player
  - Attributes: Sound wave data, current playback position, target speaker device
  - Methods: Play, pause, stop, fast-forward, rewind
- An Audio File *Object*
  Example: A *NeverGonnaGiveYouUp* object that is "rolled wave data", 0:00, speaker01

3 First Program

Here's a simple "hello world" program in the C# language:

3.0.0.1 Hello World

```
/* I'm a multi-line comment,
 * I can span over multiple lines!
 */
using System;

class Program
{
    static void Main()
    {
        Console.WriteLine("Hello, world!"); // I'm an in-line comment.
    }
}
```

Features of this program:

- A multi-line comment: everything between the `/*` and `*/` is considered a *comment*, i.e. text for humans to read. It will be ignored by the C# compiler and has no effect on the program.
- A `using` statement: This imports code definitions from the System *namespace*, which is part of the .NET Framework (the standard library).
  - In C#, code is organized into **namespaces**, which group related classes together
  - If you want to use code from a different namespace, you need a `using` statement to "import" that namespace
  - All the standard library code is in different namespaces from the code you will be writing, so you'll need `using` statements to access it
- A class declaration
  - Syntax:
  - All code between opening `{` and closing `}` is part of the class named by the `class [name]` statement
- A method declaration
  - The name of the method is `Main`, and is followed by empty parentheses (we'll get to those later, but they're required)
  - Just like with the class declaration, after the name, `{` begins the body of the method, `}` ends it
- A statement inside the body of the method

  - This is the part of the program that actually "does something": It prints a line of text to the console
  - A statement *must* end in a semicolon (the class header and method header aren't statements)
  - This statement contains a class name (`Console`), followed by a method name (`WriteLine`). It calls the `WriteLine` method in the `Console` class.
  - The **argument** to the `WriteLine` method is the text "Hello, world!", which is in parentheses after the name of the method. This is the text that gets printed in the console: The `WriteLine` method (which is in the standard library) takes an argument and prints it to the console.
  - Note that the argument to `WriteLine` is inside double-quotes. This means it is a **string**, i.e. textual data, not a piece of C# code. The quotes are required in order to distinguish between text and code.
- An in-line comment: All the text from the `//` to the end of the line is considered a comment, and is ignored by the C# compiler.

3.1 Rules of C# Syntax

- Each statement must end in a semicolon (`;`),
  - Class and method declarations are not statements
  - A method *contains* some statements, but it is not a statement
- All words are case-sensitive
  - A class named `Program` is not the same as one named `program`
  - A method named `writeline` is not the same as one named `WriteLine`
- Braces and parentheses must always be matched
  - Once you start a class or method definition with `{`, you must end it with `}`
- Whitespace – spaces, tabs, and newlines – has almost no meaning
  - There must be at least 1 space between words
  - Spaces are counted exactly if they are inside string data, e.g. `"Hello      world!"`
  - Otherwise, entire program could be written on one line; it would have the same meaning
  - Spaces and new lines are just to help humans read the code
- All C# applications must have a `Main` method
  - Name must match exactly, otherwise .NET runtime will get confused
  - This is the first code to run when the application starts – any other code (in methods) will only run when its method is called

3.2 Conventions of C# Programs

- Conventions: Not enforced by the compiler/language, but expected by humans
  - Program will still work if you break them, but other programmers will be confused
- Indentation
  - After a class or method declaration (header), put the opening `{` on a new line underneath it
  - Then indent the next line by 4 spaces, and all other lines "inside" the class or method body
  - De-indent by 4 spaces at end of method body, so ending `}` aligns vertically with opening `{`
  - Method definition inside class definition: Indent body of method by another 4 spaces
  - In general, any code between `{` and `}` should be indented by 4 spaces relative to the `{` and `}`
- Code files

- C# code is stored in files that end with the extension ".cs"
- Each ".cs" file contains exactly one class
- The name of the file is the same as the name of the class (Program.cs contains `class Program`)

3.3 Reserved Words and Identifiers

- Reserved words: Keywords in the C# language
  - Note they have a distinct color in the code sample and in Visual Studio
  - Built-in commands/features of the language
  - Can only be used for one specific purpose; meaning cannot be changed
  - Examples:
    * `using`
    * `class`
    * `public`
    * `private`
    * `namespace`
    * `this`
    * `if`
    * `else`
    * `for`
    * `while`
    * `do`
    * `return`
- Identifiers: Human-chosen names
  - Names for classes (`Rectangle`, `ClassRoom`, etc.), variables (`age`, `name`, etc.), methods (`ComputeArea`, `GetLength`, etc), namespaces, etc.
  - Some have already been chosen for the standard library (e.g. `Console`, `WriteLine`), but they are still identifiers, not keywords
  - Rules for identifiers:
    * Must not be a reserved word
    * Must contain only letters (`a` → `Z`), numbers (`0` → `9`), and underscore (`_`)– no spaces
    * Must not begin with a number
    * Are case sensitive
    * Must be unique (you cannot re-use the same identifier twice in the same scope – a concept we will discuss later)
  - Conventions for identifiers
    * Should be descriptive, e.g. "`AudioFile`" or "`userInput`" not "`a`" or "`x`"
    * Should be easy for humans to read and type
    * If name is multiple words, use CamelCase[5] (or its variation Pascal case[6]) to distinguish words
    * Class and method names should start with capitals, e.g. "`class AudioFile`"
    * Variable names should start with lowercase letters, then capitalize subsequent words, e.g. "`myFavoriteNumber`"

3.4 Write and WriteLine

- The `WriteLine` method

[5] https://en.wikipedia.org/wiki/Camel_case
[6] https://www.c-sharpcorner.com/UploadFile/8a67c0/C-Sharp-coding-standards-and-naming-conventions/

- We saw this in the "Hello World" program: `Console.WriteLine("Hello World!");` results in "Hello World!" being displayed in the terminal
- In general, `Console.WriteLine("text");` will display the text in the terminal, then *start a new line*
- This means a second `Console.WriteLine` will display its text on the next line of the terminal. For example, this program:

```
using System;

class Welcome
{
    static void Main()
    {
        Console.WriteLine("Hello");
        Console.WriteLine("World!");
    }
}
```

will display the following output in the terminal:

```
Hello
World!
```

- Methods with multiple statements
  - Note that our two-line example has a `Main` method with multiple statements
  - In C#, each statement must end in a semicolon
  - Class and method declarations are not statements
  - Each line of code in your .cs file is not necessarily a statement
  - A single invocation/call of the `WriteLine` method is a statement
- The `Write` method
  - `Console.WriteLine("text")` prints the text, then starts a new line in the terminal – it effectively "hits enter" after printing the text
  - `Console.Write("text")` just prints the text, without starting a new line. It's like typing the text without hitting "enter" afterwards.
  - Even though two `Console.Write` calls are two statements, and appear on two lines, they will result in the text being printed on just one line. For example, this program:

```
using System;

class Welcome
{
    static void Main()
    {
        Console.Write("Hello");
        Console.Write("World!");
    }
}
```

will display the following output in the terminal:

```
HelloWorld!
```

- Note that there is no space between "Hello" and "World!" because we didn't type one in the argument to `Console.Write`

- Combining `Write` and `WriteLine`
  - We can use both `WriteLine` and `Write` in the same program
  - After a call to `Write`, the "cursor" is on the same line after the printed text; after a call to `WriteLine` the "cursor" is at the beginning of the next line
  - This program:

```
using System;

class Welcome
{
    static void Main()
    {
        Console.Write("Hello ");
        Console.WriteLine("World!");
        Console.Write("Welcome to ");
        Console.WriteLine("CSCI 1301!");
    }
}
```

    will display the following output in the terminal:

```
Hello world!
Welcome to CSCI 1301!
```

3.5 Escape Sequences

- Explicitly writing a new line
  - So far we've used `WriteLine` when we want to create a new line in the output
  - The **escape sequence** `\n` can also be used to create a new line – it represents the "newline character," which is what gets printed when you type "enter"
  - This program will produce the same output as our two-line "Hello World" example, with each word on its own line:

```
using System;

class Welcome
{
    static void Main()
    {
        Console.Write("Hello\nWorld!\n");
    }
}
```

- Escape sequences in detail
  - An **escape sequence** uses "normal" letters to represent "special", hard-to-type characters
  - `\n` represents the newline character, i.e. the result of pressing "enter"

- `\t` represents the tab character, which is a single extra-wide space (you usually get it by pressing the "tab" key)
- `\"` represents a double-quote character that will get printed on the screen, rather than ending the text string in the C# code.
  - Without this, you couldn't write a sentence with quotation marks in a `Console.WriteLine`, because the C# compiler would assume the quotation marks meant the string was ending
  - This program won't compile because `in quotes` is not valid C# code, and the compiler thinks it is not part of the string:

```
class Welcome
{
    static void Main()
    {
        Console.WriteLine("This is "in quotes"");
    }
}
```

  - This program will display the sentence including the quotation marks:

```
using System;

class Welcome
{
    static void Main()
    {
        Console.WriteLine("This is \"in quotes\"");
    }
}
```

- Note that all escape sequences begin with a backslash character (`\`)
- General format is `\[key letter]` – the letter after the backslash is like a "keyword" indicating which special character to display
- If you want to put an actual backslash in your string, you need the escape sequence `\\`, which prints a single backslash
  - This will result in a compile error because `\U` is not a valid escape sequence:

```
Console.WriteLine("Go to C:\Users\Edward");
```

  - This will display the path correctly:

```
Console.WriteLine("Go to C:\\Users\\Edward");
```

4 Datatypes and Variables

4.1 Datatype Basics

- Recall the basic structure of a program
  - Program receives input from some source, uses input to make decisions, produces output for the outside world to see
  - In other words, the program reads some data, manipulates data, and writes out new data
  - In C#, data is stored in objects during the program's execution, and manipulated using the methods of those objects

- This data has **types**
  - Numbers (the number 2) are different from text (the word "two")
  - Text data is called "strings" because each letter is a **character** and a word is a *string of characters*
  - Within "numeric data," there are different types of numbers
    - Natural numbers ($\mathbb{N}$): 0, 1, 2, …
    - Integers ($\mathbb{Z}$): … -2, -1, 0, 1, 2, …
    - Real numbers ($\mathbb{R}$): 0.5, 1.333333…, -1.4, etc.
- Basic Datatypes in C#
  - C# uses keywords to name the types of data
  - Text data:
    - `string`: a string of characters, like `"Hello world!"`
    - `char`: a single character, like `'e'` or `'t'`
  - Numeric data:
    - `int`: An integer, as defined previously
    - `uint`: An *unsigned* integer, in other words, a natural number (positive integers only)
    - `float`: A "floating-point" number, which is a real number with a fractional part, such as 3.85
    - `double`: A floating-point number with "double precision" – also a real number, but capable of storing more significant figures
    - `decimal`: An "exact decimal" number – also a real number, but has fewer rounding errors than `float` and `double` (we'll explore the difference later)

4.2 Literals and Variables

- Literals and their types
  - A **literal** is a data value written in the code
  - A form of "input" provided by the programmer rather than the user; its value is fixed throughout the program's execution
  - Literal data must have a type, indicated by syntax:
    - `string` literal: text in double quotes, like `"hello"`
    - `char` literal: a character in single quotes, like `'a'`
    - `int` literal: a number without a decimal point, with or without a minus sign (e.g. `52`)
    - `long` literal: just like an `int` literal but with the suffix `l` or `L`, e.g. `4L`
    - `double` literal: a number with a decimal point, with or without a minus sign (e.g. `-4.5`)
    - `float` literal: just like a `double` literal but with the suffix `f` or `F` (for "float"), e.g. `4.5f`
    - `decimal` literal: just like a `double` literal but with the suffix `m` or `M`(for "deciMal"), e.g. `6.01m`
- Variables overview
  - Variables store data that can *vary* (change) during the program's execution
  - They have a type, just like literals, and also a name
  - You can use literals to write data that gets stored in variables
  - Sample program with variables:

```
using System;

class MyFirstVariables
{
    static void Main()
    {
        // Declaration
        int myAge;
```

```
        string myName;
        // Assignment
        myAge = 29;
        myName = "Edward";
        // Displaying
        Console.WriteLine($"My name is {myName} and I am {myAge} years old.");
    }
}
```

This program shows three major operations you can do with variables.

* First it **declares** two variables, an `int`-type variable named "myAge" and a `string`-type variable named "myName"
* Then, it **assigns** values to each of those variables, using literals of the same type. `myAge` is assigned the value 29, using the `int` literal `29`, and `myName` is assigned the value "Edward", using the `string` literal `"Edward"`
* Finally, it **displays** the current value of each variable by using the `Console.WriteLine` method and **string interpolation**, in which the values of variables are inserted into a string by writing their names with some special syntax (a `$` character at the beginning of the string, and braces around the variable names)

4.3 Variable Operations

- Declaration
  - This is when you specify the *name* of a variable and its *type*
  - Syntax: `type_keyword variable_name;`
  - Examples: `int myAge;`, `string myName;`, `double winChance;`
  - A variable name is an identifier, so it should follow the rules and conventions
    * Can only contain letters and numbers
    * Must be unique among all variable, method, and class names
    * Should use CamelCase if it contains multiple words
  - Note that the variable's type is not part of its name: two variables cannot have the same name *even if* they are different types
  - Multiple variables can be declared in the same statement: `string myFirstName, myLastName;` would declare *two* strings called respectively `myFirstName` and `myLastName`.
- Assignment
  - The act of changing the value of a variable
  - Uses the symbol =, which is the *assignment operator*, not a statement of equality – it does not mean "equals"
  - Direction of assignment is **right to left**: the variable goes on the left side of the = symbol, and its new value goes on the right
  - Syntax: `variable_name = value;`
  - Example: `myAge = 29;`
  - Value *must* match the type of the variable. If `myAge` was declared as an `int`-type variable, you cannot write `myAge = "29";` because `"29"` is a `string`
- Initialization (Declaration + Assignment)
  - Initialization statement combines declaration and assignment in one line (it's just a shortcut, not a new operation)
  - Creates a new variable and also gives it an initial value
  - Syntax: `type variable_name = value;`
  - Example: `string myName = "Edward";`
  - Can only be used once per variable, since you can only declare a variable once

- Assignment Details
  - Assignment replaces the "old" value of the variable with a "new" one; it's how variables *vary*
    - If you initialize a variable with `int myAge = 29;` and then write `myAge = 30;`, the variable `myAge` now store the value 30
  - You can assign a variable to another variable: just write a variable name on both sides of the = operator
    - This will take a "snapshot" of the current value of the variable on the right side, and store it into the variable on the left side
    - For example, in this code:

      ```
      int a = 12;
      int b = a;
      a = -5;
      ```

      the variable `b` gets the value 12, because that's the value that `a` had when the statement `int b = a` was executed. Even though `a` was then changed to -5 afterward, `b` is still `12`.
- Displaying
  - When you want to print a mixture of values and variables with `Console.WriteLine`, we should convert all of them to a string
  - **String interpolation**: a mechanism for converting a variable's value to a `string` and inserting it into the main string
    - Syntax: `$"text {variable} text"` – begin with a `$` symbol, then put variable's name inside brackets within the string
    - Example: `$"I am {myAge} years old"`
    - When this line of code is executed, it reads the variable's current value, converts it to a string (`29` becomes `"29"`), and inserts it into the surrounding string
    - Displayed: `I am 29 years old`
  - When string interpolation converts a variable to a string, it must call a "string conversion" method supplied with the data type (`int`, `double`, etc.). All built-in C# datatypes come with string conversion methods, but when you write your own data types (classes), you'll need to write your own string conversions – string interpolation won't magically "know" how to convert `MyClass` variables to `string`s

On a final note, observe that you can write statements mixing multiple declarations and assignments, as in `int myAge = 10, yourAge, ageDifference;` that declares three variables of type `int` and set the value of the first one. It is generally recommended to separate those instructions in different statements as you begin, to ease debugging and have a better understanding of the "atomic steps" your program should perform.

4.4 Variables in Memory

- A variable names a memory location
  - Data is stored in memory (RAM), so a variable "stores data" by storing it in memory
  - Declaring a variable reserves a memory location (address) and gives it a name
  - Assigning to a variable stores data to the memory location (address) named by that variable
- Numeric datatypes have different sizes
  - Amount of memory used/reserved by each variable depends on the variable's type
  - Amount of memory needed for an integer data type depends on the size of the number
    - `int` uses 4 bytes of memory, can store numbers in the range $[-2^{31}, 2^{31} - 1]$
    - `long` uses 8 bytes of memory can store numbers in the range $[-2^{63}, 2^{63} - 1]$
    - `short` uses 2 bytes of memory, can store numbers in the range $[-2^{15}, 2^{15} - 1]$
    - `sbyte` uses only 1 bytes of memory, can store numbers in the range $[-128, 127]$

- Unsigned versions of the integer types use the same amount of memory, but can store larger positive numbers
  - `byte` uses 1 byte of memory, can store numbers in the range $[0, 255]$
  - `ushort` uses 2 bytes of memory, can store numbers in the range $[0, 2^{16} - 1]$
  - `uint` uses 4 bytes of memory, can store numbers in the range $[0, 2^{32} - 1]$
  - `ulong` uses 8 bytes of memory, can store numbers in the range $[0, 2^{64} - 1]$
  - This is because in a signed integer, one bit (digit) of the binary number is needed to represent the sign (+ or -). This means the actual number stored must be 1 bit smaller than the size of the memory (e.g. 31 bits out of the 32 bits in 4 bytes). In an unsigned integer, there is no "sign bit", so all the bits can be used for the number.
- Amount of memory needed for a floating-point data type depends on the precision (significant figures) of the number
  - `float` uses 4 bytes of memory, can store positive or negative numbers in a range of approximately $[10^{-45}, 10^{38}]$, with 7 significant figures of precision
  - `double` uses 8 bytes of memory, and has both a wider range (10^{-324} to 10^{308}) and more significant figures (15 or 16)
  - `decimal` uses 16 bytes of memory, and has 28 or 29 significant figures of precision, but it actually has the smallest range (10^{-28} to 10^{28}) because it stores decimal fractions exactly
- Difference between binary fractions and decimal fractions
  - `float` and `double` store their data as binary (base 2) fractions, where each digit represents a power of 2
    - The binary number 101.01 represents $4 + 1 + 1/4$, or 5.25 in base 10
  - More specifically, they use binary scientific notation: A mantissa (a binary integer), followed by an exponent assumed to be a power of 2, which is applied to the mantissa
    - 10101e-10 means a mantissa of 10101 (i.e. 21 in base 10) with an exponent of -10 (i.e. 2^{-2} in base 10), which also produces the value 101.01 or 5.25 in base 10
  - Binary fractions can't represent all base-10 fractions, because they can only represent fractions that are negative powers of 2. 1/10 is not a negative power of 2 and can't be represented as a sum of 1/16, 1/32, 1/64, etc.
  - This means some base-10 fractions will get "rounded" to the nearest finite binary fraction, and this will cause errors when they are used in arithmetic
  - On the other hand, `decimal` stores data as a base-10 fraction, using base-10 scientific notation
  - This is slower for the computer to calculate with (since computers work only in binary) but has no "rounding errors" with fractions that include 0.1
  - Use `decimal` when working with money (since money uses a lot of 0.1 and 0.01 fractions), `double` when working with non-money fractions

Summary of numeric data types and sizes:

Type	Size	Range of Values	Precision
`sbyte`	1 bytes	$-128...127$	N/A
`byte`	1 bytes	$0...255$	N/A
`short`	2 bytes	$-2^{15}...2^{15} - 1$	N/A
`ushort`	2 bytes	$0...2^{16} - 1$	N/A
`int`	4 bytes	$-2^{31}...2^{31} - 1$	N/A
`uint`	4 bytes	$0...2^{32} - 1$	N/A
`long`	8 bytes	$-2^{63}...2^{63} - 1$	N/A
`ulong`	8 bytes	$0...2^{64} - 1$	N/A
`float`	4 bytes	$\pm 1.5 \cdot 10^{-45} ... \pm 3.4 \cdot 10^{38}$	7 digits
`double`	8 bytes	$\pm 5.0 \cdot 10^{-324} ... \pm 1.7 \cdot 10^{308}$	15-16 digits
`decimal`	16 bytes	$\pm 1.0 \cdot 10^{-28} ... \pm 7.9 \cdot 10^{28}$	28-29 digits

- Value and reference types: different ways of storing data in memory
  - Variables name memory locations, but the data that gets stored at the named location is different for each type
  - For a **value type** variable, the named memory location stores the exact data value held by the variable (just what you'd expect)
  - Value types: all the numeric types (`int`, `float`, `double`, `decimal`, etc.), `char`, and `bool`
  - For a **reference type** variable, the named memory location stores a *reference* to the data, not the data itself
    - The contents of the memory location named by the variable are the address of another memory location
    - The *other* memory location is where the variable's data is stored
    - To get to the data, the computer first reads the location named by the variable, then uses that information (the memory address) to find and read the other memory location where the data is stored
  - Reference types: `string`, `object`, and all objects you create from your own classes
  - Assignment works differently for reference types
    - Assignment always copies the value in the variable's named memory location - but in the case of a reference type that's just a memory address, not the data
    - Assigning one reference-type variable to another copies the memory address, so now both variables "refer to" the same data
    - Example:

      ```
      string word = "Hello";
      string word2 = word;
      ```

      Both `word` and `word2` contain the same memory address, pointing to the same memory location, which contains the string "Hello". There is only one copy of the string "Hello"; `word2` doesn't get its own copy.

4.5 Overflow

- Assume a car has a 4-digit odometer, and currently, it shows `9999`. What does the odometer show if you drive the car another mile? As you guess, it shows `0000` while it should show `10000`. The reason is the odometer does not have a counter for the fifth digit. Similarly, in C#, when you do arithmetic operations on integral data, the result may not fit in the corresponding data type. This situation is called `overflow` error.
- In an unsigned data type variable with N bits, we can store the numbers ranged from 0 to $2^(N-1)$. In signed data type variables, the high order bit represents the sign of the number as follows:
  - 0 means zero or a positive value
  - 1 means a negative value
- With the remaining $N-1$ bits, we can represent $2^(N-1)$ states. Hence, considering the sign bit, we can store a number from $-2^(N-1)$ to $2^(N-1)-1$ in the variable.
- In many programming languages like C, overflow error raise an exceptional situation that crashes the program if it is not handled. But, in C#, the extra bits are just ignored, and if the programmer does not care about such a possibility, it can lead to a severe security problem.
- For example, assume a company gives loans to its employee. Couples working for the company can get loans separately, but the total amount can not exceed $10,000. The underneath program looks like it does this job, but there is a risk of attacks. (This program uses notions you have not studied yet, but that should not prevent you from reading the source code and executing it.)

```
using System;

class Program
{
    static void Main()
    {
    uint n1, n2;

    Console.WriteLine("Enter the requested loan amount for the first person:");
    n1 = uint.Parse(Console.ReadLine());

    Console.WriteLine("Enter the requested loan amount for the second person:");
    n2 = uint.Parse(Console.ReadLine());

    if(n1 + n2 < 10000)
    {
        Console.WriteLine($"Pay ${n1} for the first person");
        Console.WriteLine($"Pay ${n2} for the second person");
    }
    else
    {
        Console.WriteLine("Error: the sum of loans exceeds the maximum allowance.");
    }
    }
}
```

- If the user enters 2 and 4,294,967,295, we expect to see the error message ("Error: the sum of loans exceeds the maximum allowance."). However, this is not what will happened, and the request will be accepted even if it should not have. The reason can be explained as follows:
  - `uint` is a 32-bit data type.
  - The binary representation of 2 and 4,294,967,295 are `00000000000000000000000000000010` and `11111111111111111111111111111111`.
  - Therefore, the sum of these numbers should be `100000000000000000000000000000001`, which needs 33 bits.
  - Nevertheless, there is only 32 bits available for the result, and the extra bits will be dropped, and the result looks like `00000000000000000000000000000001`, which is less than 10,000.

4.6 Underflow ♡

- Sometimes, the result of arithmetic operations over floating-point numbers is smaller than what can be stored in the corresponding data type. This problem is known as the underflow problem.
- In C#, in case of an underflow problem, the result will be zero.

```
using System;

class Program
{
    static void Main()
    {
        float myNumber;
        myNumber = 1E-45f;
        Console.WriteLine(myNumber); //outputs 1.401298E-45
        myNumber = myNumber / 10;
```

```
            Console.WriteLine(myNumber); //outputs 0
            myNumber = myNumber * 10;
            Console.WriteLine(myNumber); //outputs 0
        }
    }
```

5 Operators

5.1 Arithmetic Operators

Variables or literals of numeric data types (`int`, `double`, etc.) can be used to do math. All the usual arithmetic operations are available in C#:

Operation	C# Operator	Algebraic Expression	C# Expression
Addition	`+`	$x + 7$	`myVar + 7`
Subtraction	`-`	$x - 7$	`myVar - 7`
Multiplication	`*`	$x \times 7$	`myVar * 7`
Division	`/`	$x/7$, $x \div 7$	`myVar / 7`
Remainder (a.k.a. modulo)	`%`	$x \bmod 7$	`myVar % 7`

Note: the "remainder" or "modulo" operator represents the remainder after doing integer division between its two operands. For example, $44 \bmod 7 = 2$ because $44 \div 7 = 6$ *with remainder* 2.

- Arithmetic and variables
  - The result of an arithmetic expression (like those shown in the table) is a numeric value
    - For example, the C# expression `3 * 4` has the value `12`, which is `int` data
  - A numeric value can be assigned to a variable of the same type, just like a literal: `int myVar = 3 * 4;` initializes the variable `myVar` to contain the value `12`
  - A numeric-type variable can be used in an arithmetic expression
  - When a variable is used in an arithmetic expression, its current value is read, and the math is done on that value
  - Example:

    ```
    int a = 4;
    int b = a + 5;
    a = b * 2;
    ```

    - To execute the second line of the code, the computer will first evaluate the expression on the right side of the = sign. It reads the value of the variable `a`, which is 4, and then computes the result of `4 + 5`, which is 9. Then, it assigns this value to the variable `b` (remember assignment goes right to left).
    - To execute the third line of code, the computer first evaluates the expression on the right side of the = sign, which means reading the value of `b` to use in the arithmetic operation. `b` contains 9, so the expression is `9 * 2`, which evaluates to 18. Then it assigns the value 18 to the variable `a`, which now contains 18 instead of 4.
  - A variable can appear on both sides of the = sign, like this:

    ```
    int myVar = 4;
    myVar = myVar * 2;
    ```

This looks like a paradox because `myVar` is assigned to itself, but it has a clear meaning because assignment is evaluated right to left. When executing the second line of code, the computer evaluates the right side of the = before doing the assignment. So it first reads the current ("old") value of `myVar`, which is 4, and computes `4 * 2` to get the value 8. Then, it assigns the new value to `myVar`, overwriting its old value.

- Compound assignment operators
  - The pattern of "compute an expression with a variable, then assign the result to that variable" is common, so there are shortcuts for doing it
  - The **compound assignment operators** change the value of a variable by adding, subtracting, etc. from its current value, equivalent to an assignment statement that has the value on both sides:

Statement	Equivalent
`x += 2;`	`x = x + 2;`
`x -= 2;`	`x = x - 2;`
`x *= 2;`	`x = x * 2;`
`x /= 2;`	`x = x / 2;`
`x %= 2;`	`x = x % 2;`

5.2 Implicit and Explicit Conversions Between Datatypes

- Assignments from different types
  - The "proper" way to initialize a variable is to assign it a literal of the same type:

```
int myAge = 29;
double myHeight = 1.77;
float radius = 2.3f;
```

    Note that `1.77` is a `double` literal, while `2.3f` is a `float` literal
  - If the literal is not the same type as the variable, you will sometimes get an error – for example, `float radius = 2.3` will result in a compile error – but sometimes, it appears to work fine: for example `float radius = 2;` compiles and runs without error even though 2 is an `int` value.
  - In fact, the value being assigned to the variable **must** be the same type as the variable, but some types can be **implicitly converted** to others
- Implicit conversions
  - Implicit conversion allows variables to be assigned from literals of the "wrong" type: the literal value is first implicitly converted to the right type
    - In the statement `float radius = 2;`, the `int` value 2 is implicitly converted to an equivalent `float` value, `2.0f`. Then the computer assigns `2.0f` to the `radius` variable.
  - Implicit conversion also allows variables to be assigned from other variables that have a different type:

```
int length = 2;
float radius = length;
```

When the computer executes the second line of this code, it reads the variable `length` to get an `int` value 2. It then implicitly converts that value to `2.0f`, and then assigns `2.0f` to the `float`-type variable `radius`.

- Implicit conversion only works between *some* data types: a value will only be implicitly converted if it is "safe" to do so without losing data
- Summary of possible implicit conversions:

Type	Possible Implicit Conversions
`short`	`int`, `long`, `float`, `double`, `decimal`
`int`	`long`, `float`, `double`, `decimal`
`long`	`float`, `double`, `decimal`
`ushort`	`uint`, `int`, `ulong`, `long`, `decimal`, `float`, `double`
`uint`	`ulong`, `long`, `decimal`, `float`, `double`
`ulong`	`decimal`, `float`, `double`
`float`	`double`

- In general, a data type can only be implicitly converted to one with a *larger range* of possible values
- Since an `int` can store any integer between -2^{31} and $2^{31} - 1$, but a `float` can store any integer between -3.4×10^{38} and 3.4×10^{38} (as well as fractional values), it's always safe to store an `int` value in a `float`
- You *cannot* implicitly convert a `float` to an `int` because an `int` stores fewer values than a `float` – it can't store fractions – so converting a `float` to an `int` will **lose data**
- Note that all integer data types can be implicitly converted to `float` or `double`
- Each integer data type can be implicitly converted to a larger integer type: `short` → `int` → `long`
- Unsigned integer data types can be implicitly converted to a *larger* signed integer type, but not the *same* signed integer type: `uint` → `long`, but **not** `uint` → `int`
  - This is because of the "sign bit": a `uint` can store larger values than an `int` because it doesn't use a sign bit, so converting a large `uint` to an `int` might lose data

- Explicit conversions
  - Any conversion that is "unsafe" because it might lose data will not happen automatically: you get a compile error if you assign a `double` variable to a `float` variable
  - If you want to do an unsafe conversion anyway, you must perform an **explicit conversion** with the **cast operator**
  - Cast operator syntax: `([type name]) [variable or value]` – the cast is "right-associative", so it applies to the variable to the right of the type name
  - Example: `(float) 2.8` or `(int) radius`
  - Explicit conversions are often used when you (the programmer) know the conversion is actually "safe" – data won't actually be lost
    - For example, in this code, we know that 2.886 is within the range of a `float`, so it's safe to convert it to a `float`:

      ```
      float radius = (float) 2.886;
      ```

      The variable `radius` will be assigned the value `2.886f`.
    - For example, in this code, we know that 2.0 is safe to convert to an `int` because it has no fractional part:

```
double length = 2.0;
int height = (int) length;
```

The variable `height` will be assigned the value `2`.

- Explicit conversions only work if there exists code to perform the conversion, usually in the standard library. The cast operator isn't "magic" – it just calls a method that is defined to convert one type of data (e.g. `double`) to another (e.g. `int`).
  - All the C# numeric types have explicit conversions to each other defined
  - `string` does not have explicit conversions defined, so you cannot write `int myAge = (int) "29";`
- If the explicit conversion is truly unsafe (will lose data), data is lost in a specific way
  - Casting from floating-point (e.g. `double`) types to integer types: fractional part of number is *truncated* (ignored/dropped)
  - In `int length = (int) 2.886;`, the value 2.886 is truncated to 2 by the cast to `int`, so the variable `length` gets the value 2.
  - Casting from more-precise to less-precise floating point type: number is *rounded* to nearest value that fits in less-precise type:

    ```
    decimal myDecimal = 123456789.999999918m;
    double myDouble = (double) myDecimal;
    float myFloat = (float) myDouble;
    ```

    In this code, `myDouble` gets the value 123456789.99999993, while `myFloat` gets the value `123456790.0f`, as the original `decimal` value is rounded to fit types with fewer significant figures of precision.
  - Casting from a larger integer to a smaller integer: the most significant *bits* are truncated – remember that numbers are stored in binary format
  - This can cause weird results, since the least-significant *bits* of a number in binary don't correspond to the least significant *digits* of the equivalent base-10 number
  - Casting from another floating point type to `decimal`: Either value is stored precisely (no rounding), or *program crashes* with `System.OverflowException` if value is larger than `decimal`'s maximum value:

    ```
    decimal fromSmall = (decimal) 42.76875;
    double bigDouble = 2.65e35;
    decimal fromBig = (decimal) bigDouble;
    ```

    In this code, `fromSmall` will get the value `42.76875m`, but the program will crash when attempting to cast `bigDouble` to a `decimal` because 2.65×10^{35} is larger than `decimal`'s maximum value of 7.9×10^{28}
  - `decimal` is more precise than the other two floating-point types (thus doesn't need to round), but has a smaller range (only 10^{28}, vs. 10^{308})

Summary of implicit and explicit conversions for the numeric datatypes:

Refer to the "Result Type of Operations" chart from the cheatsheet[7] for more detail.

[7] ../datatypes_in_csharp.html#result-type-of-operations

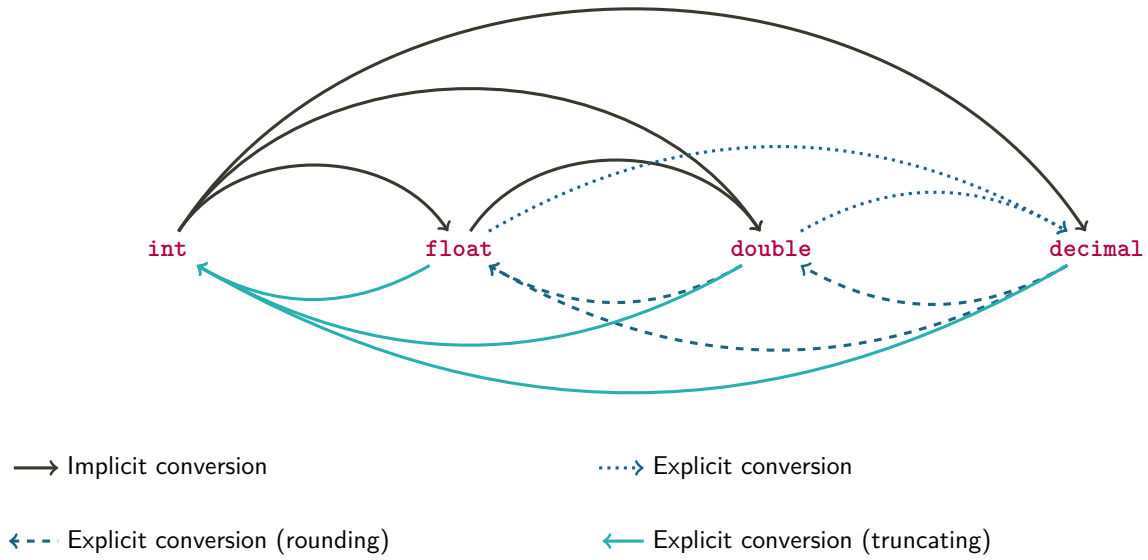


Figure 4: "Implicit and Explicit Conversion Between Datatypes"

5.3 Arithmetic on Mixed Data Types

- Math operators for each data type
  - The math operators (+, -, *, /) are defined separately for each data type: There is an `int` version of + that adds `int`s, a `float` version of + that adds `float`s, etc.
  - Each operator expects to get two values of the same type on each side, and produces a result of that same type. For example, `2.25 + 3.25` uses the `double` version of +, which adds the two `double` values to produce a `double`-type result, 5.5.
  - Most operators have the same effect regardless of their type, except for /
  - The `int`/`short`/`long` version of / does **integer division**, which returns only the quotient and drops the remainder: In the statement `int result = 21 / 5;`, the variable `result` gets the value 4, because $21 \div 5$ is 4 with a remainder of 1. If you want the fractional part, you need to use the floating-point version (for `float`, `double`, and `decimal`): `double fracDiv = 21.0 / 5.0;` will initialize `fracDiv` to 4.2.
- Implicit conversions in math
  - If the two operands/arguments to a math operator are not the same type, they must become the same type – one must be converted
  - C# will first try implicit conversion to "promote" a less-precise or smaller value to a more precise, larger type
  - Example: with the expression `double fracDiv = 21 / 2.4;`
    - Operand types are `int` and `double`
    - `int` is smaller/less-precise than `double`
    - 21 gets implicitly converted to 21.0, a `double` value
    - Now the operands are both `double` type, so the `double` version of the / operator gets executed
    - The result is 8.75, a `double` value, which gets assigned to the variable `fracDiv`

  - Implicit conversion also happens in assignment statements, which happen *after* the math expression is computed
  - Example: with the expression `double fraction = 21 / 5;`
    - Operand types are `int` and `int`
    - Since they match, the `int` version of / gets executed
    - The result is 4, an `int` value
    - Now this value is assigned to the variable `fraction`, which is `double` type
    - The `int` value is implicitly converted to the `double` value 4.0, and `fraction` is assigned the value 4.0

- Explicit conversions in math
  - If the operands are `int` type, the `int` version of / will get called, even if you assign the result to a `double`
  - You can "force" floating-point division by explicitly converting one operand to `double` or `float`
  - Example:

    ```
    int numCookies = 21;
    int numPeople = 6;
    double share = (double) numCookies / numPeople;
    ```

    Without the cast, `share` would get the value 3.0 because `numCookies` and `numPeople` are both `int` type (just like the `fraction` example above). With the cast, `numCookies` is converted to the value 21.0 (a `double`), which means the operands are no longer the same type. This will cause `numPeople` to be implicitly converted to `double` in order to make them match, and the `double` version of / will get called to evaluate `21.0 / 6.0`. The result is 3.5, so `share` gets assigned 3.5.
  - You might also *need* a cast to ensure the operands are the same type, if implicit conversion doesn't work
  - Example:

    ```
    decimal price = 3.89;
    double shares = 47.75;
    decimal total = price * (decimal) shares;
    ```

    In this code, `double` can't be implicitly converted to `decimal`, and `decimal` can't be explicitly converted to `double`, so the multiplication `price * shares` would produce a compile error. We need an explicit cast to `decimal` to make both operands the same type (`decimal`).

5.4 Order of Operations

- Math operations in C# follow PEMDAS from math class: Parentheses, Exponents, Multiplication, Division, Addition, Subtraction
  - Multiplication/division are evaluated together, as are addition/subtraction
  - Expressions are evaluated left-to-right
  - Example: `int x = 4 = 10 * 3 - 21 / 2 - (3 + 3);`
    - Parentheses: `(3 + 3)` is evaluated, returns 6
    - Multiplication/Division: `10 * 3` is evaluated to produce 30, then `21 / 2` is evaluated to produce 10 (left-to-right)
    - Addition/Subtraction: 4 + 30 - 10 - 6 is evaluated, result is 18
- Cast operator is higher priority than all binary operators
  - Example: `double share = (double) numCookies / numPeople;`

    - Cast operator is evaluated first, converts `numCookies` to a `double`
    - Division is evaluated next, but operand types don't match
    - `numPeople` is implicitly converted to `double` to make operand types match
    - Then division is evaluated, result is 21.0 / 6.0 = 3.5

- Parentheses always increase priority, even with casts
  - An expression in parentheses gets evaluated before the cast "next to" it
  - Example:

    ```
    int a = 5, b = 4;
    double result = (double) (a / b);
    ```

    The expression in parentheses gets evaluated first, then the result has the `(double)` cast applied to it. That means `a / b` is evaluated to produce 1, since `a` and `b` are both `int` type, and then that result is cast to a `double`, producing 1.0.

6 Reading Input, Displaying Output, and Concatenation

6.1 Output with Variables

- Converting from numbers to strings
  - As we saw in a previous lecture (Datatypes and Variables), the `Console.WriteLine` method needs a `string` as its argument
  - If the variable you want to display is not a `string`, you might think you could cast it to a `string`, but that won't work – there is no explicit conversion from `string` to numeric types
    - This code:

      ```
      double fraction = (double) 47 / 6;
      string text = (string) fraction;
      ```

      will produce a compile error
  - You *can* convert numeric data to a `string` using string interpolation, which we've used before in `Console.WriteLine` statements:

    ```
    int x = 47, y = 6;
    double fraction = (double) x / y;
    string text = $"{x} divided by {y} is {fraction}";
    ```

    After executing this code, `text` will contain "47 divided by 6 is 7.8333333"
  - String interpolation can convert any expression to a `string`, not just a single variable. For example, you can write:

    ```
    Console.WriteLine($"{x} divided by {y} is {(double) x / y}");
    Console.WriteLine($"{x} plus 7 is {x + 7}");
    ```

    This will display the following output:

    ```
    47 divided by 6 is 7.8333333
    47 plus 7 is 54
    ```

    Note that writing a math expression inside a string interpolation statement does not change the values of any variables. After executing this code, `x` is still 47, and `y` is still 6.

- The `ToString()` method

- String interpolation doesn't "magically know" how to convert numbers to strings – it delegates the task to the numbers themselves
- This works because all data types in C# are objects, even the built-in ones like `int` and `double`
  - Since they are objects, they can have methods
- **All** objects in C# are guaranteed to have a method named `ToString()`, whose return value (result) is a `string`
- Meaning of `ToString()` method: "Convert this object to a `string`, and return that `string`"
- This means you can call the `ToString()` method on any variable to convert it to a `string`, like this:

  ```
  int num = 42;
  double fraction = 33.5;
  string intText = num.ToString();
  string fracText = fraction.ToString();
  ```

  After executing this code, `intText` will contain the string "42", and `fracText` will contain the string "33.5"
- String interpolation calls `ToString()` on each variable or expression within braces, asking it to convert itself to a string
  - In other words, these three statements are all the same:

    ```
    Console.WriteLine($"num is {num}");
    Console.WriteLine($"num is {intText}");
    Console.WriteLine($"num is {num.ToString()}");
    ```

    Putting `num` within the braces is the same as calling `ToString()` on it.

6.2 String Concatenation

- Now that we've seen `ToString()`, we can introduce another operator: the concatenation operator
- Concatenation basics
  - Remember, the `+` operator is defined separately for each data type. The "`double + double`" operator is different from the "`int + int`" operator.
  - If the operand types are `string` (i.e. `string + string`), the `+` operator performs concatenation, not addition
  - You can concatenate `string` literals or `string` variables:

    ```
    string greeting = "Hi there, " + "John";
    string name = "Paul";
    string greeting2 = "Hi there, " + name;
    ```

    After executing this code, `greeting` will contain "Hi there, John" and `greeting2` will contain "Hi there, Paul"
- Concatenation with mixed types
  - Just like with the other operators, both operands (both sides of the `+`) must be the same type
  - If one operand is a `string` and the other is not a `string`, the `ToString()` method will automatically be called to convert it to a `string`

- Example: In this code:

```
int bananas = 42;
string text = "Bananas: " + bananas;
```

The + operator has a `string` operand and an `int` operand, so the `int` will be converted to a `string`. This means the computer will call `bananas.ToString()`, which returns the string "42". Then the `string + string` operator is called with the operands "Bananas:" and "42", which concatenates them into "Bananas: 42".

- Output with concatenation
  - We now have two different ways to construct a string for `Console.WriteLine`: Interpolation and concatenation
  - Concatenating a string with a variable will automatically call its `ToString()` method, just like interpolation will. These two `WriteLine` calls are equivalent:

```
int num = 42;
Console.WriteLine($"num is {num}");
Console.WriteLine("num is " + num);
```

  - It's usually easier to use interpolation, since when you have many variables the + signs start to add up. Compare the length of these two equivalent lines of code:

```
Console.WriteLine($"The variables are {a}, {b}, {c}, {d}, and {e}");
Console.WriteLine("The variables are " + a + ", " + b + ", " + c + ", " + d + ",
↪  and " + e);
```

  - Be careful when using concatenation with numeric variables: the meaning of + depends on the types of its two operands
    - If both operands are numbers, the + operator does addition
    - If both operands are strings, the + operator does concatenation
    - If *one* argument is a string, the other argument will be converted to a string using `ToString()`
    - Expressions in C# are always evaluated **left-to-right**, just like arithmetic
    - Therefore, in this code:

```
int var1 = 6, var2 = 7;
Console.WriteLine(var1 + var2 + " is the result");
Console.WriteLine("The result is " + var1 + var2);
```

The first `WriteLine` will display "13 is the result", because `var1` and `var2` are both `int`s, so the first + operator performs addition on two `int`s (the resulting number,13, is then converted to a `string` for the second + operator). However, the second `WriteLine` will display "The result is 67", because both + operators perform concatenation: The first one concatenates a string with `var1` to produce a string, and then the second one concatenates this string with `var2`

    - If you want to combine addition and concatenation in the same line of code, use parentheses to make the order and grouping of operations explicit. For example:

```
int var1 = 6, var2 = 7;
Console.WriteLine((var1 + var2) + " is the result");
Console.WriteLine("The result is " + (var1 + var2));
```

In this code, the parentheses ensure that `var1 + var2` is always interpreted as addition.

6.3 Reading Input from the User

- Input and output in CLI
  - Our programs use a command-line interface, where input and output come from text printed in a "terminal" or "console"
  - We've already seen that `Console.WriteLine` prints text on the screen to provide output to the user
  - The equivalent method for reading input is `Console.ReadLine()`, which waits for the user to type some text in the console and then returns it
  - In general, the `Console` class represents the command-line interface
- Using `Console.ReadLine()`
  - This method is the "inverse" of `Console.WriteLine`, and the way you use it is also the "inverse"
  - While `Console.WriteLine` takes an argument, which is the text you want to display on the screen, `Console.ReadLine()` takes no arguments because it doesn't need any input from your program – it will always do the same thing
  - `Console.WriteLine` has no "return value" - it doesn't give any output back to your program, and the only effect of calling it is that text is displayed on the screen
  - `Console.ReadLine()` does have a return value, specifically a `string`, just like `ToString()`. This means you can use the result of this method to assign a `string` variable.
  - The `string` that `Console.ReadLine()` returns is **one line of text** typed in the console. When you call it, the computer will wait for the user to type some text and then press "Enter", and everything the user typed before pressing "Enter" gets returned from `Console.ReadLine()`
  - Example usage:

```
using System;

class PersonalizedWelcomeMessage
{
  static void Main()
  {
    string firstName;
    Console.WriteLine("Enter your first name:");
    firstName = Console.ReadLine();
    Console.WriteLine($"Welcome, {firstName}!");
  }
}
```

    This program first declares a `string` variable named `firstName`. On the second line, it uses `Console.WriteLine` to display a message (instructions for the user). On the third line, it calls the `Console.ReadLine()` method, and assigns its return value (result) to the `firstName` variable. This means the program waits for the user to type some text and press "Enter", and then stores that text in `firstName`. Finally, the program uses string interpolation in `Console.WriteLine` to display a message including the contents of the `firstName` variable.

- Parsing user input
  - Casting cannot be used to convert numeric data *to or from* `string` data
  - When converting numeric data to `string` data, we use the `ToString()` method:

```
int myAge = 29;
//This does not work:
//string strAge = (string) myAge;
string strAge = myAge.ToString();
```

  - Similarly, we use a method to convert `string`s to numbers:

```
string strAge = "29";
//This does not work:
//int myAge = (int) strAge;
int myAge = int.Parse(strAge);
```

- The `int.Parse` method takes a `string` as an argument, and returns an `int` containing the numeric value written in that `string`
- Each built-in numeric type has its own `Parse` method
  - `int.Parse("42")` returns the value 42
  - `long.Parse("42")` returns the value 42L
  - `double.Parse("3.65")` returns the value 3.65
  - `float.Parse("3.65")` returns the value 3.65f
- The Parse methods are useful for converting user input to useable data. Remember, `Console.ReadLine()` will always return a `string`, even if you asked the user to enter a number.
- Example of parsing user input:

  ```
  Console.WriteLine("Please enter the year.");
  string userInput = Console.ReadLine();
  int curYear = int.Parse(userInput);
  Console.WriteLine($"Next year it will be {curYear + 1}");
  ```

  In order to do arithmetic with the user's input (i.e. add 1), it must be a numeric type (i.e. `int`), not a `string`.
- The Parse methods *assume* that the string they are given as an argument (i.e. the user input) actually contains a valid number. If not, they will make the program crash
  - If the string does not contain a number at all – e.g. `int badIdea = int.Parse("Hello");` – the program will fail with the error `System.FormatException`
  - If the string contains a number that cannot fit in the desired datatype, the program will fail with the error `System.OverflowException`. For example, `int.Parse("52.5")` will cause this error because an `int` cannot contain a fraction, and `int.Parse("3000000000")` will fail because 3000000000 is larger than $2^{31} - 1$ (the maximum value an `int` can store)

7 Classes, Objects, and UML

7.1 Class and Object Basics

- Classes vs. Objects
  - A **class** is a specification, blueprint, or template for an object; it is the code that describes what data the object stores and what it can do
  - An **object** is a single instance of a class, created using its "template." It is running code, with specific values stored in each variable
  - To **instantiate** an object is to create a new object from a class
- Object design basics
  - Objects have **attributes**: data stored in the object. This data is different in each instance, although the type of data is defined in the class.
  - Objects have **methods**: functions that use or modify the object's data. The code for these functions is defined in the class, but it is executed on (and modifies) a specific object
- Encapsulation: An important principle in class/object design
  - Attribute data is stored in **instance variables**, a special kind of variable

  - Called "instance" because each instance, i.e. object, has its own copy of them
  - **Encapsulation** means instance variables (attributes) are "hidden" inside an object: other code cannot access them directly
    * Only the object's own methods can access the instance variables
    * Other code must "ask permission" from the object in order to read or write the variables
  - **Accessor** method: a method written specifically to allow other code to access instance variables (i.e. attributes)

7.2 Writing Our First Class

- Designing the class
  - Our first class will be used to represent rectangles; each instance (object) will represent one rectangle
  - Attributes of a rectangle:
    * Length
    * Width
  - Methods that will use the rectangle's attributes
    * Get length
    * Get width
    * Set length
    * Set width
    * Compute the rectangle's area
  - Note that the first four are **accessor** methods because they allow other code to read (get) or write (set) the rectangle's instance variables

The Rectangle class:

```
class Rectangle
{
    private int length;
    private int width;

    public void SetLength(int lengthParameter)
    {
        length = lengthParameter;
    }
    public int GetLength()
    {
        return length;
    }
    public void SetWidth(int widthParameter)
    {
        width = widthParameter;
    }
    public int GetWidth()
    {
        return width;
    }
    public int ComputeArea()
    {
        return length * width;
    }
}
```

Let's look at each part of this code in order.

- Attributes
  - Each attribute (length and width) is stored in an instance variable
  - Instance variables are declared similarly to "regular" variables, but with one additional feature: the **access modifier**
  - Syntax: `[access modifier] [type] [variable name]`
  - The access modifier can be either `public` or `private`
  - An access modifier of `private` is what enforces encapsulation: when you use this access modifier, it means the instance variable cannot be accessed by any code outside the `Rectangle` class
  - The C# compiler will give you an error if you write code that attempts to use a `private` instance variable anywhere other than a method of that variable's class
- SetLength method - our first accessor method
  - This method will allow code outside the `Rectangle` class to modify a `Rectangle` object's "length" attribute
  - Note that the header of this method has an access modifier, just like the instance variable
  - In this case the access modifier is `public` because we *want* to allow other code to call the `SetLength` method
  - Syntax of a method declaration: `[access modifier] [return type] [method name]([parameters])`
  - This method has one **parameter**, named `lengthParameter`, whose type is `int`. This means the method must be called with one **argument** that is `int` type.
    - Similar to how `Console.WriteLine` must be called with one argument that is `string` type – the `Console.WriteLine` declaration has one parameter that is `string` type.
    - Note that it's declared just like a variable, with a type and a name
  - A parameter works like a variable: it has a type and a value, and you can use it in expressions and assignment
  - When you call a method with a particular argument, like 15, the parameter is assigned this value, so within the method's code you can assume the parameter value is "the argument to this method"
  - The body of the `SetLength` method has one statement, which assigns the instance variable `length` to the value contained in the parameter `lengthParameter`. In other words, whatever argument `SetLength` is called with will get assigned to `length`
  - This is why it's called a "setter": `SetLength(15)` will set `length` to 15.
- GetLength method
  - This method will allow code outside the `Rectangle` class to read the current value of a `Rectangle` object's "length" attribute
  - The **return type** of this method is `int`, which means that the value it returns to the calling code is an `int` value
  - Recall that `Console.ReadLine()` returns a `string` value to the caller, which is why you can write `string userInput = Console.ReadLine()`. The `GetLength` method will do the same thing, only with an `int` instead of a `string`
  - This method has no parameters, so you don't provide any arguments when calling it. "Getter" methods never have parameters, since their purpose is to "get" (read) a value, not change anything
  - The body of `GetLength` has one statement, which uses a new keyword: `return`. This keyword declares what will be returned by the method, i.e. what particular value will be given to the caller to use in an expression.
  - In a "getter" method, the value we return is the instance variable that corresponds to the attribute named in the method. `GetLength` returns the `length` instance variable.
- SetWidth method
  - This is another "setter" method, so it looks very similar to `SetLength`
  - It takes one parameter (`widthParameter`) and assigns it to the `width` instance variable

  - Note that the return type of both setters is `void`. The return type `void` means "this method does not return a value." `Console.WriteLine` is an example of a `void` method we've used already.
  - Since the return type is `void`, there is no `return` statement in this method

- GetWidth method
  - This is the "getter" method for the width attribute
  - It looks very similar to `GetLength`, except the instance variable in the `return` statement is `width` rather than `length`

- The ComputeArea method
  - This is *not* an accessor method: its goal is not to read or write a single instance variable
  - The goal of this method is to compute and return the rectangle's area
  - Since the area of the rectangle will be an `int` (it's the product of two `int`s), we declare the return type of the method to be `int`
  - This method has no parameters, because it doesn't need any arguments. Its only "input" is the instance variables, and it will always do the same thing every time you call it.
  - The body of the method has a `return` statement with an expression, rather than a single variable
  - When you write `return [expression]`, the expression will be evaluated first, then the resulting value will be used by the `return` command
  - In this case, the expression `length * width` will be evaluated, which computes the area of the rectangle. Since both `length` and `width` are `int`s, the `int` version of the `*` operator runs, and it produces an `int` result. This resulting `int` is what the method returns.

7.3 Using Our Class

- We've written a class, but it doesn't do anything yet
  - The class is a blueprint for an object, not an object
  - To make it "do something" (i.e. execute some methods), we need to instantiate an object using this class
  - The code that does this should be in a separate file (e.g. Program.cs), not in Rectangle.cs

- Here is a program that uses our `Rectangle` class:

```
using System;

class Program
{
    static void Main(string[] args)
    {
        Rectangle myRectangle = new Rectangle();
        myRectangle.SetLength(12);
        myRectangle.SetWidth(3);
        int area = myRectangle.ComputeArea();
        Console.WriteLine("Your rectangle's length is " +
        $"{myRectangle.GetLength()}, and its width is " +
        $"{myRectangle.GetWidth()}, so its area is {area}.");
    }
}
```

- Instantiating an object
  - The first line of code creates a `Rectangle` object
  - The left side of the = sign is a variable declaration – it declares a variable of type `Rectangle`
    - Classes we write become new data types in C#

  - The right side of the = sign assigns this variable a value: a `Rectangle` object
  - We **instantiate** an object by writing the keyword `new` followed by the name of the class (syntax: `new [class name]()`). The empty parentheses are required, but we'll explain why later.
  - This statement is really an initialization statement: It declares and assigns a variable in one line
  - The value of the `myRectangle` variable is the `Rectangle` object that was created by `new Rectangle()`

- Calling setters on the object
  - The next two lines of code call the `SetLength` and `SetWidth` methods on the object
  - Syntax: `[object name].[method name]([argument])`. Note the "dot operator" between the variable name and the method name.
  - `SetLength` is called with an argument of 12, so `lengthParameter` gets the value 12, and the rectangle's `length` instance variable is then assigned this value
  - Similarly, `SetWidth` is called with an argument of 3, so the rectangle's `width` instance variable is assigned the value 3

- Calling ComputeArea
  - The next line calls the `ComputeArea` method and assigns its result to a new variable named `area`
  - The syntax is the same as the other method calls
  - Since this method has a return value, we need to do something with the return value – we assign it to a variable
  - Similar to how you must do something with the result (return value) of `Console.ReadLine()`, i.e. `string userInput = Console.ReadLine()`

- Calling getters on the object
  - The last line of code displays some information about the rectangle object using string interpolation
  - One part of the string interpolation is the `area` variable, which we've seen before
  - The other interpolated values are `myRectangle.GetLength()` and `myRectangle.GetWidth()`
  - Looking at the first one: this will call the `GetLength` method, which has a return value that is an `int`. Instead of storing the return value in an `int` variable, we put it in the string interpolation brackets, which means it will be converted to a string using `ToString`. This means the rectangle's length will be inserted into the string and displayed on the screen

7.4 Flow of Control with Objects

- Consider what happens when you have multiple objects in the same program, like this:

```
class Program
{
    static void Main(string[] args)
    {
        Rectangle rect1;
        rect1 = new Rectangle();
        rect1.SetLength(12);
        rect1.SetWidth(3);
        Rectangle rect2 = new Rectangle();
        rect2.SetLength(7);
        rect2.SetWidth(15);
    }
}
```

  - First, we declare a variable of type `Rectangle`
  - Then we assign `rect1` a value, a new `Rectangle` object that we instantiate

  - We call the `SetLength` and `SetWidth` methods using `rect1`, and the `Rectangle` object that `rect1` refers to gets its `length` and `width` instance variables set to 12 and 3
  - Then we create another `Rectangle` object and assign it to the variable `rect2` . This object has its own copy of the `length` and `width` instance variables, not 12 and 3
  - We call the `SetLength` and `SetWidth` methods again, using `rect2` on the left side of the dot instead of `rect1`. This means the `Rectangle` object that `rect2` refers to gets its instance variables set to 7 and 15, while the other `Rectangle` remains unmodified

- The same method code can modify different objects at different times
  - Calling a method transfers control from the current line of code (i.e. in Program.cs) to the method code within the class (Rectangle.cs)
  - The method code is always the same, but the specific object that gets modified can be different each time
  - The variable on the left side of the dot operator determines which object gets modified
  - In `rect1.SetLength(12)`, `rect1` is the **calling object**, so `SetLength` will modify `rect1`
    - `SetLength` begins executing with `lengthParameter` equal to 12
    - The instance variable `length` in `length = lengthParameter` refers to `rect1`'s length
  - In `rect2.SetLength(7)`, `rect2` is the calling object, so `SetLength` will modify `rect2`
    - `SetLength` begins executing with `lengthParameter` equal to 7
    - The instance variable `length` in `length = lengthParameter` refers to `rect2`'s length

- Accessing object members
  - The "dot operator" that we use to call methods is technically the **member access operator**
  - A **member** of an object is either a method or an instance variable
  - When we write `objectName.methodName()`, e.g. `rect1.SetLength(12)`, we are using the dot operator to access the "SetLength" member of `rect1`, which is a method; this means we want to call (execute) the `SetLength` method of `rect1`
  - We can also use the dot operator to access instance variables, although we usually don't do that because of encapsulation
  - If we wrote the `Rectangle` class like this:

```
class Rectangle
{
    public int length;
    public int width;
}
```

    Then we could write a Main method that uses the dot operator to access the `length` and `width` instance variables, like this:

```
static void Main(string[] args)
{
    Rectangle rect1 = new Rectangle();
    rect1.length = 12;
    rect1.width = 3;
}
```

  But this code violates encapsulation, so we won't do this.

- Method calls in more detail
  - Now that we know about the member access operator, we can explain how method calls work a little better

- When we write `rect1.SetLength(12)`, the `SetLength` method is executed with `rect1` as the calling object – we're accessing the `SetLength` member of `rect1` in particular (even though every Rectangle has the same `SetLength` method)
- This means that when the code in `SetLength` uses an instance variable, i.e. `length`, it will automatically access `rect1`'s copy of the instance variable
- You can imagine that the `SetLength` method "changes" to this when you call `rect1.SetLength()`:

```
public void SetLength(int lengthParameter)
{
    rect1.length = lengthParameter;
}
```

Note that we use the "dot" (member access) operator on `rect1` to access its `length` instance variable.

- Similarly, you can imagine that the `SetLength` method "changes" to this when you call `rect2.SetLength()`:

```
public void SetLength(int lengthParameter)
{
    rect2.length = lengthParameter;
}
```

- The calling object is automatically "inserted" before any instance variables in a method
- The keyword `this` is an explicit reference to "the calling object"
  - Instead of imagining that the calling object's name is inserted before each instance variable, you could write the `SetLength` method like this:

```
public void SetLength(int lengthParameter)
{
    this.length = lengthParameter;
}
```

  - This is valid code (unlike our imaginary examples) and will work exactly the same as our previous way of writing `SetLength`
  - When `SetLength` is called with `rect1.SetLength(12)`, `this` becomes equal to `rect1`, just like `lengthParameter` becomes equal to 12
  - When `SetLength` is called with `rect2.SetLength(7)`, `this` becomes equal to `rect2` and `lengthParameter` becomes equal to 7

- Methods don't always change instance variables
  - Using a variable in an expression means *reading* its value
  - A variable only changes when it's on the left side of an assignment statement; this is *writing* to the variable
  - A method that uses instance variables in an expression, but doesn't assign to them, will not modify the object
  - For example, consider the `ComputeArea` method:

```
public int ComputeArea()
{
    return length * width;
}
```

It reads the current values of `length` and `width` to compute their product, but the product is returned to the method's caller. The instance variables are not changed.

- After executing the following code:

```
Rectangle rect1 = new Rectangle();
rect1.SetLength(12);
rect1.SetWidth(3);
int area = rect1.ComputeArea();
```

`rect1` has a `length` of 12 and a `width` of 3. The call to `rect1.ComputeArea()` computes $12 \cdot 3 = 36$, and the `area` variable is assigned this return value, but it does not change `rect1`.

- Methods and return values
  - Recall the basic structure of a program: receive input, compute something, produce output
  - A method has the same structure: it *receives input* from its parameters, *computes* by executing the statements in its body, then *produces output* by returning a value
    - For example, consider this method defined in the Rectangle class:

```
public int LengthProduct(int factor)
{
  return length * factor;
}
```

Its input is the parameter `factor`, which is an `int`. In the method body, it computes the product of the rectangle's length and `factor`. The method's output is the resulting product.

  - The `return` statement specifies the output of the method: a variable, expression, etc. that produces some value
  - A method call can be used in other code as if it were a value. The "value" of a method call is the method's return value.
    - In previous examples, we wrote `int area = rect1.ComputeArea();`, which assigns a variable (`area`) a value (the return value of `ComputeArea()`)
    - The `LengthProduct` method can be used like this:

```
Rectangle rect1 = new Rectangle();
rect1.SetLength(12);
int result = rect1.LengthProduct(2) + 1;
```

When executing the third line of code, the computer first runs the `LengthProduct` method with argument (input) 2, which computes the product $12 \cdot 2 = 24$. Then it uses the return value of `LengthProduct`, which is 24, to evaluate the expression `rect1.LengthProduct(2) + 1`, producing a result of 25. Finally, it assigns the value 25 to the variable `result`.

  - When writing a method that returns a value, the value in the `return` statement **must** be the same type as the method's return type
    - If the value returned by `LengthProduct` is not an `int`, we'll get a compile error
    - This won't work:

```
public int LengthProduct(double factor)
{
    return length * factor;
}
```

Now that `factor` has type `double`, the expression `length * factor` will need to implicitly convert `length` from `int` to `double` in order to make the types match. Then the product will also be a `double`, so the return value does not match the return type (`int`).

  - We could fix it by either changing the return type of the method to `double`, or adding a cast to `int` to the product so that the return value is still an `int`

- Not all methods return a value, but all methods must have a return type
  - The return type `void` means "nothing is returned"
  - If your method does not return a value, its return type *must* be `void`. If the return type is not `void`, the method *must* return a value.
  - This will cause a compile error because the method has a return type of `int` but no return statement:

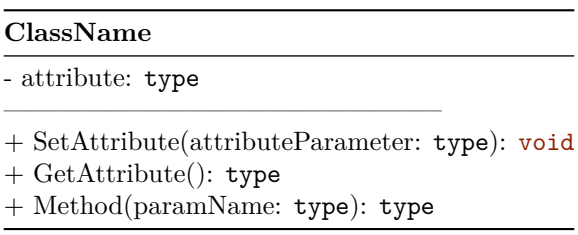
```
public int SetLength(int lengthP)
{
    length = lengthP;
}
```

  - This will cause a compile error because the method has a return type of `void`, but it attempts to return something anyway:

```
public void GetLength()
{
    return length;
}
```

7.5 Introduction to UML

- UML is a specification language for software
  - UML: Unified Modeling Language
  - Describes design and structure of a program with graphics
  - Does not include "implementation details," such as code statements
  - Can be used for any programming language, not just C#
  - Used in planning/design phase of software creation, before you start writing code
  - Process: Determine program requirements → Make UML diagrams → Write code based on UML → Test and debug program
- UML Class Diagram elements



  - Top box: Class name, centered
  - Middle box: Attributes (i.e. instance variables)
    - On each line, one attribute, with its name and type
    - Syntax: `[+/-] [name]: [type]`
    - Note this is the opposite order from C# variable declaration: type comes after name

    - Minus sign at beginning of line indicates "private member"
  - Bottom box: Operations (i.e. methods)
    - On each line, one method header, including name, parameters, and return type
    - Syntax: `[+/-] [name]([parameter name]: [parameter type]): [return type]`
    - Also backwards compared to C# order: parameter types come after parameter names, and return type comes after method name instead of before it
    - Plus sign at beginning of line indicates "public", which is what we want for methods

- UML Diagram for the Rectangle class

Rectangle
- width: `int` - length: `int`
+ SetLength(lengthParameter: `int`) + GetLength(): `int` + SetWidth(widthParameter: `int`) + GetWidth(): `int` + ComputeArea(): `int`

  - Note that when the return type of a method is `void`, we can omit it in UML
  - In general, attributes will be private (- sign) and methods will be public (+ sign), so you can expect most of your classes to follow this pattern (-s in the upper box, +s in the lower box)
  - Note that there is no code or "implementation" described here: it doesn't say that `ComputeArea` will multiply `length` by `width`

- Writing code based on a UML diagram
  - Each diagram is one class, everything within the box is between the class's header and its closing brace
  - For each attribute in the attributes section, write an instance variable of the right name and type
    - See "- width: int", write `private int width;`
    - Remember to reverse the order of name and type
  - For each method in the methods section, write a method header with the matching return type, name, and parameters
    - Parameter declarations are like the instance variables: in UML they have a name followed by a type, in C# you write the type name first
  - Now the method bodies need to be filled in - UML just defined the interface, now you need to write the implementation

7.6 Variable Scope

- Instance variables are different from local variables
  - Instance variables: Stored (in memory) with the object, shared by all methods of the object. Changes made within a method persist after method finishes executing.
  - Local variables: Visible to only one method, not shared. Disappear after method finishes executing. Variables we've created before in the Main method (they're local to the Main method!).
  - Example: In class Rectangle, we have these two methods:

```
public void SwapDimensions()
{
    int temp = length;
    length = width;
    width = temp;
}
public int GetLength()
{
    return length;
}
```

  * `temp` is a local variable within `SwapDimensions`, while `length` and `width` are instance variables
  * The `GetLength` method can't use `temp`; it is visible only to `SwapDimensions`
  * When `SwapDimensions` changes `length`, that change is persistent – it will still be different when `GetLength` executes, and the next call to `GetLength` after `SwapDimensions` will return the new length
  * When `SwapDimensions` assigns a value to `temp`, it only has that value within the current call to `SwapDimensions` – after `SwapDimensions` finishes, `temp` disappears, and the next call to `SwapDimensions` creates a new `temp`

- Each variable has a **scope**
  - Variables exist only in limited **time** and **space** within the program
  - Outside those limits, the variable cannot be accessed – e.g. local variables cannot be accessed outside their method
  - Scope of a variable: The region of the program where it is accessible/visible
    * A variable is "in scope" when it is accessible
    * A variable is "out of scope" when it doesn't exist or can't be accessed
  - Time limits to scope: Scope begins *after* the variable has been declared
    * This is why you can't use a variable before declaring it
  - Space limits to scope: Scope is within the same *code block* where the variable is declared
    * Code blocks are defined by curly braces: everything between matching `{` and `}` is in the same code block
    * Instance variables are declared in the class's code block (they are inside `class Rectangle`'s body, but not inside anything else), so their scope extends to the entire class
    * Code blocks nest: A method's code block is inside the class's code block, so instance variables are also in scope within each method's code block
    * Local variables are declared inside a method's code block, so their scope is limited to that single method
  - The scope of a parameter (which is a variable) is the method's code block - it's the same as a local variable for that method
  - Scope example:

```
public void SwapDimensions()
{
    int temp = length;
    length = width;
    width = temp;
}
public void SetWidth(int widthParam)
```

```
{
    int temp = width;
    width = widthParam;
}
```

  * The two variables named `temp` have different scopes: One has a scope limited to the `SwapDimensions` method's body, while the other has a scope limited to the `SetWidth` method's body
  * This is why they can have the same name: variable names must be unique *within the variable's scope*. You can have two variables with the same name if they are in different scopes.
  * The scope of instance variables `length` and `width` is the body of class `Rectangle`, so they are in scope for both of these methods

- Be careful when mixing instance and local variables
  - This code is legal (compiles) but doesn't do what you want:

```
class Rectangle
{
    private int length;
    private int width;
    public void UpdateWidth(int newWidth)
    {
        int width = 5;
        width = newWidth;
    }
}
```

  - The instance variable `width` and the local variable `width` have different scopes, so they can have the same name
  - But the instance variable's scope (the class `Rectangle`) *overlaps* with the local variable's scope (the method `UpdateWidth`)
  - If two variables have the same name and overlapping scopes, the variable with the *closer* or *smaller* scope **shadows** the variable with the *farther* or *wider* scope: the name will refer *only* to the variable with the smaller scope
  - In this case, that means `width` inside `UpdateWidth` refers only to the local variable named `width`, whose scope is smaller because it is limited to the `UpdateWidth` method. The line `width = newWidth` actually changes the local variable, not the instance variable named `width`.
  - Since instance variables have a large scope (the whole class), they will always get shadowed by variables declared within methods
  - You can prevent shadowing by using the keyword `this`, like this:

```
class Rectangle
{
    private int length;
    private int width;
    public void UpdateWidth(int newWidth)
    {
        int width = 5;
        this.width = newWidth;
    }
}
```

Since `this` means "the calling object", `this.width` means "access the `width` member of the calling object." This can only mean the instance variable `width`, not the local variable with the same name

– Incidentally, you can also use `this` to give your parameters the same name as the instance variables they're modifying:

```
class Rectangle
{
    private int length;
    private int width;
    public void SetWidth(int width)
    {
        this.width = width;
    }
}
```

Without `this`, the body of the `SetWidth` method would be `width = width;`, which doesn't do anything (it would assign the parameter `width` to itself).

7.7 Constants

- Classes can also contain constants
- Syntax: `[public/private] const [type] [name] = [value];`
- This is a named value that never changes during program execution
- Safe to make it `public` because it can't change – no risk of violating encapsulation
- Can only be built-in types (`int`, `double`, etc.), not objects
- Can make your program more readable by giving names to "magic numbers" that have some significance
- Convention: constants have names in ALL CAPS
- Example:

```
class Calendar
{
    public const int MONTHS = 12;
    private int currentMonth;
    //...
}
```

The value "12" has a special meaning here, i.e. the number of months in a year, so we use a constant to name it.

- Constants are accessed using the name of the class, not the name of an object – they are the same for every object of that class. For example:

```
Calendar myCal = new Calendar();
decimal yearlyPrice = 2000.0m;
decimal monthlyPrice = yearlyPrice / Calendar.MONTHS;
```

7.8 Reference Types: More Details

- Data types in C# are either value types or reference types
  - This difference was introduced in an earlier lecture (Datatypes and Variables)
  - For a **value type** variable (`int`, `long`, `float`, `double`, `decimal`, `char`, `bool`) the named memory location stores the exact data value held by the variable
  - For a **reference type** variable, such as `string`, the named memory location stores a *reference to the value*, not the value itself
  - All objects you create from your own classes, like `Rectangle`, are reference types
- Object variables are references
  - When you have a variable for a reference type, or "reference variable," you need to be careful with the assignment operation
  - Consider this code:

```
using System;
class Program
{
    static void Main(string[] args)
    {
        Rectangle rect1 = new Rectangle();
        rect1.SetLength(8);
        rect1.SetWidth(10);
        Rectangle rect2 = rect1;
        rect2.SetLength(4);
        Console.WriteLine($"Rectangle 1: {rect1.GetLength()} "
           + $"by {rect1.GetWidth()}");
        Console.WriteLine($"Rectangle 2: {rect2.GetLength()} "
           + $"by {rect2.GetWidth()}");
    }
}
```

  - The output is:

```
Rectangle 1: 4 by 10
Rectangle 2: 4 by 10
```

  - The variables `rect1` and `rect2` actually refer to the same `Rectangle` object, so `rect2.SetLength(4)` seems to change the length of "both" rectangles
  - The assignment operator copies the contents of the variable, but a reference variable contains a *reference* to an object – so that's what gets copied (in `Rectangle rect2 = rect1`), not the object itself
  - In more detail:
    - `Rectangle rect1 = new Rectangle()` creates a new Rectangle object somewhere in memory, then creates a reference variable named `rect1` somewhere else in memory. The variable named `rect1` is initialized with the memory address of the Rectangle object, i.e. a reference to the object
    - `rect1.SetLength(8)` reads the address of the Rectangle object from the `rect1` variable, finds the object in memory, and runs the `SetLength` method on that object (changing its length to 8)
    - `rect1.SetWidth(10)` does the same thing, finds the same object, and sets its width to 10
    - `Rectangle rect2 = rect1` creates a reference variable named `rect2` in memory, but does not create a new Rectangle object. Instead, it initializes `rect2` with the same memory address that is stored in `rect1`, referring to the same Rectangle object

    - `rect2.SetLength(4)` reads the address of a Rectangle object from the `rect2` variable, finds that object in memory, and sets its length to 4 – but this is the exact same Rectangle object that `rect1` refers to

- Reference types can also appear in method parameters
  - When you call a method, you provide an argument (a value) for each parameter in the method's declaration
  - Since the parameter is really a variable, the computer will then assign the argument to the parameter, just like variable assignment
    - For example, when you write `rect1.SetLength(8)`, there's an implicit assignment `lengthParameter = 8` that gets executed before executing the body of the `SetLength` method
  - This means if the parameter is a reference type (like an object), the parameter will get a copy of the reference, not a copy of the object
  - When you use the parameter to modify the object, you will modify the same object that the caller provided as an argument
  - This means objects can change other objects!
  - For example, imagine we added this method to the Rectangle class:

```
public void CopyToOther(Rectangle otherRect)
{
    otherRect.SetLength(length);
    otherRect.SetWidth(width);
}
```

    It uses the `SetLength` and `SetWidth` methods to modify its parameter, `otherRect`. Specifically, it sets the parameter's length and width to its own length and width.
  - The Main method of a program could do something like this:

```
Rectangle rect1 = new Rectangle();
Rectangle rect2 = new Rectangle();
rect1.SetLength(8);
rect1.SetWidth(10);
rect1.CopyToOther(rect2);
Console.WriteLine($"Rectangle 2: {rect2.GetLength()} "
    + $"by {rect2.GetWidth()}");
```

    - First it creates two different `Rectangle` objects (note the two calls to `new`), then it sets the length and width of one object, using `rect1.SetLength` and `rect1.SetWidth`
    - Then it calls the `CopyToOther` method with an argument of `rect2`. This transfers control to the method and (implicitly) makes the assignment `otherRect = rect2`
    - Since `otherRect` and `rect2` are now reference variables referring to the same object, the calls to `otherRect.SetLength` and `otherRect.SetWidth` within the method will modify that object
    - After the call to `CopyToOther`, the object referred to by `rect2` has a length of 8 and a width of 10, even though we never called `rect2.SetLength` or `rect2.SetWidth`

8 More Advanced Object Concepts

8.1 Default Values and the ClassRoom Class

- Instance variables get default values
  - In lab, you were asked to run a program like this:

```
using System;

class Program
{
    static void Main(string[] args)
    {
        Rectangle myRect = new Rectangle();
        Console.WriteLine($"Length is {myRect.GetLength()}");
        Console.WriteLine($"Width is {myRect.GetWidth()}");
    }
}
```

Note that we create a Rectangle object, but do not use the `SetLength` or `SetWidth` methods to assign values to its instance variables. It displays the following output:

```
Length is 0
Width is 0
```

- This works because the instance variables `length` and `width` have a default value of 0, even if you never assign them a value
- Local variables, like the ones we write in the Main method, do *not* have default values. You must assign them a value before using them in an expression.
  - For example, this code will produce a compile error:

    ```
    int myVar1;
    int myVar2 = myVar1 + 5;
    ```

    You can't assume `myVar1` will be 0; it has no value at all until you use an assignment statement.
- When you create (instantiate) a new object, its instance variables will be assigned specific default values based on their type:

Type	Default Value
Numeric types	0
`string`	`null`
objects	`null`
`bool`	`false`
`char`	`'\0'`

- Remember, `null` is the value of a reference-type variable that refers to "nothing" - it does not contain the location of any object at all. You can't do anything with a reference variable containing `null`.

- A class we'll use for subsequent examples
  - ClassRoom: Represents a room in a building on campus
  - UML Diagram:

ClassRoom
- building: `string` - number: `int`
+ SetBuilding(buildingParam : `string`)

ClassRoom
+ GetBuilding(): `string`
+ SetNumber(numberParameter: `int`)
+ GetNumber(): `int`

  * There are two attributes: the name of the building (a string) and the room number (an `int`)
  * Each attribute will have a "getter" and "setter" method

– Implementation:

```
class ClassRoom
{
    private string building;
    private int number;

    public void SetBuilding(string buildingParam)
    {
        building = buildingParam;
    }
    public string GetBuilding()
    {
        return building;
    }
    public void SetNumber(int numberParam)
    {
        number = numberParam;
    }
    public int GetNumber()
    {
        return number;
    }
}
```

  * Each attribute is implemented by an instance variable with the same name
  * To write the "setter" for the building attribute, we write a method whose return type is `void`, with a single `string`-type parameter. Its body assigns the `building` instance variable to the value in the parameter `buildingParam`
  * To write the "getter" for the building attribute, we write a method whose return type is `string`, and whose body returns the instance variable `building`

– Creating an object and using its default values:

```
using System;

class Program
{
    static void Main(string[] args)
    {
        ClassRoom english = new ClassRoom();
        Console.WriteLine($"Building is {english.GetBuilding()}");
        Console.WriteLine($"Room number is {english.GetNumber()}");
    }
}
```

This will print the following output:

```
Building is
Room number is 0
```

Remember that the default value of a `string` variable is `null`. When you use string interpolation on `null`, you get an empty string.

8.2 Constructors

- Instantiation and constructors
  - Instantiation syntax requires you to write parentheses after the name of the class, like this:
    ```
    ClassRoom english = new ClassRoom();
    ```
  - Parentheses indicate a method call, like in `Console.ReadLine()` or `english.GetBuilding()`
  - In fact, the instantiation statement `new ClassRoom()` does call a method: the **constructor**
  - Constructor: A special method used to create an object. It "sets up" a new instance by **initializing its instance variables**.
  - If you don't write a constructor in your class, C# will generate a "default" constructor for you – this is what's getting called when we write `new ClassRoom()` here
  - The default constructor initializes each instance variable to its default value – that's where default values come from
- Writing a constructor
  - Example for ClassRoom:
    ```
    public ClassRoom(string buildingParam, int numberParam)
    {
        building = buildingParam;
        number = numberParam;
    }
    ```
  - To write a constructor, write a method whose name is *exactly the same* as the class name
  - This method has *no return type*, not even `void`. It does not have a `return` statement either
  - For `ClassRoom`, this means the constructor's header starts with `public ClassRoom`
    - You can think of this method as "combining" the return type and name. The name of the method is `ClassRoom`, and its output is of type `ClassRoom`, since the return value of `new ClassRoom()` is always a `ClassRoom` object
    - You don't actually write a `return` statement, though, because `new` will always return the new object after calling the constructor
  - A custom constructor usually has parameters that correspond to the instance variables: for `ClassRoom`, it has a `string` parameter named `buildingParam`, and an `int` parameter named `numberParam`
    - Note that when we write a method with two parameters, we separate the parameters with a comma
  - The body of a constructor must assign values to **all** instance variables in the object
  - Usually this means assigning each parameter to its corresponding instance variable: initialize the instance variable to equal the parameter
    - Very similar to calling both "setters" at once
- Using a constructor
  - An instantiation statement will call a constructor for the class being instantiated
  - Arguments in parentheses must match the parameters of the constructor

- Example with the `ClassRoom` constructor:

```
using System;

class Program
{
    static void Main(string[] args)
    {
        ClassRoom csci = new ClassRoom("Allgood East", 356);
        Console.WriteLine($"Building is {csci.GetBuilding()}");
        Console.WriteLine($"Room number is {csci.GetNumber()}");
    }
}
```

This program will produce this output:

```
Building is Allgood East
Room number is 356
```

- The instantiation statement `new ClassRoom("Allgood East", 356)` first creates a new "empty" object of type `ClassRoom`, then calls the constructor to initialize it. The first argument, "Allgood East", becomes the constructor's first parameter (`buildingParam`), and the second argument, 356, becomes the constructor's second parameter (`numberParam`).
- After executing the instantiation statement, the object referred to by `csci` has its instance variables set to these values, even though we never called `SetBuilding` or `SetNumber`

- Methods with multiple parameters
  - The constructor we wrote is an example of a method with two parameters
  - The same syntax can be used for ordinary, non-constructor methods, if we need more than one input value
  - For example, we could write this method in the `Rectangle` class:

```
public void MultiplyBoth(int lengthFactor, int widthFactor)
{
    length *= lengthFactor;
    width *= widthFactor;
}
```

  - The first parameter has type `int` and is named lengthFactor. The second parameter has type `int` and is named `widthFactor`
  - You can call this method by providing two arguments, separated by a comma:

```
Rectangle myRect = new Rectangle();
myRect.SetLength(5);
myRect.SetWidth(10);
myRect.MultiplyBoth(3, 5);
```

The first argument, 3, will be assigned to the first parameter, `lengthFactor`. The second argument, 5, will be assigned to the second parameter, `widthFactor`

  - The order of the arguments matters when calling a multi-parameter method. If you write `myRect.MultiplyBoth(5, 3)`, then `lengthFactor` will be 5 and `widthFactor` will be 3.
  - The type of each argument must match the type of the corresponding parameter. For example, when you call the `ClassRoom` constructor we just wrote, the first argument must be a `string` and the second argument must be an `int`

- Writing multiple constructors
  - Remember that if you don't write a constructor, C# generates a "default" one with no parameters, so you can write `new ClassRoom()`

- Once you add a constructor to your class, C# will **not** generate a default constructor
  - This means once we write the `ClassRoom` constructor (as shown earlier), this statement will produce a compile error: `ClassRoom english = new ClassRoom();`
  - The constructor we wrote has 2 parameters, so now you always need 2 arguments to instantiate a `ClassRoom`
- If you still want the option to create an object with no arguments (i.e. `new ClassRoom()`), you must write a constructor with no parameters
- A class can have more than one constructor, so it would look like this:

```
class ClassRoom
{
    //...
    public ClassRoom(string buildingParam, int numberParam)
    {
        building = buildingParam;
        number = numberParam;
    }
    public ClassRoom()
    {
        building = null;
        number = 0;
    }
    //...
}
```

- The "no-argument" constructor must still initialize all the instance variables, even though it has no parameters
  - You can pick any "default value" you want, or use the same ones that C# would use (0 for numeric variables, `null` for object variables, etc.)
- When a class has multiple constructors, the instantiation statement must decide which constructor to call
- The instantiation statement will call the constructor whose parameters match the arguments you provide
  - For example, each of these statements will call a different constructor:

    ```
    ClassRoom csci = new ClassRoom("Allgood East", 356);
    ClassRoom english = new ClassRoom();
    ```

    The first statement calls the two-parameter constructor we wrote, since it has a `string` argument and an `int` argument (in that order), and those match the parameters (`string buildingParam, int numberParam`). The second statement calls the zero-parameter constructor since it has no arguments.
  - If the arguments don't match any constructor, it's still an error:

    ```
    ClassRoom csci = new ClassRoom(356, "Allgood East");
    ```

    This will produce a compile error, because the instantiation statement has two arguments in the order `int`, `string`, but the only constructor with two parameters needs the first parameter to be a `string`.

8.3 Writing ToString Methods

- ToString recap
  - String interpolation automatically calls the `ToString` method on each variable or value
  - `ToString` returns a string "equivalent" to the object; for example, if `num` is an `int` variable containing 42, `num.ToString()` returns "42".

  - C# datatypes already have a `ToString` method, but you need to write a `ToString` method for your own classes to use them in string interpolation

- Writing a ToString method
  - To add a `ToString` method to your class, you must write this header: `public override string ToString()`
  - The access modifier must be `public` (so other code, like string interpolation, can call it)
  - The return type must be `string` (ToString must output a string)
  - It must have no parameters (the string interpolation code won't know what arguments to supply)
  - The keyword `override` means your class is "overriding," or providing its own version of, a method that is already defined elsewhere – `ToString` is defined by the base `object` type, which is why string interpolation "knows" it can call `ToString` on any object
    - If you do not use the keyword `override`, then the pre-existing `ToString` method (defined by the base `object` type) will be used instead, which only returns the name of the class
  - The goal of ToString is to return a "string representation" of the object, so the body of the method should use all of the object's attributes and combine them into a string somehow
  - Example ToString method for `ClassRoom`:

```
public override string ToString()
{
    return building + " " + number;
}
```

    - There are two instance variables, `building` and `number`, and we use both of them
    - A natural way to write the name of a classroom is the building name followed by the room number, like "University Hall 124", so we concatenate the variables in that order
    - Note that we add a space between the variables
    - Note that `building` is already a string, but `number` is an `int`, so string concatenation will implicitly call `number.ToString()` – ToString methods can call other ToString methods
    - Another way to write the body would be `return $"{building} {number}";`

- Using a ToString method
  - Any time an object is used in string interpolation or concatenation, its ToString method will be called
  - You can also call ToString by name using the "dot operator," like any other method
  - This code will call the ToString method we just wrote for `ClassRoom`:

```
ClassRoom csci = new ClassRoom("Allgood East", 356);
Console.WriteLine(csci);
Console.WriteLine($"The classroom is {csci}");
Console.WriteLine("The classroom is " + csci.ToString());
```

8.4 Method Signatures and Overloading

- Name uniqueness in C#
  - In general, variables, methods, and classes must have unique names, but there are several exceptions
  - **Variables** can have the same name if they are in *different scopes*
    - Two methods can each have a local variable with the same name
    - A local variable (scope limited to the method) can have the same name as an instance variable (scope includes the whole class), but this will result in **shadowing**
  - **Classes** can have the same name if they are in *different namespaces*

* This is one reason C# has namespaces: you can name your classes anything you want. Otherwise, if a library (someone else's code) used a class name, you would be prevented from using that name
* For example, imagine you were using a "shapes library" that provided a class named `Rectangle`, but you also wanted to write your own class named `Rectangle`
* The library's code would use its own namespace, like this:

```
namespace ShapesLibrary
{
    class Rectangle
    {
        //instance variables, methods, etc.
    }
}
```

Then your own code could have a `Rectangle` class in your own namespace:

```
namespace MyProject
{
    class Rectangle
    {
        //instance variables, methods, etc.
    }
}
```

* You can use both `Rectangle` classes in the same code, as long as you specify the namespace, like this:

```
MyProject.Rectangle rect1 = new MyProject.Rectangle();
ShapesLibrary.Rectangle rect2 = new ShapesLibrary.Rectangle();
```

– **Methods** can have the same name if they have *different signatures*; this is called **overloading**

* We'll explain signatures in more detail in a minute
* Briefly, methods can have the same name if they have different parameters
* For example, you can have two methods named Multiply in the Rectangle class, as long as one has one parameter and the other has two parameters:

```
public void Multiply(int factor)
{
    length *= factor;
    width *= factor;
}
public void Multiply(int lengthFactor, int widthFactor)
{
    length *= lengthFactor;
    width *= widthFactor;
}
```

C# understands that these are different methods, even though they have the same name, because their parameters are different. If you write `myRect.Multiply(2)` it can only mean the first "Multiply" method, not the second one, because there is only one argument.

* We have used overloading already when we wrote multiple constructors – constructors are methods too. For example, these two constructors have the same name, but different parameters:

```
public ClassRoom(string buildingParam, int numberParam)
{
    building = buildingParam;
    number = numberParam;
}
```

```
public ClassRoom()
{
    building = null;
    number = 0;
}
```

- Method signatures
  - A method's **signature** has 3 components: its **name**, the **type** of each parameter, and the **order** the parameters appear in
  - Methods are unique if their *signatures* are unique, which is why they can have the same name
  - Signature examples:
    - `public void Multiply(int lengthFactor, int widthFactor)` – the signature is `Multiply(int, int)` (name is `Multiply`, parameters are `int` and `int` type)
    - `public void Multiply(int factor)` – signature is `Multiply(int)`
    - `public void Multiply(double factor)` – signature is `Multiply(double)`
    - These could all be in the same class since they all have different signatures
  - Parameter *names* are not part of the signature, just their types
    - Note that the parameter names are omitted when I write down the signature
    - That means these two methods are not unique and could not be in the same class:

      ```
      public void SetWidth(int widthInMeters)
      {
          //...
      }
      public void SetWidth(int widthInFeet)
      {
          //...
      }
      ```

      Both have the same signature, `SetWidth(int)`, even though the parameters have different names. You might intend the parameters to be different (i.e. represent feet vs. meters), but any `int`-type parameter is the same to C#
  - The method's return type is not part of the signature
    - So far all the examples have the same return type (`void`), but changing it would not change the signature
    - The signature of `public int Multiply(int factor)` is `Multiply(int)`, which is the same as `public void Multiply(int factor)`
    - The signature "begins" with the name of the method; everything "before" that doesn't count (i.e. `public`, `int`)
  - The order of parameters is part of the signature, as long as the types are different
    - Since parameter name is not part of the signature, only the type can determine the order
    - These two methods have different signatures:

      ```
      public int Update(int number, string name)
      {
          //...
      }
      public int Update(string name, int number)
      {
          //..
      }
      ```

      The signature of the first method is `Update(int, string)`. The signature of the second method is `Update(string, int)`.
    - These two methods have the same signature, and could not be in the same class:

```
public void Multiply(int lengthFactor, int widthFactor)
{
    //...
}
public void Multiply(int widthFactor, int lengthFactor)
{
    //...
}
```

The signature for both methods is `Multiply(int, int)`, even though we switched the order of the parameters – the name doesn't count, and they are both `int` type

- Constructors have signatures too
  - The constructor `ClassRoom(string buildingParam, int numberParam)` has the signature `ClassRoom(string, int)`
  - The constructor `ClassRoom()` has the signature `ClassRoom()`
  - Constructors all have the same name, but they are unique if their signatures (parameters) are different

- Calling overloaded methods
  - Previously, when you used the dot operator and wrote the name of a method, the name was enough to determine which method to run – `myRect.GetLength()` would call the `GetLength` method
  - When a method is overloaded, you must use the entire signature to determine which method gets executed
  - A method call has a "signature" too: the name of the method, and the type and order of the arguments
  - C# will execute the method whose signature matches the signature of the method call
  - Example: `myRect.Multiply(4);` has the signature `Multiply(int)`, so C# will look for a method in the Rectangle class that has the signature `Multiply(int)`. This matches the method `public void Multiply(int factor)`
  - Example: `myRect.Multiply(3, 5);` has the signature `Multiply(int, int)`, so C# will look for a method with that signature in the Rectangle class. This matches the method `public void Multiply(int lengthFactor, int widthFactor)`
  - The same process happens when you instantiate a class with multiple constructors: C# calls the constructor whose signature matches the signature of the instantiation
  - If no method or constructor matches the signature of the method call, you get a compile error. You still can't write `myRect.Multiply(1.5)` if there is no method whose signature is `Multiply(double)`.

8.5 Constructors in UML

- Now that we can write constructors, they should be part of the UML diagram of a class
  - No need to include the default constructor, or one you write yourself that takes no arguments
  - Non-default constructors go in the operations section (box 3) of the UML diagram
  - Similar syntax to a method: `[+/-] <<constructor>> [name]([parameter name]: [parameter type])`
  - Note that the name will always match the class name
  - No return type, ever
  - Annotation "«constructor»" is nice, but not necessary: if the method name matches the class name, it's a constructor

- Example for ClassRoom:

ClassRoom
- building: `string` - number: `int`
+ «constructor» ClassRoom(buildingParam: `string`, numberParam: `int`) + SetBuilding(buildingParam : `string`) + GetBuilding(): `string` + SetNumber(numberParameter: `int`) + GetNumber(): `int`

8.6 Properties

- Attributes are implemented with a standard "template" of code
  - Remember, "attribute" is the abstract concept of some data stored in an object; "instance variable" is the way that data is actually stored
  - First, declare an instance variable for the attribute
  - Then write a "getter" method for the instance variable
  - Then write a "setter" method for the instance variable
  - With this combination of instance variable and methods, the object has an attribute that can be read (with the getter) and written (with the setter)
  - For example, this code implements a "width" attribute for the class Rectangle:

```
class Rectangle
{
    private int width;
    public void SetWidth(int value)
    {
        width = value;
    }
    public int GetWidth()
    {
        return width;
    }
}
```

  - Note that there's a lot of repetitive or "obvious" code here:
    - The name of the attribute is intended to be "width," so you must name the instance variable `width`, and the methods `GetWidth` and `SetWidth`, repeating the name three times.
    - The attribute is intended to be type `int`, so you must ensure that the instance variable is type `int`, the getter has a return type of `int`, and the setter has a parameter type of `int`. Similarly, this repeats the data type three times.
    - You need to come up with a name for the setter's parameter, even though it also represents the width (i.e. the new value you want to assign to the width attribute). We usually end up naming it "widthParameter" or "widthParam" or "newWidth" or "newValue."
  - Properties are a "shorthand" way of writing this code: They implement an attribute with less repetition
- Writing properties
  - Declare an instance variable for the attribute, like before
  - A **property declaration** has 3 parts:
    - Header, which gives the property a name and type (very similar to variable declaration)

    - `get` section, which declares the "getter" method for the property
    - `set` section, which declares the "setter" method for the property
  - Example code, implementing the "width" attribute for Rectangle (this replaces the code in the previous example):

```
class Rectangle
{
    private int width;
    public int Width
    {
        get
        {
            return width;
        }
        set
        {
            width = value;
        }
    }
}
```

  - Header syntax: `[public/private] [type] [name]`
  - *Convention* (not rule) is to give the property the same name as the instance variable, but capitalized – C# is case sensitive
  - `get` section: Starts with the keyword `get`, then a method body inside a code block (between braces)
    - `get` is like a method header that always has the same name, and its other features are implied by the property's header
    - Access modifier: Same as the property header's, i.e. `public` in this example
    - Return type: Same as the property header's type, i.e. `int` in this example (so imagine it says `public int get()`)
    - Body of `get` section is exactly the same as body of a "getter": return the instance variable
  - `set` section: Starts with the keyword `set`, then a method body inside a code block
    - Also a method header with a fixed name, access modifier, return type, and parameter
    - Access modifier: Same as the property header's, i.e. `public` in this example
    - Return type: Always `void` (like a setter)
    - Parameter: Same type as the property header's type, name is always "value". In this case that means the parameter is `int value`; imagine the method header says `public void set(int value)`
    - Body of `set` section looks just like the body of a setter: Assign the parameter to the instance variable (and the parameter is always named "value"). In this case, that means `width = value`

- Using properties
  - Properties are members of an object, just like instance variables and methods
  - Access them with the "member access" operator, aka the dot operator
    - For example, `myRect.Width` will access the property we wrote, assuming `myRect` is a Rectangle
  - A complete example, where the "length" attribute is implemented the "old" way with a getter and setter, and the "width" attribute is implemented with a property:

```
using System;

class Program
{
```

```
    static void Main(string[] args)
    {
        Rectangle myRectangle = new Rectangle();
        myRectangle.SetLength(6);
        myRectangle.Width = 15;
        Console.WriteLine("Your rectangle's length is " +
            $"{myRectangle.GetLength()}, and " +
            $"its width is {myRectangle.Width}");
    }
}
```

  - Properties "act like" variables: you can assign to them and read from them
  - Reading from a property will *automatically* call the `get` method for that property
    * For example, `Console.WriteLine($"The width is {myRectangle.Width}");` will call the `get` section inside the `Width` property, which in turn executes `return width` and returns the current value of the instance variable
    * This is equivalent to `Console.WriteLine($"The width is {myRectangle.GetWidth()}");` using the "old" Rectangle code
  - Assigning to (writing) a property will *automatically* call the `set` method for that property, with an argument equal to the right side of the = operator
    * For example, `myRectangle.Width = 15;` will call the `set` section inside the `Width` property, with `value` equal to 15
    * This is equivalent to `myRectangle.SetWidth(15);` using the "old" Rectangle code

- Properties in UML
  - Since properties represent attributes, they go in the "attributes" box (the second box)
  - If a property will simply "get" and "set" an instance variable of the same name, you do *not* need to write the instance variable in the box
    * No need to write both the property `Width` and the instance variable `width`
  - Syntax: `[+/-] <<property>> [name]: [type]`
  - Note that the access modifier (+ or -) is for the property, not the instance variable, so it's + if the property is `public` (which it usually is)
  - Example for `Rectangle`, assuming we converted both attributes to use properties instead of getters and setters:

Rectangle
+ «property» Width: `int` + «property» Length: `int`
+ ComputeArea(): `int`

  - We no longer need to write all those setter and getter methods, since they are "built in" to the properties

9 Decisions and Decision Structures

Decisions are a constant occurence in daily life. For instance consider an instructor teaching CSCI 1301. At the beginning of class the instructor may

- Ask if there are questions. If a student has a question, then the instructor will answer it, and ask again ("Anything else?").
- When there are no more questions, the instructor will move on to the next step.
- If there is a quiz scheduled, the next step will be distributing the quiz.
- If there is no quiz scheduled or the quiz is complete (and collected), the instructor may introduce the lecture topic ("Today, we will be discussing Decisions and Decision Structures") and start the class.
- etc.

This type of "branching" between multiple choices can be represented with an activity diagram[8]:

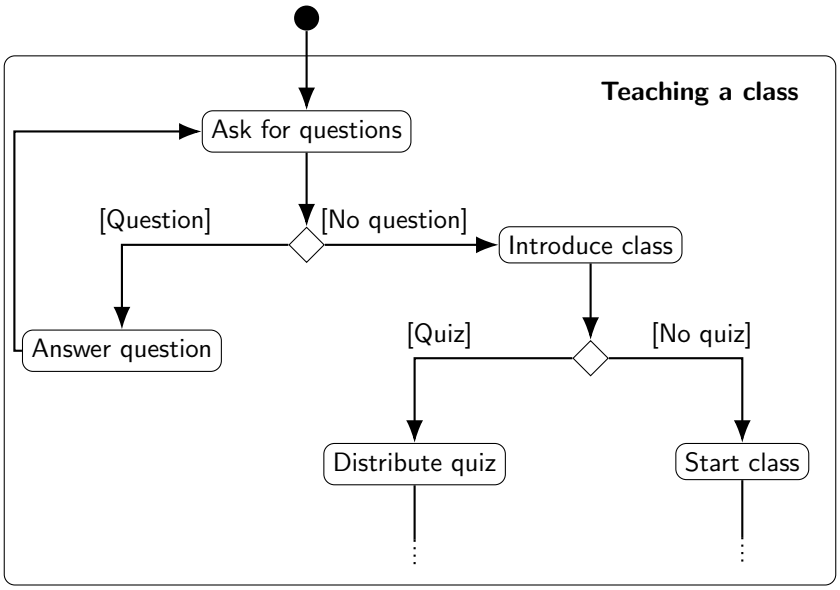


Figure 5: "An Activity Diagram on Teaching a Class"

In C#, we will express

- repetitions (or "loops") ("As long as there are questions…") with the `while`, `do…while` and `for` keywords,
- branchings ("If there is a quiz…") with the `if`, `if…else` and `switch` keywords.

Both structures need a datatype to express the result of a decision ("Is it *true* that there are questions.", or "Is it *false* that there is a quiz.") called booleans. Boolean values can be set with conditions, that can be composed in different ways using three operators ("and", "or" and "not"). For example, "If today is a Monday or Wednesday, and it is not past 10:10 am, the class will also include a brief reminder about the upcoming exam."

10 Boolean Variables and Values

10.1 Variables

We can store if something is true or false ("The user has reached the age of majority", "The switch is on", "The user is using Windows", "This computer's clock indicates that we are in the afternoon", …) in a

[8] https://en.wikipedia.org/wiki/Activity_diagram

(boolean) *flag*, which is simply a variable of type boolean. Note that `true` and `false` are the only possible two values for boolean variables: there is no third option!

We can declare, assign, initialize and display a boolean variable (flag) as with any other variable:

```
bool learning_how_to_program = true;
Console.WriteLine(learning_how_to_program);
```

10.2 Operations on Boolean Values

Boolean variables have only two possible values (`true` and `false`), but three operations to construct more complex booleans:

1. "and" (`&&`, conjunction),
2. "or" (`||`, disjunction),
3. and "not" (`!`, negation).

Each has the precise meaning described here:

1. the condition "A and B" is true if and only if A is true, and B is true,
2. "A or B" is false if and only if A is false, and B is false (that is, it takes only one to make their disjunction true),
3. "not A" is true if and only if A is false (that is, "not" "flips" the value it is applied to).

The expected results of these operations can be displayed in *truth tables*, as follows:

```
true && true    true
true && false   false
false && true   false
false && false  false
```

```
true || true    true
true || false   true
false || true   true
false || false  false
```

```
!true   false
!false  true
```

These tables can also be written in 2-dimensions, as can be seen for conjunction on wikipedia[9].

[9] https://en.wikipedia.org/wiki/Truth_table#Logical_conjunction_(AND)

11 Equality and Relational Operators

Boolean values can also be set through expressions, or tests, that "evaluate" a condition or series of conditions as `true` or `false`. For instance, you can write an expression meaning "variable `myAge` has the value 12" which will evaluate to `true` if the value of `myAge` is indeed 12, and to `false` otherwise. *To ease your understanding*, we will write "expression → `true`" to indicate that "expression" evaluates to `true` below, but this is *not* part of C#'s syntax.

Here we use two kinds of operators: - Equality operators test if two values (literal or variable) are the same. This works on all datatypes. - Relational operators test if a value (literal or variable) is greater or smaller (strictly or largely) than an other value or variable.

Relational operators will be primarily used for numerical values.

11.1 Equality Operators

In C#, we can test for equality and inequality using two operators, `==` and `!=`.

Mathematical Notation	C# Notation	Example
$=$	`==`	`3 == 4` → `false`
$\neq$	`!=`	`3!=4` → `true`

Note that testing for equality uses *two equal signs*: C# already uses a single equal sign for assignments (e.g. `myAge = 12;`), so it had to pick another notation! It is fairly common accross programing languages to use a single equal sign for assignments and double equal for comparisons.

Writing `a != b` ("`a` is not the same as `b`") is actually logically equivalent to writing `!(a == b)` ("it is not true that `a` is the same as `b`"), and both expressions are acceptable in C#.

We can test numerical values for equality, but actually any datatype can use those operators. Find below examples for `int`, `string`, `char` and `bool`:

```
int myAge = 12;
string myName = "Thomas";
char myInitial = 'T';
bool cs_major = true;
Console.WriteLine("My age is 12: " + (myAge == 12));
Console.WriteLine("My name is Bob: " + (myName == "Bob"));
Console.WriteLine("My initial is Q: " + (myInitial == 'Q'));
Console.WriteLine("My major is Computer Science: " + cs_major);
```

This program will display

```
My age is 12: True
My name is Bob: False
My initial is Q: False
My major is Computer Science: True
```

Remember that C# is case-sensitive, and that applies to the equality operators as well: for C#, the string `Thomas` is not the same as the string `thomas`. This also holds for characters like `a` versus `A`.

```
Console.WriteLine("C# is case-sensitive for string comparison: " + ("thomas" !=
 ↪  "Thomas"));
Console.WriteLine("C# is case-sensitive for character comparison: " + ('C' != 'c'));
Console.WriteLine("But C# does not care about 0 decimal values: " + (12.00 == 12));
```

This program will display:

```
C# is case-sensitive for string comparison: True
C# is case-sensitive for character comparison: True
But C# does not care about 0 decimal values: True
```

11.2 Relational Operators

We can test if a value or a variable is greater than another, using the following *relational* operators.

Mathematical Notation	C# Notation	Example
$>$	`>`	`3 > 4` → **`false`**
$<$	`<`	`3 < 4` → **`true`**
$\geq$ or $\geqslant$	`>=`	`3 >= 4` → **`false`**
$\leq$ or $\leqslant$	`<=`	`3 <= 4` → **`true`**

Relational operators can also compare `char`, but the order is a bit complex (you can find it explained, for instance, in this stack overflow answer[10]).

11.3 Precedence of Operators

All of the operators have a "precedence", which is the order in which they are evaluated. The precedence is as follows:

Operator	
`!`	is evaluated before
`*`, `/`, and `%`	which are evaluated before
`+` and `-`	which are evaluated before
`<`, `>`, `<=`, and `>=`	which are evaluated before
`==` and `!=`	which are evaluated before
`&&`	which is evaluated before
`||`	which comes last.

- Operators with higher precedence are on the left and operators with lower precedence are on the right: for instance, in an expression like `2*3+4`, `2*3` will have higher precedence than `3+4`, and thus be evaluated first: `2*3+4` is to be read as `(2*3)+4 = 6 + 4 = 10` and *not* as `2*(3+4) = 2*7 = 14`.
- Operators on the same row have equal precedence and are evaluated in the order they appear, from left to right: in `1-2+3`, `1-2` will be evaluated before `2+3`: `1-2+3` is to be read as `(1-2)+3 = -1 + 3 = 2` and *not* as `1-(2+3) = 1-5 = 4`.
- Forgetting about precendence can lead to errors that can be hard for debug: for instance, an expression such as `! 4 == 2` will give the error

[10] https://stackoverflow.com/a/14967721/

```
The `!' operator cannot be applied to operand of type `int'
```

Since `!` has a higher precendence than ==, C# first attempts to compute the result of `!4`, which corresponds to "not 4". As negation (`!`) is an operation that can be applied only to booleans, this expression does not make sense and C# reports an error. The expression can be rewritten to change the order of evaluation by using parenthesis, e.g. to write `!(4 == 2)`, which will correctly be evaluated to `true`.

12 if, if-else and if-else-if Statements

12.1 if Statements

- Introduction
  - Recall from a previous lecture (Booleans and Comparisons) that decision structures change the flow of code execution based on conditions
  - Now that we know how to write conditions in C#, we can write decision structures
  - Our first decision structure is the **if statement**, which executes a block of code *only if a condition is true*
- Example code with an if statement:

```
Console.WriteLine("Enter your age");
int age = int.Parse(Console.ReadLine());
if (age >= 18)
{
    Console.WriteLine("You can vote!");
}
Console.WriteLine("Goodbye");
```

  - After the keyword `if` is a condition, in parentheses: `age >= 18`
  - On the next line after the `if` statement, the curly brace begins a code block. The code in this block is "controlled" by the `if` statement.
  - If the condition `age >= 18` is true, the code in the block (the WriteLine statement with the text "You can vote!") gets executed, then execution proceeds to the next line (the WriteLine statement that prints "Goodbye")
  - If the condition `age >= 18` is false, the code in the block gets *skipped*, and execution proceeds directly to the line that prints "Goodbye"
  - The behavior of this program can be represented by this flowchart:
  - Example interaction 1:

```
Enter your age
20
You can vote!
Goodbye
```

    When the user enters "20", the value 20 is assigned to the `age` variable, so the condition `age >= 18` is true. This means the code inside the `if` statement's block gets executed.

  - Example interaction 2:

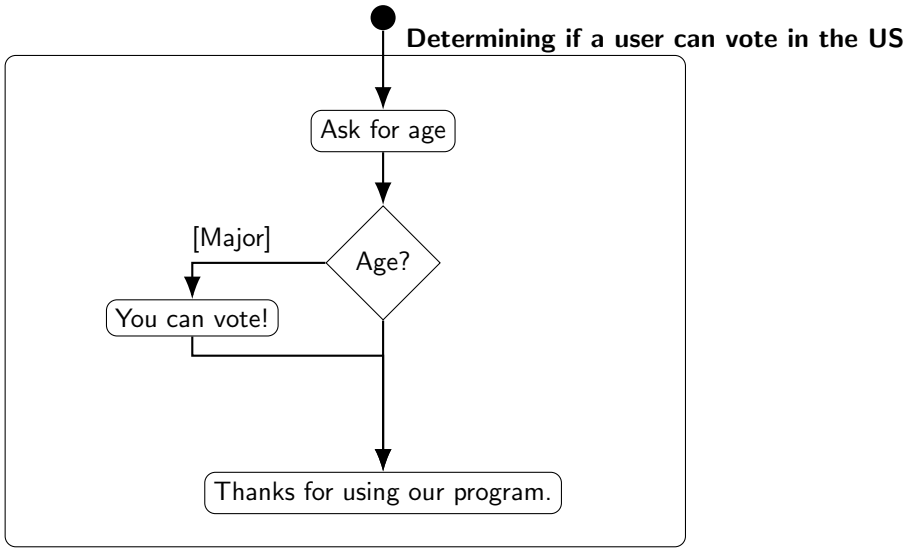


Figure 6: "A flowchart representation of an if statement"

```
Enter your age
17
Goodbye
```

When the user enters "17", the value 17 is assigned to the `age` variable, so the condition `age >= 18` is false, and the `if` statement's code block gets skipped.

- Syntax and rules for if statements
  - Formally, the syntax for an `if` statement is this:

    ```
    if (<condition>)
    {
        <statements>
    }
    ```

  - The "condition" in parentheses can be any expression that produces a `bool` value, including all of the combinations of conditions we saw in the previous lecture (Booleans and Comparisons). It can even be a `bool` variable, since a `bool` variable "contains" a `bool` value.
  - Note that there is no semicolon after the `if (<condition>)`. It's a kind of "header" for the following block of code, like a method header.
  - The statements in the code block will be executed if the condition evaluates to `true`, or skipped if it evaluates to `false`
  - If the code block contains only *one* statement, the curly braces can be omitted, producing the following syntax:

    ```
    if(<condition>)
        <statement>
    ```

    For example, the `if` statement in our previous example could be written like this, since there was only one statement in the code block:

```
if(age >= 18)
    Console.WriteLine("You can vote!");
Console.WriteLine("Goodbye");
```

  - Omitting the curly braces is slightly dangerous, though, because it makes it less obvious which line of code is controlled by the `if` statement. It is up to you, the programmer, to remember to indent the line after the `if` statement, and then de-indent the line after that; indentation is just a convention. Curly braces make it easier to see where the `if` statement starts and ends.

12.2 if-else Statements

- Introductory example:

```
if(age >= 18)
{
    Console.WriteLine("You can vote!");
}
else
{
    Console.WriteLine("You are too young to vote");
}
Console.WriteLine("Goodbye");
```

  - The **if-else statement** is a decision structure that chooses *which* block of code to execute, based on whether a condition is true or false
  - In this example, the condition is `age >= 18` again
  - The first block of code (underneath the `if`) will be executed if the statement is true – the console will display "You can vote!"
  - The *second* block of code, which comes after the keyword `else`, will be executed if the statement is *false* – so if the user's age is less than 18, the console will display "You are too young to vote"
  - Only one of these blocks of code will be executed; the other will be skipped
  - After executing one of the two code blocks, execution continues at the next line after the `else` block, so in either case the console will next display "Goodbye"
  - The behavior of this program can be represented by this flowchart:

    "A flowchart representation of an if-else statement"

- Syntax and comparison
  - Formally, the syntax for an `if-else` statement is this:

```
if (<condition>)
{
    <statement block 1>
}
else
{
    <statement block 2>
}
```

  - As with the `if` statement, the condition can be anything that produces a `bool` value
  - Note that there is no semicolon after the `else` keyword

- If the condition is true, the code in statement block 1 is executed (this is sometimes called the "if block"), and statement block 2 is skipped
- If the condition is false, the code in statement block 2 is executed (this is sometimes called the "else block"), and statement block 1 is skipped
- This is very similar to an if statement; the difference is what happens if the condition is false
  - With an `if` statement, the "if block" is executed if the condition is true, but *nothing happens* if the condition is false.
  - With an `if-else` statement, the code in the "else block" is executed if the condition is false, so something always happens - one of the two code blocks will get executed

12.3 Nested if-else Statements

- Decisions with more complex conditions
  - If-else statements are used to change program flow based on a condition; they represent making a decision
  - Sometimes decisions are more complex than a single yes/no question: once you know whether a certain condition is true or false, you then need to ask another question (check another condition) based on the outcome
  - For example, we could improve our voting program to ask the user whether he/she is a US citizen, as well as his/her age. This means there are two conditions to evaluate, as shown in this flowchart:
    - First, the program should test whether the user is a citizen. If not, there is no need to check the user's age, since he/she can't vote anyway
    - If the user is a citizen, the program should then test whether the user is over 18 to determine if he/she is old enough to vote.
- Using nested if statements
  - An `if` statement's code block can contain any kind of statements, including another `if` statement
  - Putting an `if` statement inside an if block represents making a sequence of decisions - once execution has reached the inside of an if block, your program "knows" that the `if` condition is true, so it can proceed to make the next decision
  - For the voting example, we can implement the decision structure from the flowchart above with this code, assuming `age` is an `int` and `usCitizen` is a `bool`:

```
if(usCitizen == true)
{
    if(age >= 18)
    {
        Console.WriteLine("You can vote!");
    }
    else
    {
      Console.WriteLine("You are too young to vote");
    }
}
else
{
    Console.WriteLine("Sorry, only citizens can vote");
}
Console.WriteLine("Goodbye");
```

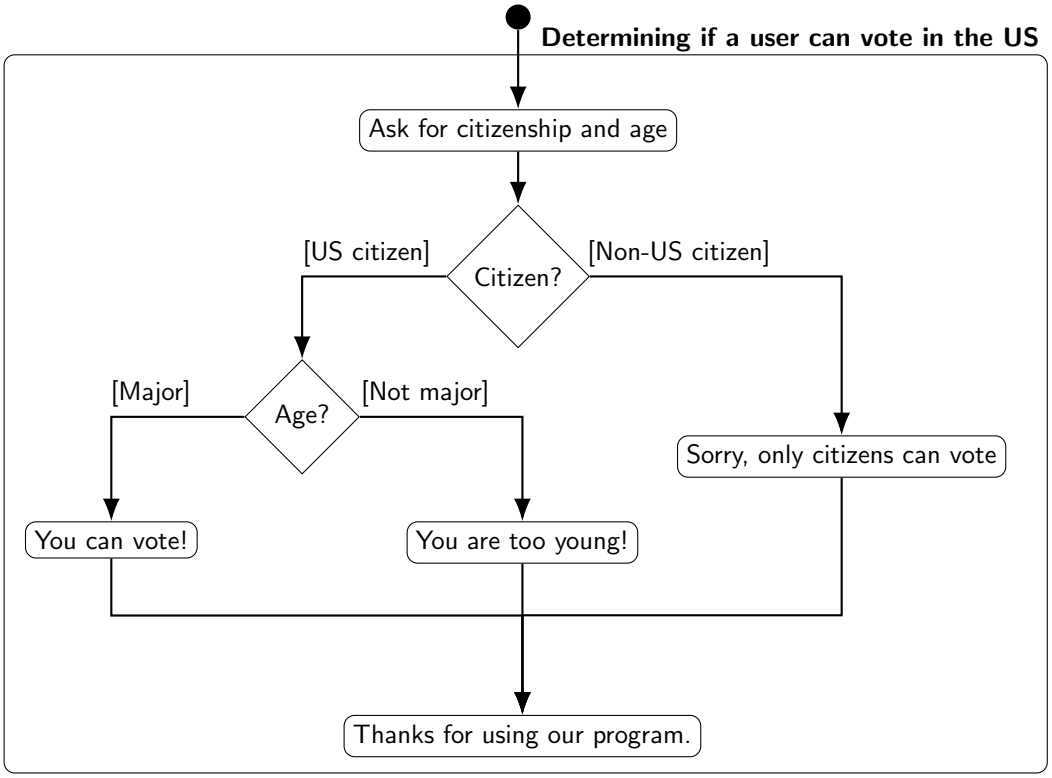


Figure 7: "A flowchart representation of the nested if-else statement"

    - First, the program tests the condition `usCitizen == true`, and if it is true, the code in the first "if block" is executed
    - Within this if block is another `if` statement that tests the condition `age >= 18`. This represents checking the user's age after determining that he/she is a US citizen - execution only reaches this second `if` statement if the first one evaluated to true. So "You can vote" is printed if both `usCitizen == true` and `age >= 18`
    - If the condition `usCitizen == true` is false, the if block is skipped and the else block is executed instead, so the entire inner `if` statement is never executed – the user's age doesn't matter if he/she isn't a citizen
    - Note that the condition `usCitizen == true` could also be expressed by just writing the name of the variable `usCitizen` (i.e. the if statement would be `if(usCitizen)`), because `usCitizen` is a `bool` variable. We don't need the equality comparison operator to test if it is `true`, because an `if` statement already tests whether its condition is `true` (and a `bool` variable by itself is a valid condition)
    - Note that indentation helps you match up an `else` block to its corresponding `if` block. The meaning of `else` depends on which `if` statement it goes with: the "outer" `else` will be executed if the condition `usCitizen == true` is false, while the "inner" `else` will be executed if the condition `age >= 18` is false.
  - Nested `if` statements don't need to be the *only* code in the if block; you can still write other statements before or after the nested `if`
  - For example, we could change our voting program so that it only asks for the user's age if he/she is a citizen:

```
if(usCitizen == true)
{
    Console.WriteLine("Enter your age");
    int age = int.Parse(Console.ReadLine());
    if(age >= 18)
    {
        Console.WriteLine("You can vote!");
    }
    else
    {
      Console.WriteLine("You are too young to vote");
    }
}
else
{
    Console.WriteLine("Sorry, only citizens can vote");
}
Console.WriteLine("Goodbye");
```

12.4 if-else-if Statements

- Mutually exclusive conditions
  - Sometimes your program needs to test multiple conditions at once, and take different actions depending on which one is true
  - Example: We want to write a program that tells the user which floor a `ClassRoom` object is on, based on its room number
    - If the room number is between 100 and 200 it's on the first floor; if it's between 200 and 300 it's on the second floor; if it's greater than 300 it's on the third floor
  - There are 3 ranges of numbers to test, and 3 possible results, so we can't do it with a single if-else statement

- If-else-if syntax
  - An if-else-if statement looks like this:

```
if(<condition 1>)
{
    <statement block 1>
}
else if(<condition 2>)
{
    <statement block 2>
}
else if(<condition 3>)
{
    <statement block 3>
}
else
{
    <statement block 4>
}
```

  - Unlike an `if` statement, there are multiple conditions
  - They are evaluated *in order*, top to bottom
  - Just like with `if-else`, exactly one block of code will get executed
  - If condition 1 is true, statement block 1 is executed, and everything else is skipped
  - If condition 1 is false, statement block 1 is skipped, and execution proceeds to the first `else if` line; condition 2 is then evaluated
  - If condition 2 is true, statement block 2 is executed, and everything else is skipped
    - Thus, statement block 2 is only executed if condition 1 is false *and* condition 2 is true
  - Same process repeats for condition 3: If condition 2 is false, condition 3 is evaluated, and statement block 3 is either executed or skipped
  - If *all* the conditions are false, the final else block (statement block 4) is executed
- Using if-else-if to solve the "floors problem"
  - Assuming `myRoom` is a `ClassRoom` object, this code will display which floor it is on:

```
if(myRoom.GetNumber() >= 300)
{
    Console.WriteLine("Third floor");
}
else if(myRoom.GetNumber() >= 200)
{
    Console.WriteLine("Second floor");
}
else if(myRoom.GetNumber() >= 100)
{
    Console.WriteLine("First floor");
}
else
{
```

```
    Console.WriteLine("Invalid room number");
}
```

- If the room number 300 or greater (e.g. 365), the first "if" block is executed, and the rest are skipped. The program prints "Third floor"
- If the room number is less than 300, the program continues to the line `else if(myRoom.GetNumber() >= 200)` and evaluates the condition
- If `myRoom.GetNumber() >= 200` is true, it means the room number is between 200 and 299, and the program will print "Second floor." Even though the condition only tests whether the room number is >= 200, this condition is only evaluated if the first one was false, so we know the room number must be < 300.
- If the second condition is false, the program continues to the line `else if(myRoom.GetNumber() >= 100)`, evaluates the condition, and prints "First floor" if it is true.
- Again, the condition `myRoom.GetNumber() >= 100` is only evaluated if the first two conditions have already been tested and turned out false, so we know the room number is less than 300 and less than 200.
- In the final `else` block, the program prints "Invalid room number" because this block is only executed if the room number is less than 100 (all three conditions were false).

- if-else-if with different conditions
  - We often use if-else-if statements to test the same variable multiple times, but there is no requirement for the conditions to use the same variable
  - An if-else-if statement can use several different variables, and its conditions can be completely unrelated, like this:

```
int x;
if(myIntVar > 12)
{
    x = 10;
}
else if(myStringVar == "Yes")
{
    x = 20;
}
else if(myBoolVar)
{
    x = 30;
}
else
{
    x = 40;
}
```

  - Note that the order of the else-if statements still matters, because they are evaluated top-to-bottom. If `myIntVar` is 15, it doesn't matter what values `myStringVar` or `myBoolVar` have, because the first if block (setting `x` to 10) will get executed.
  - Example outcomes of running this code (which value `x` is assigned) based on the values of `myIntVar`, `myStringVar`, and `myBoolVar`:

myIntVar	myStringVar	myBoolVar	x
12	"Yes"	`true`	20
15	"Yes"	`false`	10
-15	"yes"	`true`	30
10	"yes"	`false`	40

- if-else-if vs. nested if
  - Sometimes a nested `if` statement can be rewritten as an `if-else-if` statement
  - This reduces the amount of indentation in your code, which makes it easier to read
  - To convert a nested `if` statement to `if-else-if`, you'll need to combine the conditions of the "outer" and "inner" `if` statements, using the logical operators
  - A nested `if` statement inside an `if` block is testing whether the outer `if`'s condition is true *and* its own condition is true, so combine them with the `&&` operator
  - The `else` block of the inner `if` statement can be rewritten as an `else if` by combining the outer `if`'s condition with the *opposite* of the inner `if`'s condition, since "else" means "the condition is false." We need to explicitly write down the "false condition" that is normally implied by `else`.
  - For example, we can rewrite this nested `if` statement:

```
if(usCitizen == true)
{
    if(age >= 18)
    {
        Console.WriteLine("You can vote!");
    }
    else
    {
      Console.WriteLine("You are too young to vote");
    }
}
else
{
    Console.WriteLine("Sorry, only citizens can vote");
}
```

    as this `if-else-if` statement:

```
if(usCitizen == true && age >= 18)
{
    Console.WriteLine("You can vote!");
}
else if(usCitizen == true && age < 18)
{
    Console.WriteLine("You are too young to vote");
}
else
{
    Console.WriteLine("Sorry, only citizens can vote");
}
```

- Note that the `else` from the inner if statement becomes `else if(usCitizen == true && age < 18)` because we combined the outer if condition (`usCitizen == true`) with the opposite of the inner if condition (`age >= 18`).
- Not all nested `if` statements can be rewritten this way. If there is additional code in a block, other than the nested `if` statement, it's harder to convert it to an if-else-if
- For example, in this nested `if` statement:

```
if(usCitizen == true)
{
    Console.WriteLine("Enter your age");
    int age = int.Parse(Console.ReadLine());
    if(age >= 18)
    {
        Console.WriteLine("You can vote!");
    }
    else
    {
      Console.WriteLine("You are too young to vote");
    }
}
else
{
    Console.WriteLine("Sorry, only citizens can vote");
}
Console.WriteLine("Goodbye");
```

  the code that asks for the user's age executes after the outer `if` condition is determined to be true, but before the inner `if` condition is tested. There would be nowhere to put this code if we tried to convert it to an if-else-if statement, since both conditions must be tested at the same time (in `if(usCitizen == true && age >= 18)`).
- On the other hand, any if-else-if statement can be rewritten as a nested `if` statement
- To convert an if-else-if statement to a nested `if` statement, rewrite each `else if` as an `else` block with a nested `if` statement inside it – like you're splitting the "if" from the "else"
- This results in a lot of indenting if there are many `else if` lines, since each one becomes another nested `if` inside an `else` block
- For example, the "floors problem" could be rewritten like this:

```
if(myRoom.GetNumber() >= 300)
{
    Console.WriteLine("Third floor");
}
else
{
    if(myRoom.GetNumber() >= 200)
    {
        Console.WriteLine("Second floor");
    }
    else
    {
        if(myRoom.GetNumber() >= 100)
        {
            Console.WriteLine("First floor");
```

```
        }
        else
        {
            Console.WriteLine("Invalid room number");
        }
    }
}
```

13 Switch Statements and the Conditional Operator

13.1 Switch Statements

- Introduction: Multiple equality comparisons
  - In some situations, your program will need to test if a variable is equal to one of several values, and perform a different action based on which value the variable matches
  - For example, you have an `int` variable named `month` containing a month number, and want to convert it to a `string` with the name of the month. This means your program needs to take a different action depending on whether `month` is equal to 1, 2, 3, … or 12:

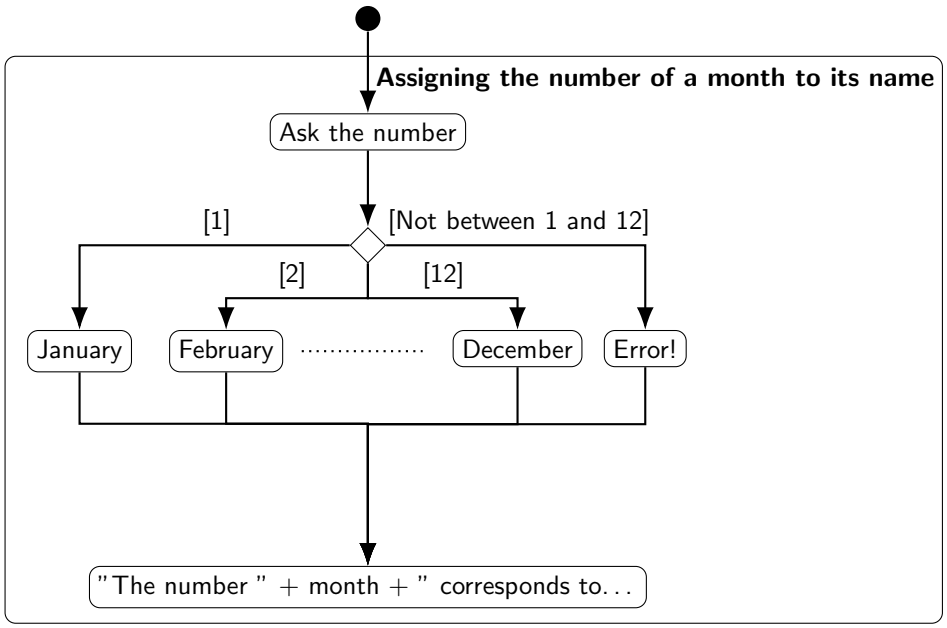


Figure 8: "A flowchart representation of the mapping between month number and name"

  - One way to do this is with a series of `if-else-if` statements, one for each possible value, like this:

```
Console.WriteLine("Enter the month as a number between 1 and 12.");
int month = int.Parse(Console.ReadLine());
string monthName;
if(month == 1)
```

```
{
    monthName = "January";
}
else if(month == 2)
{
    monthName = "February";
}
else if(month == 3)
{
    monthName = "March";
}
else if(month == 4)
{
    monthName = "April";
}
else if(month == 5)
{
    monthName = "May";
}
else if(month == 6)
{
    monthName = "June";
}
else if(month == 7)
{
    monthName = "July";
}
else if(month == 8)
{
    monthName = "August";
}
else if(month == 9)
{
    monthName = "September";
}
else if(month == 10)
{
    monthName = "October";
}
else if(month == 11)
{
    monthName = "November";
}
else if(month == 12)
{
    monthName = "December";
}
else
{
    monthName = "Invalid month"
}
Console.WriteLine("The number " + month + " corresponds to the month " +
 ↪  monthName + ".")
```

- This code is very repetitive, though: every `else if` statement is almost the same, with only the number changing. The text "`if(month ==`" is copied over and over again.

- Syntax for `switch` statements
  - A `switch` statement is a simpler, easier way to compare a single variable against multiple possible values
  - It is written like this:

```
switch (<variable name>)
{
    case <value 1>:
        <statement block 1>
        break;
    case <value 2>:
        <statement block 2>
        break;
    …
    default:
        <statement block n>
        break;
}
```

  - First, the "header" of the `switch` statement names the variable that will be compared
  - The "body" of the switch statement is enclosed in curly braces, and contains multiple `case` statements
  - Each `case` statement gives a possible value the variable could have, and a block of statements to execute if the variable equals that value. Statement block 1 is executed if the variable is equal to value 1, statement block 2 is executed if the variable is equal to value 2, etc.
  - The statement "block" within each `case` is **not** enclosed in curly braces, unlike `if` and `else if` blocks. Instead, it begins on the line after the `case` statement, and ends with the keyword `break`.
  - The `default` statement is like the `else` statement: It defines code that gets executed if the variable does not match any of the values in the `case` statements.
  - The values in each `case` statement must be **literals**, not variables, and they must be **unique** (you can't write two `case` statements with the same value)

- Example `switch` statement
  - This program has the same behavior as our previous example, but uses a `switch` statement instaed of an `if-else-if` statement:

```
Console.WriteLine("Enter the month as a number between 1 and 12.");
int month = int.Parse(Console.ReadLine());
string monthName;
switch(month)
{
    case 1:
        monthName = "January";
        break;
    case 2:
        monthName = "February";
        break;
    case 3:
        monthName = "March";
```

```
            break;
        case 4:
            monthName = "April";
            break;
        case 5:
           monthName = "May";
           break;
        case 6:
            monthName = "June";
            break;
        case 7:
            monthName = "July";
            break;
        case 8:
            monthName = "August";
            break;
        case 9:
            monthName = "September";
            break;
        case 10:
            monthName = "October";
            break;
        case 11:
            monthName = "November";
            break;
        case 12:
            monthName = "December";
            break;
        default:
            monthName = "Invalid month"
            break;
    }
    Console.WriteLine("The number " + month + " corresponds to the month " +
     ↪  monthName + ".")
```

  - Since the variable in the `switch` statement is `month`, each `case` statement means, effectively, `if (month == <value>)`. For example, `case 1:` has the same effect as `if (month == 1)`
  - The values in each `case` statement must be `int` literals, since `month` is an `int`
  - The `default` statement has the same effect as the final `else` in the `if-else-if` statement: it contains code that will be executed if `month` didn't match any of the values

- `switch` with multiple statements
  - So far, our examples have used only one line of code in each `case`
  - Unlike `if-else`, you do not need curly braces to put multiple lines of code in a `case`
  - For example, imagine our "months" program needed to convert a month number to both a month name and a three-letter abbreviation. The `switch` would look like this:

```
string monthName;
string monthAbbrev;
switch(month)
{
    case 1:
```

```
            monthName = "January";
            monthAbbrev = "Jan";
            break;
        case 2:
            monthName = "February";
            monthAbbrev = "Feb";
            break;
        // and so on, with all the other months...
    }
```

  - The computer knows which statements are included in each case because of the `break` keyword. For the "1" case, the block of statements starts after `case 1:` and ends with the `break;` after `monthAbbrev = "Jan";`

- The importance of `break`
  - The curly braces in an `if` statement *must* be matched up because this is a rule in C#; you will get a compile error if you forget the `}`
  - There is *not* a rule stating that each `case` must have a matching `break`, so if you forget the `break`, the compiler will not give you an error – but your program might not behave the way you want
  - The `case` statement only defines where code execution *starts* when the variable matches a value, not where it *ends*. The `break` statement is what defines where code execution stops after a `case` is matched.
  - Thus, if your "case block" does not end with `break`, the computer will continue executing code within the `switch`, and proceed to the next case's statements. This behavior is called **fall-through**.
  - For example, imagine you forgot to write `break` at the end of the first "case block" in the months program:

    ```
    switch(month)
    {
        case 1:
            monthName = "January";
        case 2:
            monthName = "February";
            break;
        //...
    }
    ```

    When this program executes, if `month` is equal to 1, this is what will happen:

    * When the computer encounters `switch(month)`, it compares `month` to each value in a `case`
    * Since `month == 1`, the computer starts executing code at the line `case 1:`
    * `monthName` gets assigned the value "January"
    * The computer continues past the line `case 2:` without doing anything, since the `switch` comparison has already been done
    * The computer executes `monthName = "February";` and `monthName` gets assigned the value "February"
    * The computer encounters a `break;` statement and stops executing code from the `switch`. It skips to the closing `}` for the `switch` and continues with the next line of code after that.

    As a result, `monthName` will end up with the value "February" even though `month` was equal to 1.

- Intentionally omitting `break`

– It's not always a mistake to write a `case` without a matching `break`

– If there is more than one value that should have the same behavior (i.e. you would write an `if` condition with an `||`, like `if(x == 1 || x == 2)`), you can "combine" multiple cases by omitting the `break` between them

– In a switch statement with this structure:

```
switch(<variable>)
{
    case <value 1>:
    case <value 2>:
        <statement block 1>
        break;
    case <value 3>:
    case <value 4>:
        <statement block 2>
        break;
    default:
        <statement block 3>
        break;
}
```

The statements in block 1 will execute if the variable matches value 1 *or* value 2, and the statements in block 2 will execute if the variable matches value 3 *or* value 4.

– For example, imagine our program needs to tell the user which season the month is in. If the month number is 1, 2, or 3, the season is the same (winter), so we can combine these 3 cases. This code will correctly initialize the string `season`:

```
switch(month)
{
    case 1:
    case 2:
    case 3:
        season = "Winter";
        break;
    case 4:
    case 5:
    case 6:
        season = "Spring";
        break;
    case 7:
    case 8:
    case 9:
        season = "Summer";
        break;
    case 10:
    case 11:
    case 12:
        season = "Fall";
        break;
    default:
        season = "Error!"
        break;
}
```

If `month` is equal to 1, execution will start at `case 1:`, but the computer will continue past `case 2` and `case 3` and execute `season = "Winter"`. It will then stop when it reaches the `break`, so `season` gets the value "Winter".

- Scope and `switch`
  - In C#, the scope of a variable is defined by curly braces (recall that local variables defined in a method have a scope that ends with the `}` at the end of the method)
  - Since the `case` statements in a `switch` do not have curly braces, they are all in the same scope: the one defined by the `switch` statement's curly braces
  - This means you cannot declare a "local" variable within a `case` statement – it will be in scope (visible) to all the other `case` statements
  - For example, imagine you wanted to use a local variable named `nextMonth` to do some local computation within each case in the "months" program. This code will not work:

```
switch(month)
{
    case 1:
        int nextMonth = 2;
        monthName = "January";
        // do something with nextMonth...
        break;
    case 2:
        int nextMonth = 3;
        monthName = "February";
        // do something with nextMonth...
        break;
    //...
}
```

    The line `int nextMonth = 3` would cause a compile error because a variable named `nextMonth` already exists – the one declared within `case 1`.

- Limitations of `switch`
  - Not all `if-else-if` statements can be rewritten as `switch` statements
  - `switch` can only test equality, so in general, only `if` statements whose condition uses `==` can be converted to `switch`
  - For example, imagine we have a program that determines how much of a fee to charge a rental car customer based on the number of miles the car was driven. A variable named `mileage` contains the number of miles driven, and it is used in this `if-else-if` statement:

```
decimal fee = 0;
if(mileage > 1000)
{
    fee = 50.0M;
}
else if(mileage > 500)
{
    fee = 25.0M;
}
```

  - This `if-else-if` statement could not be converted to `switch(mileage)` because of the condition `mileage > 1000`. The `switch` statement would need to have a `case` for each number greater than 1000, which is infinitely many.

13.2 The Conditional Operator

- Assignment and `if` statements
  - There are many situations where we need to assign a variable to a different value depending on the result of a condition
  - For example, the `if-else-if` and `switch` statements in the previous section were used to decide which value to assign to the variable `monthName`
  - A simpler example: Imagine your program needs to tell the user whether a number is even or odd. You need to initialize a `string` variable to either "Even" or "Odd" depending on whether `myInt % 2` is equal to 0. We could write an `if` statement to do this:

```
string output;
if(myInt % 2 == 0)
{
    output = "Even";
}
else
{
    output = "Odd";
}
```

- Assignment with the conditional operator
  - If the only thing an `if` statement does is assign a value to a variable, there's a much shorter way to write it
  - The **conditional operator** `?:` tests a condition, and then outputs one of two values based on the result
  - Continuing the "even or odd" example, the conditional operator is used like this:

```
string output = (myInt % 2 == 0) ? "Even" : "Odd";
```

    When this line of code is executed:

    * The condition `(myInt % 2 == 0)` is evaluated, and the result is either true or false
    * If the condition is true, the conditional operator returns (outputs) the value `"Even"` (the left side of the `:`)
    * If the condition is false, the operator returns the value `"Odd"` (the right side of the `:`)
    * This value, either "Even" or "Odd", is used in the initialization statement for `string output`
    * Thus, `output` gets assigned the value `"Even"` if `(myInt % 2 == 0)` is true, or `"Odd"` if `(myInt % 2 == 0)` is false

  - In general, the syntax for the conditional operator is:

```
condition ? true_expression : false_expression;
```

    * The "condition" can be any expression that produces a `bool` when evaluated, just like in an `if` statement
    * `true_expression` and `false_expression` can be variables, values, or more complex expressions, but they must both produce the same *type* of data when evaluated
    * For example, if `true_expression` is `myInt * 1.5`, then `false_expression` must also produce a `double`
    * When the conditional operator is evaluated, it returns either the value of `true_expression` or the value of `false_expression` (depending on the condition) and this value can then be used in other operations such as assignment

- Conditional operator examples
  - The `true_expression` and `false_expression` can both be mathematical expressions, and only one of them will get computed. For example:

    ```
    int answer = (myInt % 2 == 0) ? myInt / 2 : myInt + 1;
    ```

    If `myInt` is even, the computer will evaluate `myInt / 2` and assign the result to `answer`. If it is odd, the computer will evaluate `myInt + 1` and assign the result to `answer`.
  - Conditional operators can be used with user input to quickly provide a "default value" if the user's input is invalid. For example, we can write a program that asks the user their height, but uses a default value of 0 if the user enters a negative height:

    ```
    Console.WriteLine("What is your height in meters?");
    double userHeight = double.Parse(Console.ReadLine());
    double height = (userHeight >= 0.0) ? userHeight : 0.0;
    ```
  - The condition can be a Boolean variable by itself, just like in an if statement. This allows you to write code that looks kind of like English, due to the question mark in the conditional operator. For example,

    ```
    bool isAdult = age >= 18;
    decimal price = isAdult ? 5.0m : 2.5m;
    string closingTime = isAdult ? "10:00 pm" : "8:00 pm";
    ```

14 Loops, Increment Operators, and Input Validation

14.1 The -- and ++ Operators

- Increment and decrement basics
  - In C#, we have already seen multiple ways to add 1 to a numeric variable:

    ```
    int myVar = 1;
    myVar = myVar + 1;
    myVar += 1
    ```

    These two lines of code have the same effect; the += operator is "shorthand" for "add and assign"
  - The **increment operator**, ++, is an even shorter way to add 1 to a variable. It can be used in two ways:

    ```
    myVar++;
    ++myVar;
    ```
  - Writing ++ after the name of the variable is called a **postfix increment**, while writing ++ before the name of the variable is called a **prefix increment**. They both have the same effect on the variable: its value increases by 1.
  - Similarly, there are multiple ways to subtract 1 from a numeric variable:

    ```
    int myVar = 10;
    myVar = myVar - 1;
    myVar -= 1;
    ```
  - The **decrement operator**, --, is a shortcut for subtracting 1 from a variable, and is used just like the increment operator:

```
myVar--;
--myVar;
```

  - To summarize, the increment and decrement operators both have a prefix and postfix version:

	Increment	Decrement
Postfix	`myVar++`	`myVar--`
Prefix	`++myVar`	`--myVar`

- Difference between prefix and postfix
  - The prefix and postfix versions of the increment and decrement operators both have the same effect on the variable: Its value increases or decreases by 1
  - The difference between prefix and postfix is whether the "old" or "new" value of the variable is *returned* by the expression
  - With postfix increment/decrement, the operator returns the value of the variable, *then* increases/decreases it by 1
    - This means the value of the increment/decrement expression is the *old* value of the variable, before it was incremented/decremented
    - Consider this example:

```
int a = 1;
Console.WriteLine(a++);
Console.WriteLine(a--);
```

    - The expression `a++` returns the current value of `a`, which is 1, to be used in Console.WriteLine. *Then* it increments `a` by 1, giving it a new value of 2. Thus, the first Console.WriteLine displays "1" on the screen.
    - The expression `a--` returns the current value of `a`, which is 2, to be used in Console.WriteLine, and *then* decrements `a` by 1. Thus, the second Console.WriteLine displays "2" on the screen.
  - With prefix increment/decrement, the operator increases/decreases the value of the variable by 1, *then* returns its value
    - This means the value of the increment/decrement expression is the *new* value of the variable, after the increment/decrement
    - Consider the same code, but with prefix instead of postfix operators:

```
int a = 1;
Console.WriteLine(++a);
Console.WriteLine(--a);
```

    - The expression `++a` increments `a` by 1, then returns the value of `a` for use in Console.WriteLine. Thus, the first Console.WriteLine displays "2" on the screen.
    - The expression `--a` decrements `a` by 1, then returns the value of `a` for use in Console.WriteLine. Thus, the second Console.WriteLine displays "1" on the screen.
- Using increment/decrement in expressions
  - The `++` and `--` operators have higher precedence than the other math operators, so if you use them in an expression they will get executed first

- The "result" of the operator, i.e. the value that will be used in the rest of the math expression, depends on whether it is the prefix or postfix increment/decrement operator: The prefix operator returns the variable's new value, while the postfix operator returns the variable's old value
- Consider these examples:

```
int a = 1;
int b = a++;
int c = ++a * 2 + 4;
int d = a-- + 1;
```

- The variable `b` gets the value 1, because `a++` returns the "old" value of `a` (1) and then increments `a` to 2
- In the expression `++a * 2 + 4`, the operator `++a` executes first, and it returns the new value of `a`, which is 3. Then the multiplication executes (`3 * 2`, which is 6), then the addition (`6 + 4`, which is 10). Thus `c` gets the value 10.
- In thee expression `a-- + 1`, the operator `a--` executes first, and it returns the *old* value of `a`, which is 3 (even though `a` is now 2). Then the addition executes, so `d` gets the value 4.

14.2 While Loops

- Introduction to `while` loops
  - There are two basic types of decision structures in all programming languages. We've just learned about the first, which is the "selection structure," or `if` statement. This allows the program to choose whether or not to execute a block of code, based on a condition.
  - The second basic decision structure is the loop, which allows the program to execute the same block of code repeatedly, and choose when to stop based on a condition.
  - The **while statement** executes a block of code repeatedly, *as long as a condition is true.* You can also think of it as executing the code repeatedly *until a condition is false*
- Example code with a `while` loop

```
int counter = 0;
while(counter <= 3)
{
    Console.WriteLine("Hello again!");
    Console.WriteLine(counter);
    counter++;
}
Console.WriteLine("Done");
```

  - After the keyword `while` is a condition, in parentheses: `counter <= 3`
  - On the next line after the `while` statement, the curly brace begins a code block. The code in this block is "controlled" by the `while` statement.
  - The computer will repeatedly execute that block of code as long as the condition `counter <= 3` is true
  - Note that inside this block of code is the statement `counter++`, which increments `counter` by 1. So eventually, `counter` will be greater than 3, and the loop will stop because the condition is false.
  - This program produces the following output:

```
Hello again!
0
Hello again!
1
Hello again!
2
Hello again!
3
Done
```

- Syntax and rules for `while` loops
  - Formally, the syntax for a `while` loop is this:

    ```
    while(<condition>)
    {
        <statements>
    }
    ```

  - Just like with an `if` statement, the condition is any expression that produces a `bool` value (including a `bool` variable by itself)
  - When the computer encounters a `while` loop, it first evaluates the condition
  - If the condition is false, the loop body (code block) is skipped, just like with an `if` statement
  - If the condition is true, the loop body is executed
  - After executing the loop body, the computer goes back to the `while` statement and evaluates the condition again to decide whether to execute the loop again
  - Just like with an `if` statement, the curly braces can be omitted if the loop body is just one statement:

    ```
    while(<condition>)
        <statement>
    ```

- Examining the example in detail
  - When our example program runs, it initializes `counter` to 0, then it encounters the loop
  - It evaluates the condition `counter <= 0`, which is true, so it executes the loop's body. The program displays "Hello again!" and "0" on the screen.
  - At the end of the code block (after `counter++`) the program returns to the `while` statement and evaluates the condition again. 1 is less than 3, so it executes the loop's body again.
  - This process repeats two more times, and the program displays "Hello again!" with "2" and "3"
  - After displaying "3", `counter++` increments `counter` to 4. Then the program returns to the `while` statement and evaluates the condition, but `counter <= 3` is false, so it skips the loop body and executes the last line of code (displaying "Done")
- While loops may execute zero times
  - You might think that a "loop" always repeats code, but nothing requires a while loop to execute at least once
  - If the condition is false when the computer first encounters the loop, the loop body is skipped
  - For example, if we initialize `counter` to 5 with our previous loop:

```
int counter = 5;
while(counter <= 3)
{
    Console.WriteLine("Hello again!");
    Console.WriteLine(counter);
    counter++;
}
Console.WriteLine("Done");
```

The program will only display "Done," because the body of the loop never executes. `counter <= 3` is false the first time it is evaluated, so the program skips the code block and continues on the next line.

- Ensuring the loop ends
  - If the loop condition is always true, the loop will never end, and your program will run "forever" (until you forcibly stop it, or the computer shuts down)
  - Obviously, if you use the value `true` for the condition, the loop will run forever, like in this example:

```
int number = 1;
while (true)
    Console.WriteLine(number++);
```

  - If you don't intend your loop to run forever, you must ensure the statements in the loop's body do something to *change a variable* in the loop condition, otherwise the condition will stay true
  - For example, this loop will run forever because the loop condition uses the variable `counter`, but the loop body does not change the value of `counter`:

```
int counter = 0;
while(counter <= 3)
{
    Console.WriteLine("Hello again!");
    Console.WriteLine(counter);
}
Console.WriteLine("Done");
```

  - This loop will also run forever because the loop condition uses the variable `num1`, but the loop body changes the variable `num2`:

```
int num1 = 0, num2 = 0;
while(num1 <= 5)
{
    Console.WriteLine("Hello again!");
    Console.WriteLine(num1);
    num2++;
}
Console.WriteLine("Done");
```

  - It's not enough for the loop body to simply change the variable; it must change the variable in a way that will eventually *make the condition false*
    - For example, if the loop condition is `counter <= 5`, then the loop body must increase the value of `counter` so that it is eventually greater than 5
    - This loop will run forever, even though it changes the right variable, because it changes the value in the wrong "direction":

```
int number = 10;
while(number >= 0)
{
    Console.WriteLine("Hello again!");
    Console.WriteLine(number);
    number++;
}
```

The loop condition checks to see whether `number` is ≥ 0, and `number` starts out at the value 10. But the loop body increments `number`, which only moves it further away from 0 in the positive direction. In order for this loop to work correctly, we need to *decrement* `number` in the loop body, so that eventually it will be less than 0.

* This loop will run forever, even though it uses the right variable in the loop body, because it multiplies the variable by 0:

```
int number = 0;
while (number <= 64)
{
    Console.WriteLine(number);
    number *= 2;
}
```

Since `number` was initialized to 0, `number *= 2` doesn't actually change the value of `number`: $2 \times 0 = 0$. So the loop body will never make the condition `number <= 64` false.

- Principles of writing a `while` loop
  - When writing a `while` loop, ask yourself these questions about your program:
    1. When (under what conditions) do I want the loop to continue?
    2. When (under what conditions) do I want the loop to stop?
    3. How will the body of the loop bring it closer to its ending condition?
  - This will help you think clearly about how to write your loop condition. You should write a condition (Boolean expression) that will be `true` in the circumstances described by (1), and `false` in the circumstances described by (2)
  - Keep your answer to (3) in mind as you write the body of the loop, and make sure the actions in your loop's body match the condition you wrote.

14.3 Loops and Input Validation

- Valid and invalid data
  - Depending on the purpose of your program, each variable might have a limited range of values that are "valid" or "good," even if the data type can hold more
  - For example, a `decimal` variable that holds a price (in dollars) should have a positive value, even though it's legal to store negative numbers in a `decimal`
  - On a recent quiz we saw the `Item` class, which represents an item sold in a store, and it has a `price` attribute that should only store positive values
  - When you write a program that constructs an `Item` from literal values, you (the programmer) can make sure you only use positive prices. However, if you construct an `Item` based on input provided by the user, you can't be certain that the user will follow directions and enter a valid price:

```
Console.WriteLine("Enter the item's description");
string desc = Console.ReadLine();
Console.WriteLine("Enter the item's price (must be positive)");
decimal price = decimal.Parse(Console.ReadLine());
Item myItem = new Item(desc, price);
```

In this code, if the user enters a negative number, the `myItem` object will have a negative price, even though that doesn't make sense.

- One way to guard against "bad" user input values is to use an `if` statement or a conditional operator, as we saw in the previous lecture (Switch and Conditional), to provide a default value if the user's input is invalid. In our example with Item, we could add a conditional operator to check whether `price` is negative before providing it to the `Item` constructor:

```
decimal price = decimal.Parse(Console.ReadLine());
Item myItem = new Item(desc, (price >= 0) ? price : 0);
```

In this code, the second argument to the `Item` constructor is the result of the conditional operator, which will be 0 if `price` is negative.

- You can also put the conditional operator inside the constructor, to ensure that an `Item` with an invalid price can never be created. If we wrote this constructor inside the `Item` class:

```
public Item(string initDesc, decimal initPrice)
{
    description = initDesc;
    price = (initPrice >= 0) ? initPrice : 0;
}
```

then the instantiation `new Item(desc, price)` would never be able to create an object with a negative price. If the user provides an invalid price, the constructor will ignore their value and initialize the `price` instance variable to 0 instead.

- Ensuring data is valid with a loop
  - Another way to protect your program from "bad" user input is to check whether the data is valid as soon as the user enters it, and prompt him/her to re-enter the data if it is not valid
  - A `while` loop is the perfect fit for this approach: you can write a loop condition that is true when the user's input is *invalid*, and ask the user for input in the body of the loop. This means your program will repeatedly ask the user for input until he/she enters valid data.
  - This code uses a `while` loop to ensure the user enters a non-negative price:

```
Console.WriteLine("Enter the item's price.");
decimal price = decimal.Parse(Console.ReadLine());
while(price < 0)
{
    Console.WriteLine("Invalid price. Please enter a non-negative price.");
    price = decimal.Parse(Console.ReadLine());
}
Item myItem = new Item(desc, price);
```

    * The condition for the `while` loop is `price < 0`, which is true when the user's input is invalid
    * If the user enters a valid price the first time, the loop will not run at all – remember that a `while` loop will skip the code block if the condition is false
    * Inside the loop's body, we ask the user for input again, and assign the result of `decimal.Parse` to the same `price` variable we use in the loop condition. This is what ensures that the loop will end: the variable in the condition gets changed in the body.

    - If the user still enters a negative price, the loop condition will be true, and the body will execute again (prompting them to try again)
    - If the user enters a valid price, the loop condition will be false, so the program will proceed to the next line and instantiate the Item
    - Note that the *only* way for the program to "escape" from the `while` loop is for the user to enter a valid price. This means that `new Item(desc, price)` is guaranteed to create an Item with a non-negative price, even if we did not write the constructor that checks whether `initPrice >= 0`. On the next line of code after the end of a `while` loop, you can be certain that the loop's condition is false, otherwise execution would not have reached that point.

- Ensuring the user enters a number with `TryParse`
  - Another way that user input might be invalid: When asked for a number, the user could enter something that is not a number
  - The `Parse` methods we have been using assume that the `string` they are given (in the argument) is a valid number, and produce a run-time error if it is not
    - For example, this program that you might remember from lab will crash if the user enters "hello" instead of a number:

```
Console.WriteLine("Guess a number"):
int guess = int.Parse(Console.ReadLine());
if(guess == favoriteNumber)
{
    Console.WriteLine("That's my favorite number!");
}
```

  - Each built-in data type has a **TryParse method** that will *attempt* to convert a `string` to a number, but will not crash (produce a run-time error) if the conversion fails. Instead, TryParse indicates failure by returning the Boolean value `false`
  - The `TryParse` method is used like this:

```
string userInput = Console.ReadLine();
int intVar;
bool success = int.TryParse(userInput, out intVar);
```

    - The first parameter is a `string` to be parsed (`userInput`)
    - The second parameter is an **out parameter**, and it is the name of a variable that will be assigned the result of the conversion. The keyword `out` indicates that a method parameter is used for *output* rather than *input*, and so the variable you use for that argument will be changed by the method.
    - The return type of `TryParse` is `bool`, not `int`, and the value returned indicates whether the input string was successfully parsed
    - If the string `userInput` contains an integer, `TryParse` will assign that integer value to `intVar` and return `true` (which gets assigned to `success`)
    - If the string `userInput` does not contain an integer, `TryParse` will assign 0 to `intVar` and return `false` (which gets assigned to `success`)
    - Either way, the program will not crash, and `intVar` will be assigned a new value
  - The other data types have `TryParse` methods that are used the same way. The code will follow this general format:

```
bool success = <numeric datatype>.TryParse(<string to convert>, out <numeric
↪  variable to store result>)
```

Note that the variable you use in the out parameter must be the same type as the one whose `TryParse` method is being called. If you write `decimal.TryParse`, the out parameter must be a `decimal` variable.

- A more complete example of using `TryParse`:

```
Console.WriteLine("Please enter an integer");
string userInput = Console.ReadLine();
int intVar;
bool success = int.TryParse(userInput, out intVar);
if(success)
{
    Console.WriteLine($"The value entered was an integer: {intVar}");
}
else
{
    Console.WriteLine($"\"{userInput}\" was not an integer");
}
Console.WriteLine(intVar);
```

  * The `TryParse` method will attempt to convert the user's input to an `int` and store the result in `intVar`
  * If the user entered an integer, `success` will be `true`, and the program will display "The value entered was an integer:" followed by the user's value
  * If the user entered some other string, `success` will be `false`, and the program will display a message indicating that it was not an integer
  * Either way, `intVar` will be assigned a value, so it's safe to write `Console.WriteLine(intVar)`. This will display the user's input if the user entered an integer, or "0" if the user did not enter an integer.

- Just like with `Parse`, you can use `Console.ReadLine()` itself as the first argument rather than a `string` variable. Also, you can declare the output variable within the out parameter, instead of on a previous line. So we can read user input, declare an `int` variable, and attempt to parse the user's input all on one line:

```
bool success = int.TryParse(Console.ReadLine(), out int intVar);
```

- You can use the return value of `TryParse` in a `while` loop to keep prompting the user until they enter valid input:

```
Console.WriteLine("Please enter an integer");
bool success = int.TryParse(Console.ReadLine(), out int number);
while(!success)
{
    Console.WriteLine("That was not an integer, please try again.");
    success = int.TryParse(Console.ReadLine(), out number);
}
```

  * The loop condition should be true when the user's input is *invalid*, so we use the negation operator `!` to write a condition that is true when `success` is `false`
  * Each time the loop body executes, both `success` and `number` are assigned new values by `TryParse`

15 Do-While Loops and Loop Vocabulary

15.1 The `do-while` Statement

- Comparing **`while`** and **`if`** statements
  - **`while`** and **`if`** are very similar: Both test a condition, execute a block of code if the condition is true, and skip the block of code if the condition is false
  - There's only a difference if the condition is true: **`if`** statements only execute the block of code once if the condition is true, but **`while`** statements may execute the block of code multiple times if the condition is true
  - Compare these snippets of code:

    ```
    if(number < 3)
    {
        Console.WriteLine("Hello!");
        Console.WriteLine(number);
        number++;
    }
    Console.WriteLine("Done");
    ```

    and

    ```
    while(number < 3)
    {
        Console.WriteLine("Hello!");
        Console.WriteLine(number);
        number++;
    }
    Console.WriteLine("Done");
    ```

    * If `number` is 4, then both will do the same thing: skip the block of code and display "Done".
    * If `number` is 2, both will also do the same thing: Display "Hello!" and "2", then increment `number` to 3 and print "Done".
    * If `number` is 1, there is a difference: The **`if`** statement will only display "Hello!" once, but the **`while`** statement will display "Hello! 2" and "Hello! 3" before displaying "Done"
- Since the **`while`** loop evaluates the condition before executing the code in the body (like an **`if`** statement), you sometimes end up duplicating code
  - For example, consider an input-validation loop like the one we wrote for Item prices:

    ```
    Console.WriteLine("Enter the item's price.");
    decimal price = decimal.Parse(Console.ReadLine());
    while(price < 0)
    {
        Console.WriteLine("Invalid price. Please enter a non-negative price.");
        price = decimal.Parse(Console.ReadLine());
    }
    Item myItem = new Item(desc, price);
    ```

  - Before the **`while`** loop, we wrote two lines of code to prompt the user for input, read the user's input, convert it to `decimal`, and store it in `price`
  - In the body of the **`while`** loop, we also wrote two lines of code to prompt the user for input, read the user's input, convert it to `decimal`, and store it in `price`

- The code before the `while` loop is necessary to give `price` an initial value, so that we can check it for validity in the `while` statement
- It would be nice if we could tell the `while` loop to execute the body first, and then check the condition

- The `do-while` loop executes the loop body **before** evaluating the condition
  - Otherwise works the same as a `while` loop: If the condition is true, execute the loop body again; if the condition is false, stop the loop
  - This can reduce repeated code, since the loop body is executed *at least once*
  - Example:

```
decimal price;
do
{
    Console.WriteLine("Please enter a non-negative price.");
    price = decimal.Parse(Console.ReadLine());
} while(price < 0);
Item myItem = new Item(desc, price);
```

    * The keyword `do` starts the code block for the loop body, but it doesn't have a condition, so the computer simply starts executing the body
    * In the loop body, we prompt the user for input, read and parse the input, and store it in `price`
    * The condition `price < 0` is evaluated at the end of the loop body, so `price` has its initial value by the time the condition is evaluated
    * If the user entered a valid price, and the condition is false, execution simply proceeds to the next line
    * If the user entered a negative price (the condition is true), the computer returns to the beginning of the code block and executes the loop body again
    * This has the same effect as the `while` loop: the user is prompted repeatedly until he/she enters a valid price, and the program can only reach the line `Item myItem = new Item(desc, price)` when `price < 0` is false
    * Note that the variable `price` must be declared before the `do-while` loop so that it is in scope after the loop. It would not be valid to declare `price` inside the body of the loop (e.g. on the line with `decimal.Parse`) because then its scope would be limited to inside that code block.

- Formal syntax and details
  - A `do-while` loop is written like this:

```
do
{
    <statements>
} while(<condition>);
```

  - The `do` keyword does nothing, but it is required to indicate the start of the loop. You can't just write a `{` by itself.
  - Unlike a `while` loop, a semicolon is required after `while(<condition>)`
  - It's a convention to write the `while` keyword on the same line as the closing `}`, rather than on its own line as in a `while` loop

- When the computer encounters a `do-while` loop, it first executes the body (code block), then evaluates the condition
- If the condition is true, the computer jumps back to the `do` keyword and executes the loop body again
- If the condition is false, execution continues to the next line after teh `while` keyword
- If the loop body is only a single statement, you can omit the curly braces, but not the semicolon:

```
do
    <statement>
while(<condition>);
```

- A `do-while` loop with multiple conditions
  - We can combine both types of user-input validation in one loop: Ensuring the user entered a number (not some other string), and ensuring the number is valid. This is easier to do with a `do-while` loop:

```
decimal price;
bool parseSuccess;
do
{
    Console.WriteLine("Please enter a price (must be non-negative).");
    parseSuccess = decimal.TryParse(Console.ReadLine(), out price);
} while(!parseSuccess || price < 0);
Item myItem = new Item(desc, price);
```

  - There are two parts to the loop condition: (1) it should be true if the user did not enter a number, and (2) it should be true if the user entered a negative number.
  - We combine these two conditions with `||` because either one, by itself, represents invalid input. Even if the user entered a valid number (which means `!parseSuccess` is false), the loop should not stop unless `price < 0` is also false.
  - Note that both variables must be declared before the loop begins, so that they are in scope both inside and outside the loop body

15.2 Vocabulary

Variables and values can have multiple roles, but it is useful to mention three different roles in the context of loops:

Counter Variable that is incremented every time a given event occurs.

```
int i = 0; // i is a counter
while (i < 10){
    Console.WriteLine($"{i}");
    i++;
}
```

Sentinel Value A special value that signals that the loop needs to end.

```
Console.WriteLine("Give me a string.");
string ans = Console.ReadLine();
while (ans != "Quit") // The sentinel value is "Quit".
{
    Console.WriteLine("Hi!");
    Console.WriteLine("Enter \"Quit\" to quit, or anything else to continue.");
    ans = Console.ReadLine();
}
```

Accumulator Variable used to keep the total of several values.

```
int i = 0, total = 0;
while (i < 10){
    total += i; // total is the accumulator.
    i++;
}

Console.WriteLine($"The sum from 0 to {i} is {total}.");
```

We can have an accumulator and a sentinel value at the same time:

```
Console.WriteLine("Enter a number to sum, or \"Done\" to stop and print the total.");
string enter = Console.ReadLine();
int sum = 0;
while (enter != "Done")
{
    sum += int.Parse(enter);
    Console.WriteLine("Enter a number to sum, or \"Done\" to stop and print the total.");
    enter = Console.ReadLine();
}
Console.WriteLine($"Your total is {sum}.");
```

You can have counter, accumulator and sentinel values at the same time:

```
int a = 0;
int sum = 0;
int counter = 0;
Console.WriteLine("Enter an integer, or N to quit.");
string entered = Console.ReadLine();
while (entered != "N") // Sentinel value
{
    a = int.Parse(entered);
    sum += a; // Accumulator
    Console.WriteLine("Enter an integer, or N to quit.");
    entered = Console.ReadLine();
    counter++; // counter
}
Console.WriteLine($"The average is {sum / (double)counter}");
```

We can distinguish between three "flavors" of loops (that are not mutually exclusive):

Sentinel controlled loop The exit condition tests if a variable has (or is different from) a *specific value*.

User controlled loop The number of iterations depends on the *user*.

Count controlled loop The number of iterations depends on a *counter*.

Note that a user-controlled loop can be sentinel-controlled (that is the example we just saw), but also count-controlled ("Give me a value, and I will iterate a task that many times").

15.3 While Loop With Complex Conditions

In the following example, a complex boolean expression is used in the *while* statement. The program gets a value and tries to parse it as an integer. If the value can not be converted to an integer, the program tries again, but not more than three times.

```
int c;
string message;
int count;
bool res;

Console.WriteLine("Please enter an integer.");
message = Console.ReadLine();
res = int.TryParse(message, out c);
count = 0; // The user has 3 tries: count will be 0, 1, 2, and then we default.
while (!res && count < 3)
{
    count++;
    if (count == 3)
    {
        c = 1;
        Console.WriteLine("I'm using the default value 1.");
    }
    else
    {
        Console.WriteLine("The value entered was not an integer.");
        Console.WriteLine("Please enter an integer.");
        message = Console.ReadLine();
        res = int.TryParse(message, out c);
    }
}
Console.WriteLine("The value is: " + c);
```

16 Combining Methods and Decision Structures

Note that we can have a decision structure inside a method! If we were to re-visit the Rectangle class, we could have a constructor of the following type:

```
public Rectangle(int wP, int lP)
    {
        if (wP <= 0 || lP <= 0)
        {
            Console.WriteLine("Invalid Data, setting everything to 0");
            width = 0;
            length = 0;
        }
        else
        {
        width = wP;
        length = lP;
    }
}
```

17 Putting it all together!

```
using System;

class Loan
{
    private string account;
    private char type;
    private int cscore;
    private decimal amount;
    private decimal rate;

    public Loan()
    {
        account = "Unknown";
        type = 'o';
        cscore = -1;
        amount = -1;
        rate = -1;
    }

    public Loan(string nameP, char typeP, int cscoreP, decimal needP, decimal downP)
    {
        account = nameP;
        type = typeP;
        cscore = cscoreP;
        if (cscore < 300)
        {
            Console.WriteLine("Sorry, we can't accept your application");
            amount = -1;
            rate = -1;
        }
        else
        {
            amount = needP - downP;

            switch (type)
            {
                case ('a'):
                    rate = .05M;
                    break;

                case ('h'):
                    if (cscore > 600 && amount < 1000000M)
                        rate = .03M;
                    else
                        rate = .04M;
                    break;
                case ('o'):
                    if (cscore > 650 || amount < 10000M)
                        rate = .07M;
                    else
                        rate = .09M;
                    break;
```

```
            }

        }
    }
    public override string ToString()
    {
        string typeName = "";
        switch (type)
        {
            case ('a'):
                typeName = "an auto";
                break;

            case ('h'):
                typeName = "a house";
                break;
            case ('o'):
                typeName = "another reason";
                break;

        }

        return "Dear " + account + $", you borrowed {amount:C} at {rate:P} for "
            + typeName + ".";
    }
}

using System;
class Program
{
    static void Main()
    {

        Console.WriteLine("What is your name?");
        string name = Console.ReadLine();

        Console.WriteLine("Do you want a loan for an Auto (A, a), a House (H, h), or for
↪   some Other (O, o) reason?");
        char type = Console.ReadKey().KeyChar; ;
        Console.WriteLine();

        string typeOfLoan;

        if (type == 'A' || type == 'a')
        {
            type = 'a';
            typeOfLoan = "an auto";
        }
        else if (type == 'H' || type == 'h')
        {
            type = 'h';
            typeOfLoan = "a house";
        }
```

```
        else
        {
            type = 'o';
            typeOfLoan = "some other reason";
        }

        Console.WriteLine($"You need money for {typeOfLoan}, great.\nWhat is your current
↪  credit score?");
        int cscore = int.Parse(Console.ReadLine());

        Console.WriteLine("How much do you need, total?");
        decimal need = decimal.Parse(Console.ReadLine());

        Console.WriteLine("What is your down payment?");
        decimal down = decimal.Parse(Console.ReadLine());

        Loan myLoan = new Loan(name, type, cscore, need, down);
        Console.WriteLine(myLoan);
    }

}
```

18 Arrays

Arrays are structures that allow you to store multiple values in memory using a single name and indexes. - Usually all the elements of an array have the same type. - You limit the type of array elements when you declare the array. - If you want the array to store elements of any type, you can specify object as its type.

An array can be: - Single-Dimensional - Multidimensional (not covered) - Jagged (not covered)

Arrays are useful, for instance, - When you want to store a collection of related values, - When you don't know in advance how many variables we need. - When you need too many variables of the same type.

18.1 Single-Dimensional Arrays

You can define a single-dimensional array as follow:

```
type[] arrayName;
```

- `type` can be any data-type and specifies the data-type of the array elements.
- `arrayName` is an identifier that you will use to access and modify the array elements.
- Before using an array, you must specify the number of elements of the array as follow:

```
arrayName = new type[number of elements];
```

- An element of a single-dimentional array can be accessed and modified by using the name of the array and the index of the element as follow:

```
arrayName[Index] = value;  \\ assigning a value to an element

value = arrayName[Index]; \\ Reading the current value of an element
```

- The index of the first element in an array is always zero; the index of the second element is one, and so on.
- If you specify an index greater or equal to the number of elements, a run time error will happen.

18.1.1 Example

In the following example, we define an array named *myArray* with three elements of type integer, and assign 10 to the first element, 20 to the second element, and 30 to the last element.

```
 int[] myArray;
myArray = new int[3]; // 3 is the size declarator
// We can now store 3 ints in this array,
// at index 0, 1 and 2

myArray[0] = 10; // 0 is the subscript, or index
myArray[1] = 20;
myArray[2] = 30;

// the following would give an error:
//myArray[3] = 40;
// Unhandled Exception: System.IndexOutOfRangeException: Index was outside the bounds of
 ↪  the array at Program.Main()
// "Array bound checking": happen at runtime.
```

If you know the number of elements when you are defining an array, you can combine declaration and assignment on one line as follow:

```
type[] arrayName = new type[number of elements];
```

So, we can combine the first two lines of the previous example and write:

```
int[] myArray = new int[3];
```

We can even initialize *and* give values on one line:

```
int[] myArray = new int[3] { 10, 20, 30 };
```

And that statement can be rewritten as any of the following:

```
int[] myArray = new int[] { 10, 20, 30 };
int[] myArray = new[] { 10, 20, 30 };
int[] myArray = { 10, 20, 30 };
```

But, we should be careful, the following would cause an error:

```
int[] myArray = new int[5];
myArray = { 1, 2 ,3, 4, 5}; // ERROR
```

If we use the shorter notation, we *have to* give the values at initialization, we cannot re-use this notation once the array was created.

Other datatype, and even objects, can be stored in arrays:

```
string[] myArray = { "Bob", "Mom", "Train", "Console" };
Rectangle[] arrayOfRectangle = new Rectangle[5];  \\ Assume there is a class called
 ↪  Rectangle
```

18.2 Custom Size and Values

One of the benefits of arrays is that they allow you to specify the number of their elements at run-time. Hence, depending on the run-time conditions, we can have enough space to store and process values.

18.2.1 Example

In the following example, we get the number of elements at run-time from the user, create an array with the appropriate size, and fill the array.

```
Console.WriteLine("What is the size of the array that you want?");
int size = int.Parse(Console.ReadLine());
int[] customArray = new int[size];

int counter = 0;
while (counter < size)
{
    Console.WriteLine($"Enter the {counter + 1}th value");
    customArray[counter] = int.Parse(Console.ReadLine());
    counter++;
}
```

18.3 Array Size

Every single-dimensional array has a property called `Length` that returns the number of the elements in the array (or size of the array).

To process an array that its size is not fixed, we can use this property to find out the number of elements in the array

18.3.1 Example

```
int counter2 = 0;
while (counter2 < customArray.Length)
{
    Console.WriteLine($"{counter2}: {customArray[counter2]}.");
    counter2++;
}
```

18.4 Changing the Size

There is a class named `Array` that can be used to resize an array. But, note that if you resize an array, you will lose all the current values and the elements will be reset to the data-type default.

18.4.1 Example

```
Array.Resize(ref myArray, 4);
myArray[3] = 40;
Array.Resize(ref myArray, 2);
```

`Resize` shrinks (and content is lost) and extends (and store the default value, i.e., 0 for `int`, etc.)!

19 For Loops

- Counter-controlled loops
  - Previously, when we learned about loop vocabulary, we looked at counter-controlled `while` loops
  - Although counter-controlled loops can perform many different kinds of actions in the body of the loop, they all use very similar code for managing the counter variable
  - Two examples of counter-controlled `while` loops:

```
int i = 0;
while(i < 10)
{
    Console.WriteLine($"{i}");
    i++;
}
Console.WriteLine("Done");
```

```
int num = 1, total = 0;
while(num <= 25)
{
    total += num;
    num++;
}
Console.WriteLine($"The sum is {total}");
```

    Notice that in both cases, we've written the same three pieces of code:

    * Initialize a counter variable (`i` or `num`) before the loop starts
    * Write a loop condition that will become false when the counter reaches a certain value (`i < 10` or `num <= 25`)
    * Increment the counter variable at the end of each loop iteration, as the last line of the body

- `for` loop example and syntax
  - This `for` loop does the same thing as the first of the two `while` loops above:

```
for(int i = 0; i < 10; i++)
{
    Console.WriteLine($"{i}");
}
Console.WriteLine("Done");
```

    * The `for` statement actually contains 3 statements in 1 line; note that they are separated by semicolons
    * The code to initialize the counter variable has moved inside the `for` statement, and appears first
    * Next is the loop condition, `i < 10`
    * The third statement is the increment operation, `i++`, which no longer needs to be written at the end of the loop body

  - In general, `for` loops have this syntax:

```
for(<initialization>; <condition>; <update>)
{
    <statements>
}
```

    - The initialization statement is executed once, when the program first reaches the loop. This is where you declare and initialize the counter variable.
    - The condition statement works exactly the same as a `while` loop's condition statement: Before executing the loop's body, the computer checks the condition, and skips the body (ending the loop) if it is false.
    - The update statement is code that will be executed each time the loop's body *ends*, before checking the condition again. You can imagine that it gets inserted right before the closing `}` of the loop body. This is where you increment the counter variable.

- Examining the example in detail
  - When the computer executes our example `for` loop, it first creates the variable `i` and initializes it to 0
  - Then it evaluates the condition `i < 10`, which is true, so it executes the loop's body. The computer displays "0" in the console.
  - At the end of the code block for the loop's body, the computer executes the update code, `i++`, and changes the value of `i` to 1.
  - Then it returns to the beginning of the loop and evaluates the condition again. Since it is still true, it executes the loop body again.
  - This process repeats several more times. On the last iteration, `i` is equal to 9. The computer displays "9" on the screen, then increments `i` to 10 at the end of the loop body.
  - The computer returns to the `for` statement and evaluates the condition, but `i < 10` is false, so it skips the loop body and proceeds to the next line of code. It displays "Done" in the console.

19.1 Limitations and Pitfalls of Using `for` Loops

- Scope of the `for` loop's variable
  - When you declare a counter variable in the `for` statement, its scope is limited to *inside* the loop
  - Just like method parameters, it's as if the variable declaration happened just inside the opening `{`, so it can only be accessed inside that code block
  - This means you can't use a counter variable after the end of the loop. This code will produce a compile error:

```
int total = 0;
for(int count = 0; count < 10; count++)
{
    total += count;
}
Console.WriteLine($"The average is {(double) total / count}");
```

  - If you want to use the counter variable after the end of the loop, you must declare it *before* the loop
  - This means your loop's initialization statement will need to assign the variable its starting value, but not declare it
  - This code works correctly, since `count` is still in scope after the end of the loop:

```
int total = 0;
int count;
for(count = 0; count < 10; count++)
{
    total += count;
}
Console.WriteLine($"The average is {(double) total / count}");
```

- Be sure not to re-declare a variable
  - If your `for` loop declares a new variable in its initialization statement, it can't have the same name as a variable already in scope
  - If you want your counter variable to still be in scope after the end of the loop, you can't also declare it in the `for` loop. This is why we had to write `for(count = 0...` instead of `for(int count = 0...` in the previous example: the name `count` was already being used.
  - Since counter variables often use short, common names (like `i` or `count`), it's more likely that you'll accidentally re-use one that's already in scope
  - For example, you might have a program with many `for` loops, and in one of them you decide to declare the counter variable outside the loop because you need to use it after the end of the loop. This can cause an error in a different `for` loop much later in the program:

```
int total = 0;
int i;
for(i = 0; i < 10; i++)
{
    total += i;
}
Console.WriteLine($"The average is {(double) total / i}");
// Many more lines of code
// ...
// Some time later:
for(int i = 0; i < 10; i++)
{
    Console.WriteLine($"{i}");
}
```

    The compiler will produce an error on the second `for` loop, because the name "i" is already being used.
  - On the other hand, if all of your `for` loops declare their variables inside the `for` statement, it's perfectly fine to reuse the same variable name. This code does not produce any errors:

```
int total = 0;
for(int i = 0; i < 10; i++)
{
    total += i;
}
Console.WriteLine($"The total is {total}");
// Some time later:
for(int i = 0; i < 10; i++)
{
    Console.WriteLine($"{i}");
}
```

- Be sure not to double-increment the counter
  - Now that you know about `for` loops, you may want to convert some of your counter-controlled `while` loops to `for` loops
  - Remember that in a `while` loop the counter must be incremented in the loop body, but in a `for` loop the increment is part of the loop's header
  - If you just convert the header of the loop and leave the body the same, you will end up incrementing the counter *twice* per iteration. For example, if you convert this `while` loop:

```
int i = 0;
while(i < 10)
{
    Console.WriteLine($"{i}");
    i++;
}
Console.WriteLine("Done");
```

to this `for` loop:

```
for(int i = 0; i < 10; i++)
{
    Console.WriteLine($"{i}");
    i++;
}
Console.WriteLine("Done");
```

it will not work correctly, because `i` will be incremented by both the loop body and the loop's update statement. The loop will seem to "skip" every other value of `i`.

19.2 More Ways to use `for` Loops

- The condition in a `for` loop can be any expression that results in a `bool` value
  - If the condition compares the counter to a variable, the number of iterations depends on the variable. If the variable comes from user input, the loop is also user-controlled, like in this example:

    ```
    Console.WriteLine("Enter a positive number.");
    int numTimes = int.Parse(Console.ReadLine());
    for(int c = 0; c < numTimes; c++)
    {
        Console.WriteLine("**********");
    }
    ```

  - The condition can compare the counter to the result of a method call. In this case, the method will get called on every iteration of the loop, since the condition is re-evaluated every time the loop returns to the beginning. For example, in this loop:

    ```
    for(int i = 1; i <= (int) myItem.GetPrice(); i++)
    {
        Console.WriteLine($"${i}");
    }
    ```

    the `GetPrice()` method of `myItem` will be called every time the condition is evaluated.

- The update statement can be anything, not just an increment operation
  - For example, you can write a loop that only processes the even numbers like this:

    ```
    for(int i = 0; i < 19; i += 2)
    {
        Console.WriteLine($"{i}");
    }
    ```

  - You can write a loop that decreases the counter variable on every iteration, like this:

```
for(int t = 10; t > 0; t--)
{
    Console.Write($"{t}...");
}
Console.WriteLine("Liftoff!");
```

- The loop body can contain more complex statements
  - `if` statements can be nested inside `for` loops, and they will be evaluated again on every iteration
  - For example, in this program:

    ```
    for(int i = 0; i < 8; i++)
    {
        if(i % 2 == 0)
        {
            Console.WriteLine("It's my turn");
        }
        else
        {
            Console.WriteLine("It's your turn");
        }
        Console.WriteLine("Switching players...");
    }
    ```

    On even-numbered iterations, the computer will display "It's my turn" followed by "Switching players...", and on odd-numbered iterations the computer will display "It's your turn" followed by "Switching players..."
  - `for` loops can contain other `for` loops. This means the "inner" loop will execute all of its iterations each time the "outer" loop executes one iteration.
  - For example, this program prints a multiplication table:

    ```
    for(int r = 0; r < 11; r++)
    {
        for(int c = 0; c < 11; c++)
        {
            Console.Write($"{r} x {c} = {r * c} \t");
        }
        Console.Write("\n");
    }
    ```

    The outer loop prints the rows of the table, while the inner loop prints the columns. On a single iteration of the outer `for` loop (i.e. when `r = 2`), the inner `for` loop executes its body 11 times, using values of `c` from 0 to 10. Then the computer executes the `Console.Write("\n")` to print a newline before the next "row" iteration.

- `for` loops can be combined with `while` loops
  - `while` loops are good for sentinel-controlled loops or user-input validation, and `for` loops are good for counter-controlled loops
  - This program asks the user to enter a number, then uses a `for` loop to print that number of lines of asterisks:

```
string userInput;
do
{
    Console.WriteLine("Enter a positive number, or \"Q\" to stop");
    userInput = Console.ReadLine();
    int inputNum;
    int.TryParse(userInput, out inputNum);
    if(inputNum > 0)
    {
        for(int c = 0; c < inputNum; c++)
        {
            Console.WriteLine("**********");
        }
    }
} while(userInput != "Q");
```

* The sentinel value "Q" is used to end the program, so the outer `while` loop repeats until the user enters this value
* Once the user enters a number, that number is used in the condition for a `for` loop that prints lines of asterisks
* Since the user could enter either a letter or a number, we need to use `TryParse` to convert the user's input to a number
* If `TryParse` fails (because the user entered a non-number), `inputNum` will be assigned the value 0. This is also an invalid value for the loop counter, so we don't need to check whether `TryParse` returned `true` or `false`. Instead, we simply check whether `inputNum` is valid (greater than 0) before executing the `for` loop, and skip the `for` loop entirely if `inputNum` is negative or 0.

19.3 For Loops With Arrays

- Using `for` loops to access array elements
  - Previously, we learned that you can access a single array element using the `<array>[<index>]` syntax. However, it can be tedious to access each element of an array one at a time.
  - For example, consider this code that finds the average of all the elements in an array:

```
int[] homeworkGrades = {89, 72, 88, 80, 91};
double average = (homeworkGrades[0] + homeworkGrades[1] +
    homeworkGrades[2] + homeworkGrades[3] + homeworkGrades[4]) / 5.0;
```

  - The sum of the array elements repeatedly accesses `homeworkGrades[<index>]` with index values that increment by 1 at a time. This can be written much more concisely by using a variable for the index value, and incrementing the variable in a `for` loop:

```
int sum = 0;
for(int i = 0; i < 5; i++)
{
    sum += homeworkGrades[i];
}
double average = sum / 5.0;
```

    * In a `for` loop that iterates over an array, the counter variable is also used as the array index
    * The loop condition should ensure that the loop stops on the last index of the array, and doesn't attempt to access the array with an invalid index

    - Since the last index is 1 less than the length of the array, the loop condition should be false when the counter is *greater than or equal to* the length of the array.
    - In this case, the array's length is 5, so the loop condition `i < 5` will ensure that the loop does not execute the body when `i` equals 5 (it will stop when `i` equals 4)
  - Using a `for` loop to access array elements makes it easy to process "the whole array" when the size of the array is user-provided:

```
Console.WriteLine("How many grades are there?");
int numGrades = int.Parse(Console.ReadLine());
int[] homeworkGrades = new int[numGrades];
for(int i = 0; i < numGrades; i++)
{
    Console.WriteLine($"Enter grade for homework {i+1}");
    homeworkGrades[i] = int.Parse(Console.ReadLine());
}
```

    - Since the size of the `homeworkGrades` array depends on user input, we don't know when writing the program how many elements it has or which indices are valid. It wouldn't be safe to try to access a specific element like `homeworkGrades[4]` because the user might enter a size smaller than 5.
    - Using a counter that starts at 0 with the loop condition `i < numGrades` means the loop body will run once on each element of the array, no matter what the user enters
    - Note that since array elements start at 0, but humans usually number their lists starting at 1, the user directions in the loop body display `"homework {i+1}"`
  - You can use the `Length` property of an array to write a loop condition, even if you didn't store the size of the array in a variable. For example, this code doesn't need the variable `numGrades`:

```
int sum = 0;
for(int i = 0; i < homeworkGrades.Length; i++)
{
    sum += homeworkGrades[i];
}
double average = (double) sum / homeworkGrades.Length;
```

  - In general, as long as the loop condition is in the format `i < <arrayName>.Length` (or, equivalently, `i <= <arrayName>.Length - 1`), the loop will access each element of the array.

- The `foreach` loop
  - When writing a `for` loop that accesses each element of an array once, you will end up writing code like this:

```
for(int i = 0; i < myArray.Length; i++)
{
    <do something with myArray[i]>;
}
```

  - In some cases, this code has unnecessary repetition: If you aren't using the counter `i` for anything other than an array index, you still need to declare it, increment it, and write the condition with `myArray.Length`
  - The **foreach loop** is a shortcut that allows you to get rid of the counter variable and the loop condition. It has this syntax:

```
foreach(<type> <variableName> in <arrayName>)
{
    <do something with variable>
}
```

  * The loop will repeat exactly as many times as there are elements in the array
  * On each iteration of the loop, the variable will be assigned the next value from the array, in order
  * The variable must be the same type as the array

- For example, this loop accesses each element of `homeworkGrades` and computes their sum:

```
int sum = 0;
foreach(int grade in homeworkGrades)
{
    sum += grade;
}
```

  * The variable `grade` is declared with type `int` since `homeworkGrades` is an array of `int`
  * `grade` has a scope limited to the body of the loop, just like the counter variable `i`
  * In successive iterations of the loop `grade` will have the value `homeworkGrades[0]`, then `homeworkGrades[1]`, and so on, through `homeworkGrades[homeworkGrades.Length - 1]`

- A `foreach` loop is **read-only** with respect to the array: The loop's variable cannot be used to *change* any elements of the array. This code will result in an error:

```
foreach(int grade in homeworkGrades)
{
    grade = int.Parse(Console.ReadLine());
}
```

19.4 `break` and `continue`

- Conditional loop control
  - Sometimes, you want to write a loop that will skip some iterations if a certain condition is met
  - For example, you may be writing a `for` loop that iterates through an array of numbers, but you only want to use *even* numbers from the array
  - One way to accomplish this is to nest an `if` statement inside the `for` loop that checks for the desired condition. For example:

```
int sum = 0;
for(int i = 0; i < myArray.Length; i++)
{
    if(myArray[i] % 2 == 0)
    {
        Console.WriteLine(myArray[i]);
        sum += myArray[i];
    }
}
```

    Since the entire body of the `for` loop is contained within an `if` statement, the iterations where `myArray[i]` is odd will skip the body and do nothing.

- Skipping iterations with `continue`
  - The `continue` keyword provides another way to conditionally skip an iteration of a loop

- When the computer encounters a `continue;` statement, it immediately returns to the beginning of the current loop, skipping the rest of the loop body
  - Then it executes the update statement (if the loop is a `for` loop) and checks the loop condition again
- A `continue;` statement inside an `if` statement will end the current iteration only if that condition is true
- For example, this code will skip the odd numbers in `myArray` and use only the even numbers:

```
int sum = 0;
for(int i = 0; i < myArray.Length; i++)
{
    if(myArray[i] % 2 != 0)
        continue;
    Console.WriteLine(myArray[i]);
    sum += myArray[i];
}
```

  If `myArray[i]` is odd, the computer will execute the `continue` statement and immediately start the next iteration of the loop. This means that the rest of the loop body (the other two statements) only gets executed if `myArray[i]` is even.
- Using a `continue` statement instead of putting the entire body within an `if` statement can reduce the amount of indentation in your code, and it can sometimes make your code's logic clearer.

- Loops with multiple end conditions
  - More advanced loops may have multiple conditions that affect whether the loop should continue
  - Attempting to combine all of these conditions in the loop condition (i.e. the expression after `while`) can make the loop more complicated
  - For example, consider a loop that processes user input, which should end either when a sentinel value is encountered or when the input is invalid. This loop ends if the user enters a negative number (the sentinel value) or a non-numeric string:

```
int sum = 0, userNum = 0;
bool success = true;
while(success && userNum >= 0)
{
    sum += userNum;
    Console.WriteLine("Enter a positive number to add it. "
        + "Enter anything else to stop.");
    success = int.TryParse(Console.ReadLine(), out userNum);
}
Console.WriteLine($"The sum of your numbers is {sum}");
```

    - The condition `success && userNum >= 0` is true if the user entered a valid number that was not negative
    - In order to write this condition, we needed to declare the extra variable `success` to keep track of the result of `int.TryParse`
    - We can't use the condition `userNum > 0`, hoping to take advantage of the fact that if `TryParse` fails it assigns its `out` parameter the value 0, because 0 is a valid input the user could give

- Ending the loop with `break`
  - The `break` keyword provides another way to write an additional end condition

- When the computer encounters a `break;` statement, it immediately ends the loop and proceeds to the next statement after the loop body
  - This is the same `break` keyword we used in `switch` statements
  - In both cases it has the same meaning: stop execution here and skip to the end of this code block (the ending `}` for the `switch` or the loop)
- Using a `break` statement inside an `if-else` statement, we can rewrite the previous `while` loop so that the variable `success` is not needed:

```
int sum = 0, userNum = 0;
while(userNum >= 0)
{
    sum += userNum;
    Console.WriteLine("Enter a positive number to add it. "
        + "Enter anything else to stop.");
    if(!int.TryParse(Console.ReadLine(), out userNum))
        break;
}
Console.WriteLine($"The sum of your numbers is {sum}");
```

  - Inside the body of the loop, the return value of `TryParse` can be used directly in an `if` statement instead of assigning it to the `success` variable
  - If `TryParse` fails, the `break` statement will end the loop, so there is no need to add `success` to the `while` condition
- We can also use the `break` statement with a `for` loop, if there are some cases where the loop should end before the counter reaches its last value
- For example, imagine that our program is given an `int` array that a user *partially* filled with numbers, and we need to find their product. The "unused" entries at the end of the array are all 0 (the default value of `int`), so the `for` loop needs to stop before the end of the array if it encounters a 0. A `break` statement can accomplish this:

```
int product = 1;
for(int i = 0; i < myArray.Length; i++)
{
    if(myArray[i] == 0)
        break;
    product *= myArray[i];
}
```

  - If `myArray[i]` is 0, the loop stops before it can multiply the product by 0
  - If all of the array entries are nonzero, though, the loop continues until `i` is equal to `myArray.Length`

20 foreach Loop

In C#, some objects can store several other objects. Arrays are one of them. The `foreach` statement provides an easy way to execute a statement or a block of statements for each element stored in an object.

20.1 Syntax

The syntax of the *foreach* statement is as follow:

```
foreach(Type ItemName in CollectionName)
{
   // the code for processing the ItemName
}
```

- **Type**: The type of items in the collection
- **ItemName**: The chosen item is accessible using ItemName
- **CollectionName**: The name of the collection Since, arrays are the only object that we study in this course, we will use the term array instead of the collections.
- The *foreach* statement picks an element from the array and copies it to *ItemName*.
- You are not allowed to change the value of *ItemName*, but if it is a complex object, you can change its member fields and properties.
- You should use `foreach` statement whenever you want to process only one element in each iteration.

20.2 Example 1

In the following example, we define an array of strings. Then, using the foreach statement, we print all the element of the array in the console. Not that to access the elements we **do not use indexes**.

```
string[] contries = { "USA", "Iran", "China", "Germany", "Canada" };
Console.WriteLine("Here is the list of eligible countries:");
foreach (string CntName in contries)
{
    Console.WriteLine(CntName);
    CntName = "something"; \\ Error: this is not allowed
}
```

20.3 Example 2

In the following example, we use *foreach* statement to accommodate an array of complex objects without dealing with indexes.

```
Employee[] empArray = new TestClass[5]; \\ Assume we have a class called Employee
foreach(TestClass m in empArray)
{
   Console.Write("Enter the name of the employee:");
   m.Name = Console.ReadLine();  \\ Assume the class Employee has a property called Name
}
```

21 Static

When we write:

```
Console.WriteLine(Math.PI);
```

The `Math` actually refers to *a class*, and not to *an object*. How is that?

Actually, everything in the `MATH` class is *static* (`public static class Math`), and the `PI` constant is actually public! (`public const double PI`).

Class attribute: can be static or not, public or private, a constant or variable.

```
public const double PI = 3.14159265358979;
```

We also have static methods:

```
Math.Min(x,y);
Math.Max(x,y);
Math.Pow(x,y);
```

A static member (variable, method, etc) belongs to the type of an object rather than to an instance of that type.

21.1 Static Class Members

Class member = methods and fields (attributes)

Motivation: the methods we are using the most (`WriteLine`, `ConsoleRead`) are static, but all the methods we are writing are not (they are "non-static", or "instance").

Static Method	Non-static Method
`ClassName.MethodName(arguments)`	`ObjectName.MethodName(arguments)`
`Math.Pow(2, 5)` ($2^5 = 32$)	`myRectangle.SetLength(5)`

A static class member is associated with the **class** instead of **with the object**.

\	Static Field	Non-static Field
Static method	✔ OK	✘ NO
Non-static method	✔ OK	✔ OK

22 A Static Class for Arrays

```
using System;
    static class Lib
    {
        public static int ValueIsIndex(int[] arrayP)
    {
        int res = 0;
        for (int i = 0; i < arrayP.Length; i++)
            if (arrayP[i] == i) res++;
        return res;
    }

    public static bool AtLeastOneValueIsIndex(int[] arrayP)
    {
        return (ValueIsIndex(arrayP) > 0);
    }
```

```
    public static int ValueMatch(int[] arrayP1, int[] arrayP2)
    {
        int res = 0;
        int smallestSize;
        if (arrayP1.Length < arrayP2.Length) smallestSize = arrayP1.Length;
        else smallestSize = arrayP2.Length;
        for (int i = 0; i < smallestSize; i++)
            if (arrayP1[i] == arrayP2[i]) res++;
        return res;
    }
}

using System;
    class Program
    {
        static void Main(string[] args)
        {
        int[] arrayA = {0, 3, 5, 12, 4, 5, 8 };
        Console.WriteLine(Lib.ValueIsIndex(arrayA));
        Console.WriteLine(Lib.AtLeastOneValueIsIndex(arrayA));

        int[] arrayB = {3, 5, 4, 12, 5, 8 };
        Console.WriteLine(Lib.ValueIsIndex(arrayB));
        Console.WriteLine(Lib.AtLeastOneValueIsIndex(arrayB));

        Console.WriteLine(Lib.ValueMatch(arrayA, arrayB));
        }
    }
```