Think Java

How to Think Like a Computer Scientist

2nd Edition, Version 7.1.0

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The original form of this book is LaTeX source code. Compiling this code has the effect of generating a device-independent representation of the book, which can be converted to other formats and printed.

The LaTeX source for this book is available from https://thinkjava.org/ and https://github.com/ChrisMayfield/ThinkJava2.

Contents

Preface

Think Java is an introduction to computer science and programming intended for readers with little or no experience. We start with the most basic concepts and are careful to define all terms when they are first used. The book presents each new idea in a logical progression. Larger topics, like control flow statements and object-oriented programming, are divided into smaller examples and introduced over the course of several chapters.

This book is intentionally concise. Each chapter is 12–14 pages and covers the material for one week of a college course. It is not meant to be a comprehensive presentation of Java, but rather, an initial exposure to programming constructs and techniques. We begin with small problems and basic algorithms and work up to object-oriented design. In the vocabulary of computer science pedagogy, this book uses the "objects late" approach.

The Philosophy Behind the Book

Here are the guiding principles that make the book the way it is:

One concept at a time: We break down topics that give beginners trouble into a series of small steps, so that they can exercise each new concept in isolation before continuing.

Balance of Java and concepts: The book is not primarily about Java; it uses code examples to demonstrate computer science. Most chapters start with language features and end with concepts.

Conciseness: An important goal of the book is to be small enough so that students can read and understand the entire text in a one-semester college or AP course.

Emphasis on vocabulary: We try to introduce the minimum number of terms and define them carefully when they are first used. We also organize them in glossaries at the end of each chapter.

Program development: There are many strategies for writing programs, including bottom-up, top-down, and others. We demonstrate multiple program development techniques, allowing readers to choose methods that work best for them.

Multiple learning curves: To write a program, you have to understand the algorithm, know the programming language, and be able to debug errors. We discuss these and other aspects throughout the book and summarize our advice in Appendix D.

Object-Oriented Programming

Some Java books introduce classes and objects immediately; others begin with procedural programming and transition to object-oriented more gradually.

Many of Java's object-oriented features are motivated by problems with previous languages, and their implementations are influenced by this history. Some of these features are hard to explain when people aren't familiar with the problems they solve.

We get to object-oriented programming as quickly as possible (beginning with Chapter 9). But we introduce concepts one at a time, as clearly as possible, in a way that allows readers to practice each idea in isolation before moving on. So it takes some time to get there.

You can't write Java programs (even Hello World) without encountering object-oriented features. In some cases we explain a feature briefly when it first appears, and then explain it more deeply later on.

If you read the entire book, you will see nearly every topic required for Java SE Programmer I certification. Supplemental lessons are available in the official Java tutorials on Oracle's website (`https://thinkjava.org/tutorial`).

This book is also well suited to prepare high school students for the AP Computer Science A exam, which includes object-oriented design and implementation. (AP is a registered trademark of The College Board.) A mapping of *Think Java* section numbers to the AP course is available on our website: https://thinkjava.org/.

Changes to the Second Edition

This new edition was written over several years, with feedback from dozens of instructors and hundreds of students. A complete history of all changes is available on GitHub. Here are some of the highlights:

Chapters 1–4: We reordered the material in Chapter 1 to present a more interesting balance of theory and practice. Chapters 2–3 are much cleaner now too. Methods are now presented in a single chapter, along with additional in-depth examples.

Chapters 5–8: We rearranged these chapters a lot, added many examples and new figures, and removed unnecessary details. Strings are covered earlier (before arrays) so that readers can apply them to loop problems. The material on recursion is now a chapter, and we added new sections to explain binary numbers and *CodingBat*.

Chapters 9–12: Our main goal for these chapters was to provide better explanations and more diagrams. Chapters 9–10 focus more on immutable versus mutable objects, and we added new sections on BigInteger and StringBuilder. The other content is largely the same, but it should be easier to understand now.

Chapters 13–17: We balanced the amount of content in Chapters 13–14 by moving ArrayLists earlier, and we implement the "War" card game as another example. Chapters 15–17 are brand new in this edition; they cover more advanced topics including 2D arrays, graphics, exceptions, abstract classes, interfaces, and events.

Appendixes: We added Appendix B to explain documentation comments and Javadoc in more detail. The other three appendixes that were present in the first edition have been revised for clarity and layout.

About the Appendixes

The chapters of this book are meant to be read in order, because each one builds on the previous one. We also include several appendixes with material that can be read at any time:

Appendix A, "Tools"

This appendix explains how to download and install Java so you can compile programs on your computer. It also provides a brief introduction to DrJava—an integrated development environment designed primarily for students—and other development tools, including Checkstyle for code quality and JUnit for testing.

Appendix B, "Javadoc"

It's important to document your classes and methods so that other programmers (including yourself in the future) will know how to use them. This appendix explains how to read documentation, how to write documentation, and how to use the Javadoc tool.

Appendix C, "Graphics"

Java provides libraries for working with graphics and animation, and these topics can be engaging for students. The libraries require object-oriented features that students will not completely understand until after Chapter 10, but they can be used much earlier.

Appendix D, "Debugging"

We provide debugging suggestions throughout the book, but this appendix provides many more suggestions on how to debug your programs. We recommend that you review this appendix frequently as you work through the book.

Using the Code Examples

Most of the code examples in this book are available from a Git repository at https://github.com/ChrisMayfield/ThinkJavaCode2. Git is a "version control system" that allows you to keep track of the files that make up a project. A collection of files under Git's control is called a "repository".

GitHub is a hosting service that provides storage for Git repositories and a convenient web interface. It provides several ways to work with the code:

- You can create a copy of the repository on GitHub by clicking the Fork button. If you don't already have a GitHub account, you'll need to create one. After forking, you'll have your own repository on GitHub that you can use to keep track of code you write. Then you can "clone" the repository, which downloads a copy of the files to your computer.
- Alternatively, you could clone the original repository without forking. If you choose this option, you don't need a GitHub account, but you won't be able to save your changes on GitHub.
- If you don't want to use Git at all, you can download the code in a ZIP archive using the Clone button on the GitHub page, or this link: https://thinkjava.org/code2zip.

After you clone the repository or unzip the ZIP file, you should have a directory named *ThinkJavaCode2* with a subdirectory for each chapter in the book.

The examples in this book were developed and tested using OpenJDK 11. If you are using a more recent version, everything should still work. If you are using an older version, some of the examples might not.

Acknowledgments

Many people have sent corrections and suggestions over the years, and we appreciate their valuable feedback! This list begins with Version 4.0 of the open source edition, so it omits those who contributed to earlier versions:

- Ellen Hildreth used this book to teach Data Structures at Wellesley College and submitted a whole stack of corrections and suggestions.
- Tania Passfield pointed out that some glossaries had leftover terms that no longer appeared in the text.
- Elizabeth Wiethoff noticed that the series expansion of $\exp(-x^2)$ was wrong. She has also worked on a Ruby version of the book.

- Matt Crawford sent in a whole patch file full of corrections.
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- Peter Knaggs ported the book to C#. https://www.rigwit.co.uk/think/sharp/
- Heidi Gentry-Kolen recorded several video lectures that follow the book. https://www.youtube.com/user/digipipeline
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- Michael Stewart made several suggestions for improving the first half of the book.
- Steven Richardson adapted the book for an online course and contributed many ideas for improving the text.
- Fazl Rahman provided detailed feedback, chapter by chapter, and offered many suggestions for improving the text.

We are especially grateful to the technical reviewers of the O'Reilly Media first edition: Blythe Samuels, David Wisneski, and Stephen Rose. They found errors, made many great suggestions, and helped make the book much better.

Likewise, we thank Marc Loy for his thorough review of the O'Reilly Media second edition. He contributed many corrections, insights, and clarifications.

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If you have additional comments or ideas about the text, please send them to: feedback@greenteapress.com.

Allen Downey and Chris Mayfield

Chapter 1

Computer Programming

The goal of this book is to teach you to think like a computer scientist. This way of thinking combines some of the best features of mathematics, engineering, and natural science. Like mathematicians, computer scientists use formal languages to denote ideas—specifically, computations. Like engineers, they design things, assembling components into systems and evaluating trade-offs among alternatives. And like scientists, they observe the behavior of complex systems, form hypotheses, and test predictions.

An important skill for a computer scientist is **problem solving**. It involves the ability to formulate problems, think creatively about solutions, and express solutions clearly and accurately. As it turns out, the process of learning to program computers is an excellent opportunity to develop problem-solving skills. On one level, you will be learning to write Java programs, a useful skill by itself. But on another level, you will use programming as a means to an end. As we go along, that end will become clearer.

1.1 What Is a Computer?

When people hear the word *computer*, they often think of a desktop or a laptop. Not surprisingly, searching for "computer" on Google Images (`https://images.google.com/`) displays rows and rows of these types of machines. However, in a more general sense, a computer can be any type of device that stores and processes data.

Dictionary.com defines a computer as "a programmable electronic device designed to accept data, perform prescribed mathematical and logical operations at high speed, and display the results of these operations. Mainframes, desktop and laptop computers, tablets, and smartphones are some of the different types of computers."

Each type of computer has its own unique design, but internally they all share the same type of **hardware**. The two most important hardware components are **processors** (or CPUs) that perform simple calculations and **memory** (or RAM) that temporarily stores information. Figure 1.1 shows what these components look like.

Figure 1.1: Example processor and memory hardware.

Users generally see and interact with touchscreens, keyboards, and monitors, but it's the processors and memory that perform the actual computation. Nowadays it's fairly standard, even for a smartphone, to have at least eight processors and four gigabytes (four billion cells) of memory.

1.2 What Is Programming?

A **program** is a sequence of instructions that specifies how to perform a computation on computer hardware. The computation might be something mathematical, like solving a system of equations or finding the roots of a polynomial. It could also be a symbolic computation, like searching and replacing text in a document or (strangely enough) compiling a program.

The details look different in different languages, but a few basic instructions appear in just about every language:

input: Get data from the keyboard, a file, a sensor, or some other device.

output: Display data on the screen, or send data to a file or other device.

math: Perform basic mathematical operations like addition and division.

decision: Check for certain conditions and execute the appropriate code.

repetition: Perform an action repeatedly, usually with some variation.

Believe it or not, that's pretty much all there is to it. Every program you've ever used, no matter how complicated, is made up of small instructions that look much like these. So you can think of **programming** as the process of breaking down a large, complex task into smaller and smaller subtasks. The process continues until the subtasks are simple enough to be performed with the electronic circuits provided by the hardware.

1.3 The Hello World Program

Traditionally, the first program you write when learning a new programming language is called the "Hello World" program. All it does is output the words `Hello, World!` to the screen. In Java, it looks like this:

```
public class Hello {

    public static void main(String[] args) {
        // generate some simple output
        System.out.println("Hello, World!");
    }
}
```

When this program runs, it displays the following:

```
Hello, World!
```

Notice that the output does not include the quotation marks.

Java programs are made up of *class* and *method* definitions, and methods are made up of *statements*. A **statement** is a line of code that performs a basic

action. In the Hello World program, this line is a **print statement** that displays a message to the user:

```
System.out.println("Hello, World!");
```

`System.out.println` displays results on the screen; the name `println` stands for "print line". Confusingly, *print* can mean both "display on the screen" and "send to the printer". In this book, we'll try to say "display" when we mean output to the screen. Like most statements, the print statement ends with a semicolon (`;`).

Java is "case-sensitive", which means that uppercase and lowercase are not the same. In the Hello World program, `System` has to begin with an uppercase letter; `system` and `SYSTEM` won't work.

A **method** is a named sequence of statements. This program defines one method named `main`:

```
public static void main(String[] args)
```

The name and format of `main` is special: when the program runs, it starts at the first statement in `main` and ends when it finishes the last statement. Later, you will see programs that define more than one method.

This program defines a class named `Hello`. For now, a **class** is a collection of methods; we'll have more to say about this later. You can give a class any name you like, but it is conventional to start with a capital letter. The name of the class has to match the name of the file it is in, so this class has to be in a file named *Hello.java*.

Java uses curly braces (`{` and `}`) to group things together. In *Hello.java*, the outermost braces contain the class definition, and the inner braces contain the method definition.

The line that begins with two slashes (`//`) is a **comment**, which is a bit of English text that explains the code. When Java sees `//`, it ignores everything from there until the end of the line. Comments have no effect on the execution of the program, but they make it easier for other programmers (and your future self) to understand what you meant to do.

1.4 Compiling Java Programs

The programming language you will learn in this book is Java, which is a **high-level language**. Other high-level languages you may have heard of include Python, C and C++, PHP, Ruby, and JavaScript.

Before they can run, programs in high-level languages have to be translated into a **low-level language**, also called "machine language". This translation takes some time, which is a small disadvantage of high-level languages. But high-level languages have two major advantages:

- It is *much* easier to program in a high-level language. Programs take less time to write, they are shorter and easier to read, and they are more likely to be correct.
- High-level languages are **portable**, meaning they can run on different kinds of computers with few or no modifications. Low-level programs can run on only one kind of computer.

Two kinds of programs translate high-level languages into low-level languages: interpreters and compilers. An **interpreter** reads a high-level program and executes it, meaning that it does what the program says. It processes the program a little at a time, alternately reading lines and performing computations. Figure 1.2 shows the structure of an interpreter.

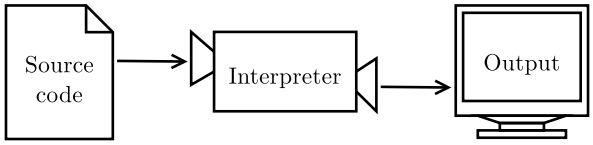


Figure 1.2: How interpreted languages are executed.

In contrast, a **compiler** reads the entire program and translates it completely before the program starts running. The high-level program is called the **source code**. The translated program is called the **object code**, or the **executable**. Once a program is compiled, you can execute it repeatedly without further translation of the source code. As a result, compiled programs often run faster than interpreted programs.

Note that object code, as a low-level language, is not portable. You cannot run an executable compiled for a Windows laptop on an Android phone, for

example. To run a program on different types of machines, it must be compiled multiple times. It can be difficult to write source code that compiles and runs correctly on different types of machines.

To address this issue, Java is *both* compiled and interpreted. Instead of translating source code directly into an executable, the Java compiler generates code for a **virtual machine**. This "imaginary" machine has the functionality common to desktops, laptops, tablets, phones, etc. Its language, called Java **byte code**, looks like object code and is easy and fast to interpret.

As a result, it's possible to compile a Java program on one machine, transfer the byte code to another machine, and run the byte code on that other machine. Figure 1.3 shows the steps of the development process. The Java compiler is a program named `javac`. It translates *.java* files into *.class* files that store the resulting byte code. The Java interpreter is another program, named `java`, which is short for "Java Virtual Machine" (JVM).

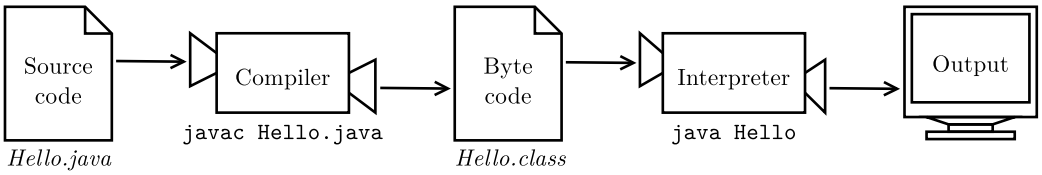


Figure 1.3: The process of compiling and running a Java program.

The programmer writes source code in the file *Hello.java* and uses `javac` to compile it. If there are no errors, the compiler saves the byte code in the file *Hello.class*. To run the program, the programmer uses `java` to interpret the byte code. The result of the program is then displayed on the screen.

Although it might seem complicated, these steps are automated for you in most development environments. Usually, you only have to press a button or type a single command to compile and interpret your program. On the other hand, it is important to know what steps are happening in the background, so if something goes wrong you can figure out what it is.

1.5 Displaying Two Messages

You can put as many statements as you like in the `main` method. For example, to display more than one line of output:

```
public class Hello2 {

    public static void main(String[] args) {
        // generate some simple output
        System.out.println("Hello, World!");  // first line
        System.out.println("How are you?");   // another line
    }
}
```

As this example also shows, you can put comments at the end of a line as well as on lines all by themselves.

Phrases that appear in quotation marks are called **strings**, because they contain a sequence of characters strung together in memory. Characters can be letters, numbers, punctuation marks, symbols, spaces, tabs, etc.

`System.out.println` appends a special character, called a **newline**, that moves to the beginning of the next line. If you don't want a newline at the end, you can use `print` instead of `println`:

```
public class Goodbye {

    public static void main(String[] args) {
        System.out.print("Goodbye, ");
        System.out.println("cruel world");
    }
}
```

In this example, the first statement does not add a newline, so the output appears on a single line:

```
Goodbye, cruel world
```

Notice that there is a space at the end of the first string, which appears in the output just before the word `cruel`.

1.6 Formatting Source Code

In Java source code, some spaces are required. For example, you need at least one space between words, so this program is not legal:

```
publicclassGoodbye{

    publicstaticvoidmain(String[] args) {
        System.out.print("Goodbye, ");
        System.out.println("cruel world");
    }
}
```

But most other spaces are optional. For example, this program *is* legal:

```
public class Goodbye {
public static void main(String[] args) {
System.out.print("Goodbye, ");
System.out.println("cruel world");
}
}
```

The newlines are optional, too. So we could just write this:

```
public class Goodbye { public static void main(String[] args)
{ System.out.print("Goodbye, "); System.out.println
("cruel world");}}
```

It still works, but the program is getting harder and harder to read. Newlines and spaces are important for visually organizing your program, making it easier to understand the program and find errors when they occur.

Many editors will automatically format source code with consistent indenting and line breaks. For example, in DrJava (see Appendix A.1) you can indent your code by selecting all text (Ctrl+A) and pressing the Tab key.

Organizations that do a lot of software development usually have strict guidelines on how to format source code. For example, Google publishes its Java coding standards for use in open source projects: https://google.github.io/styleguide/javaguide.html.

You probably won't understand these guidelines now, because they refer to language features you haven't yet seen. But you might want to refer to them periodically as you read this book.

1.7 Using Escape Sequences

It's possible to display multiple lines of output with only one line of code. You just have to tell Java where to put the line breaks:

```
public class Hello3 {

    public static void main(String[] args) {
        System.out.print("Hello!\nHow are you doing?\n");
    }
}
```

The output is two lines, each ending with a newline character:

```
Hello!
How are you doing?
```

Each `\n` is an **escape sequence**, or two characters of source code that represent a single character. (The backslash allows you to *escape* the string to write special characters.) Notice there is no space between `\n` and `How`. If you add a space there, there will be a space at the beginning of the second line.

`\n`	newline
`\t`	tab
`\"`	double quote
`\\`	backslash

Table 1.1: Common escape sequences

Java has a total of eight escape sequences, and the four most commonly used ones are listed in Table 1.1. For example, to write quotation marks inside of strings, you need to escape them with a backslash:

```
System.out.println("She said \"Hello!\" to me.");
```

The result is as follows:

```
She said "Hello!" to me.
```

1.8 What Is Computer Science?

This book intentionally omits some details about the Java language (such as the other escape sequences), because our main goal is teaching you how to think like a computer scientist. Being able to understand computation is much more valuable than just learning how to write code.

If you're interested in learning more about Java itself, Oracle maintains an official set of tutorials on its website (https://thinkjava.org/tutorial). The "Language Basics" tutorial, found under "Learning the Java Language", is a good place to start.

One of the most interesting aspects of writing programs is deciding how to solve a particular problem, especially when there are multiple solutions. For example, there are numerous ways to sort a list of numbers, and each way has its advantages. In order to determine which way is best for a given situation, we need techniques for describing and analyzing solutions formally.

An **algorithm** is a sequence of steps that specifies how to solve a problem. Some algorithms are faster than others, and some use less space in computer memory. **Computer science** is the science of algorithms, including their discovery and analysis. As you learn to develop algorithms for problems you haven't solved before, you will learn to think like a computer scientist.

Designing algorithms and writing code is difficult and error-prone. For historical reasons, programming errors are called **bugs**, and the process of tracking them down and correcting them is called **debugging**. As you learn to debug your programs, you will develop new problem-solving skills. You will need to think creatively when unexpected errors happen.

Although it can be frustrating, debugging is an intellectually rich, challenging, and interesting part of computer science. In some ways, debugging is like detective work. You are confronted with clues, and you have to infer the processes and events that led to the results you see. Thinking about how to correct programs and improve their performance sometimes even leads to the discovery of new algorithms.

1.9 Debugging Programs

It is a good idea to read this book in front of a computer so you can try out the examples as you go. You can run many of the examples directly in DrJava's Interactions pane (see Appendix A.2). But if you put the code in a source file, it will be easier to try out variations.

Whenever you are experimenting with a new feature, you should also try to make mistakes. For example, in the Hello World program, what happens if you leave out one of the quotation marks? What if you leave out both? What if you spell `println` wrong? These kinds of experiments help you remember what you read. They also help with debugging, because you learn what the error messages mean. It is better to make mistakes now and on purpose than later on and accidentally.

Debugging is like an experimental science: once you have an idea about what is going wrong, you modify your program and try again. If your hypothesis was correct, then you can predict the result of the modification, and you take a step closer to a working program. If your hypothesis was wrong, you have to come up with a new one.

Programming and debugging should go hand in hand. Don't just write a bunch of code and then perform trial-and-error debugging until it all works. Instead, start with a program that does *something* and make small modifications, debugging them as you go, until the program does what you want. That way, you will always have a working program, and isolating errors will be easier.

A great example of this principle is the Linux operating system, which contains millions of lines of code. It started out as a simple program Linus Torvalds used to explore the Intel 80386 chip. According to Larry Greenfield in *The Linux Users' Guide*, "One of Linus's earlier projects was a program that would switch between printing AAAA and BBBB. This later evolved to Linux."

Finally, programming sometimes brings out strong emotions. If you are struggling with a difficult bug, you might feel angry, despondent, or embarrassed. Remember that you are not alone, and virtually every programmer has had similar experiences. Don't hesitate to reach out to a friend and ask questions!

1.10 Vocabulary

Throughout the book, we try to define each term the first time we use it. At the end of each chapter, we include the new terms and their definitions in order of appearance. If you spend some time learning this vocabulary, you will have an easier time reading the following chapters.

problem solving: The process of formulating a problem, finding a solution, and expressing the solution.

hardware: The electronic and mechanical components of a computer, such as CPUs, RAM, and hard disks.

processor: A computer chip that performs simple instructions like basic arithmetic and logic.

memory: Circuits that store data as long as the computer is turned on. Not to be confused with permanent storage devices like hard disks and flash.

program: A sequence of instructions that specifies how to perform tasks on a computer. Also known as "software".

programming: The application of problem solving to creating executable computer programs.

statement: Part of a program that specifies one step of an algorithm.

print statement: A statement that causes output to be displayed on the screen.

method: A named sequence of statements.

class: For now, a collection of related methods. (You will see later that there is a lot more to it.)

comment: A part of a program that contains information about the program but has no effect when the program runs.

high-level language: A programming language that is designed to be easy for humans to read and write.

low-level language: A programming language that is designed to be easy for a computer to run. Also called "machine language".

portable: The ability of a program to run on more than one kind of computer.

interpret: To run a program in a high-level language by translating it one line at a time and immediately executing the corresponding instructions.

compile: To translate a program in a high-level language into a low-level language, all at once, in preparation for later execution.

source code: A program in a high-level language, before being compiled.

object code: The output of the compiler, after translating the program.

executable: Another name for object code that is ready to run on specific hardware.

virtual machine: An emulation of a real machine. The JVM enables a computer to run Java programs.

byte code: A special kind of object code used for Java programs. Byte code is similar to object code, but it is portable like a high-level language.

string: A sequence of characters; the primary data type for text.

newline: A special character signifying the end of a line of text. Also known as "line ending", "end of line" (EOL), or "line break".

escape sequence: A sequence of code that represents a special character when used inside a string.

algorithm: A procedure or formula for solving a problem, with or without a computer.

computer science: The scientific and practical approach to computation and its applications.

bug: An error in a program.

debugging: The process of finding and removing errors.

1.11 Exercises

At the end of each chapter, we include exercises you can do with the things you've learned. We encourage you to at least attempt every problem. You can't learn to program only by reading about it; you have to practice.

Before you can compile and run Java programs, you might have to download and install a few tools. There are many good options, but we recommend DrJava, which is an "integrated development environment" (IDE) well suited for beginners. Instructions for getting started are in Appendix A.

The code for this chapter is in the *ch01* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

Exercise 1.1 Computer scientists have the annoying habit of using common English words to mean something other than their common English meanings. For example, in English, statements and comments are the same thing, but in programs they are different.

1. In computer jargon, what's the difference between a *statement* and a *comment*?
2. What does it mean to say that a program is *portable*?
3. In common English, what does the word *compile* mean?
4. What is an *executable*? Why is that word used as a noun?

The vocabulary section at the end of each chapter is intended to highlight words and phrases that have special meanings in computer science. When you see familiar words, don't assume that you know what they mean!

Exercise 1.2 Before you do anything else, find out how to compile and run a Java program. Some environments provide sample programs similar to the example in Section 1.3.

1. Type in the Hello World program; then compile and run it.
2. Add a print statement that displays a second message after the `Hello, World!`. Say something witty like, `How are you?`. Compile and run the program again.

3. Add a comment to the program (anywhere), recompile, and run it again. The new comment should not affect the result.

This exercise may seem trivial, but it is the starting place for many of the programs we will work with. To debug with confidence, you will need to have confidence in your programming environment.

In some environments, it is easy to lose track of which program is executing. You might find yourself trying to debug one program while you are accidentally running another. Adding (and changing) print statements is a simple way to be sure that the program you are looking at is the program you are running.

Exercise 1.3 It is a good idea to commit as many errors as you can think of, so that you see what error messages the compiler produces. Sometimes the compiler tells you exactly what is wrong, and all you have to do is fix it. But sometimes the error messages are misleading. Over time you will develop a sense for when you can trust the compiler and when you have to figure things out yourself.

Starting with the Hello World program, try out each of the following errors. After you make each change, compile the program, read the error message (if there is one), and then fix the error.

1. Remove one of the opening curly braces.
2. Remove one of the closing curly braces.
3. Instead of `main`, write `mian`.
4. Remove the word `static`.
5. Remove the word `public`.
6. Remove the word `System`.
7. Replace `println` with `Println`.
8. Replace `println` with `print`.
9. Delete one parenthesis.
10. Add an extra parenthesis.

Chapter 2

Variables and Operators

This chapter describes how to write statements using *variables*, which store values like numbers and words, and *operators*, which are symbols that perform a computation. We also explain three kinds of programming errors and offer additional debugging advice.

To run the examples in this chapter, you will need to create a new Java class with a `main` method (see Section 1.3). Throughout the book, we often omit class and method definitions to keep the examples concise.

2.1 Declaring Variables

One of the most powerful features of a programming language is the ability to define and manipulate variables. A **variable** is a named location in memory that stores a **value**. Values may be numbers, text, images, sounds, and other types of data. To store a value, you first have to declare a variable:

```
String message;
```

This statement is called a **declaration**, because it declares that the variable `message` has the type `String`. Each variable has a **type** that determines what kind of values it can store. For example, the `int` type can store integers like `1` and `-5`, and the `char` type can store characters like `'A'` and `'z'`.

Some types begin with a capital letter and some with lowercase. You will learn the significance of this distinction later, but for now you should take care to get it right. There is no such type as `Int` or `string`.

To declare an integer variable named `x`, you simply type this:

```
int x;
```

Note that `x` is an arbitrary name for the variable. In general, you should use names that indicate what the variables mean:

```
String firstName;
String lastName;
int hour, minute;
```

This example declares two variables with type `String` and two with type `int`. The last line shows how to declare multiple variables with the same type: `hour` and `minute` are both integers. Note that each declaration statement ends with a semicolon (`;`).

Variable names usually begin with a lowercase letter, in contrast to class names (like `Hello`) that start with a capital letter. When a variable name contains more than one word (like `firstName`), it is conventional to capitalize the first letter of each subsequent word. Variable names are case-sensitive, so `firstName` is not the same as `firstname` or `FirstName`.

You can use any name you want for a variable. But there are about 50 reserved words, called **keywords**, that you are not allowed to use as variable names. These words include `public`, `class`, `static`, `void`, and `int`, which are used by the compiler to analyze the structure of the program.

You can see the full list of keywords (https://thinkjava.org/keywords), but you don't have to memorize them. Most programming editors provide "syntax highlighting", which makes different parts of the program appear in different colors. And the compiler will complain even if one does sneak past you and your editor.

2.2 Assigning Variables

Now that we have declared some variables, we can use them to store values. We do that with an **assignment** statement:

```
message = "Hello!";  // give message the value "Hello!"
hour = 11;           // assign the value 11 to hour
minute = 59;         // set minute to 59
```

This example shows three assignments, and the comments illustrate different ways people sometimes talk about assignment statements. The vocabulary can be confusing here, but the idea is straightforward:

- When you declare a variable, you create a named storage location.
- When you make an assignment to a variable, you update its value.

As a general rule, a variable has to have the same type as the value you assign to it. For example, you cannot store a string in `minute` or an integer in `message`. We will show some examples that seem to break this rule, but we'll get to that later.

A common source of confusion is that some strings *look* like integers, but they are not. For example, `message` can contain the string `"123"`, which is made up of the characters `'1'`, `'2'`, and `'3'`. But that is not the same thing as the integer `123`:

```
message = "123";     // legal
message = 123;       // not legal
```

Variables must be **initialized** (assigned for the first time) before they can be used. You can declare a variable and then assign a value later, as in the previous example. You can also declare and initialize on the same line:

```
String message = "Hello!";
int hour = 11;
int minute = 59;
```

2.3 Memory Diagrams

Because Java uses the `=` symbol for assignment, it is tempting to interpret the statement `a = b` as a statement of equality. It is not!

Equality is commutative, and assignment is not. For example, in mathematics if $a = 7$, then $7 = a$. In Java `a = 7;` is a legal assignment statement, but

`7 = a;` is not. The left side of an assignment statement has to be a variable name (storage location).

Also, in mathematics, a statement of equality is true for all time. If $a = b$ now, a is always equal to b. In Java, an assignment statement can make two variables equal, but they don't have to stay that way:

```
int a = 5;
int b = a;      // a and b are now equal
a = 3;          // a and b are no longer equal
```

The third line changes the value of `a`, but it does not change the value of `b`, so they are no longer equal.

Taken together, the variables in a program and their current values make up the program's **state**. Figure 2.1 shows the state of the program after these assignment statements run.

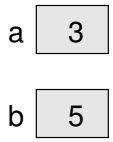


Figure 2.1: Memory diagram of the variables `a` and `b`.

Diagrams like this one that show the state of the program are called **memory diagrams**. Each variable is represented with a box showing the name of the variable on the outside and its current value inside.

As the program runs, the state of memory changes, so memory diagrams show only a particular point in time. For example, if we added the line `int c = 0;` to the previous example, the memory diagram would look like Figure 2.2.

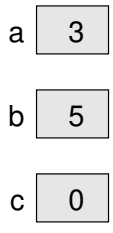


Figure 2.2: Memory diagram of the variables `a`, `b`, and `c`.

2.4 Printing Variables

You can display the current value of a variable by using `print` or `println`. The following statements declare a variable named `firstLine`, assign it the value `"Hello, again!"`, and display that value:

```
String firstLine = "Hello, again!";
System.out.println(firstLine);
```

When we talk about displaying a variable, we generally mean the *value* of the variable. To display the *name* of a variable, you have to put it in quotes:

```
System.out.print("The value of firstLine is ");
System.out.println(firstLine);
```

For this example, the output is as follows:

```
The value of firstLine is Hello, again!
```

Conveniently, the code for displaying a variable is the same regardless of its type. For example:

```
int hour = 11;
int minute = 59;
System.out.print("The current time is ");
System.out.print(hour);
System.out.print(":");
System.out.print(minute);
System.out.println(".");
```

The output of this program is shown here:

```
The current time is 11:59.
```

To output multiple values on the same line, it's common to use several `print` statements followed by `println` at the end. But don't forget the `println`! On many computers, the output from `print` is stored without being displayed until `println` is run; then the entire line is displayed at once. If you omit the `println`, the program might display the stored output at unexpected times or even terminate without displaying anything.

2.5 Arithmetic Operators

Operators are symbols that represent simple computations. For example, the addition operator is `+`, subtraction is `-`, multiplication is `*`, and division is `/`.

The following program converts a time of day to minutes:

```
int hour = 11;
int minute = 59;
System.out.print("Number of minutes since midnight: ");
System.out.println(hour * 60 + minute);
```

The output is as follows:

```
Number of minutes since midnight: 719
```

In this program, `hour * 60 + minute` is an **expression**, which represents a single value to be computed (`719`). When the program runs, each variable is replaced by its current value, and then the operators are applied. The values that operators work with are called **operands**.

Expressions are generally a combination of numbers, variables, and operators. When compiled and executed, they become a single value. For example, the expression `1 + 1` has the value `2`. In the expression `hour - 1`, Java replaces the variable with its value, yielding `11 - 1`, which has the value `10`.

In the expression `hour * 60 + minute`, both variables get replaced, yielding `11 * 60 + 59`. The multiplication happens first, yielding `660 + 59`. Then the addition yields `719`.

Addition, subtraction, and multiplication all do what you expect, but you might be surprised by division. For example, the following fragment tries to compute the fraction of an hour that has elapsed:

```
System.out.print("Fraction of the hour that has passed: ");
System.out.println(minute / 60);
```

The output is as follows:

```
Fraction of the hour that has passed: 0
```

This result often confuses people. The value of `minute` is `59`, and 59 divided by 60 should be 0.98333, not 0. The problem is that Java performs *integer division* when the operands are integers. By design, integer division always rounds toward zero, even in cases like this one where the next integer is close.

As an alternative, we can calculate a percentage rather than a fraction:

```
System.out.print("Percent of the hour that has passed: ");
System.out.println(minute * 100 / 60);
```

The new output is as follows:

```
Percent of the hour that has passed: 98
```

Again the result is rounded down, but at least now it's approximately correct.

2.6 Floating-Point Numbers

A more general solution is to use **floating-point** numbers, which represent values with decimal places. In Java, the default floating-point type is called `double`, which is short for "double-precision". You can create `double` variables and assign values to them the same way we did for the other types:

```
double pi;
pi = 3.14159;
```

Java performs *floating-point division* when one or more operands are `double` values. So we can solve the problem from the previous section:

```
double minute = 59.0;
System.out.print("Fraction of the hour that has passed: ");
System.out.println(minute / 60.0);
```

The output is shown here:

```
Fraction of the hour that has passed: 0.9833333333333333
```

Although floating-point numbers are useful, they can be a source of confusion. For example, Java distinguishes the integer value `1` from the floating-point value `1.0`, even though they seem to be the same number. They belong to

different data types, and strictly speaking, you are not allowed to make assignments between types.

The following is illegal because the variable on the left is an `int` and the value on the right is a `double`:

```
int x = 1.1;  // compiler error
```

It is easy to forget this rule, because in many cases Java *automatically* converts from one type to another:

```
double y = 1;  // legal, but bad style
```

The preceding example should be illegal, but Java allows it by converting the `int` value `1` to the `double` value `1.0` automatically. This leniency is convenient, but it often causes problems for beginners. For example:

```
double y = 1 / 3;  // common mistake
```

You might expect the variable `y` to get the value `0.333333`, which is a legal floating-point value. But instead it gets the value `0.0`. The expression on the right divides two integers, so Java does integer division, which yields the `int` value `0`. Converted to `double`, the value assigned to `y` is `0.0`.

One way to solve this problem (once you figure out the bug) is to make the right-hand side a floating-point expression. The following sets `y` to `0.333333`, as expected:

```
double y = 1.0 / 3.0;  // correct
```

As a matter of style, you should always assign floating-point values to floating-point variables. The compiler won't make you do it, but you never know when a simple mistake will come back and haunt you.

2.7 Rounding Errors

Most floating-point numbers are only *approximately* correct. Some numbers, like reasonably sized integers, can be represented exactly. But repeating fractions, like 1/3, and irrational numbers, like π, cannot. To represent these numbers, computers have to round off to the nearest floating-point number.

The difference between the number we want and the floating-point number we get is called **rounding error**. For example, the following two statements should be equivalent:

```
System.out.println(0.1 * 10);
System.out.println(0.1 + 0.1 + 0.1 + 0.1 + 0.1
                 + 0.1 + 0.1 + 0.1 + 0.1 + 0.1);
```

But on many machines, the output is as follows:

```
1.0
0.9999999999999999
```

The problem is that `0.1` is a repeating fraction when converted into binary. So its floating-point representation stored in memory is only approximate. When we add up the approximations, the rounding errors accumulate.

For many applications (like computer graphics, encryption, statistical analysis, and multimedia rendering), floating-point arithmetic has benefits that outweigh the costs. But if you need *absolute* precision, use integers instead. For example, consider a bank account with a balance of $123.45:

```
double balance = 123.45;  // potential rounding error
```

In this example, balances will become inaccurate over time as the variable is used in arithmetic operations like deposits and withdrawals. The result would be angry customers and potential lawsuits. You can avoid the problem by representing the balance as an integer:

```
int balance = 12345;      // total number of cents
```

This solution works as long as the number of cents doesn't exceed the largest `int`, which is about 2 billion.

2.8 Operators for Strings

In general, you cannot perform mathematical operations on strings, even if the strings look like numbers. The following expressions are illegal:

```
"Hello" - 1     "World" / 123     "Hello" * "World"
```

The + operator works with strings, but it might not do what you expect. For strings, the + operator performs **concatenation**, which means joining end-to-end. So `"Hello, " + "World!"` yields the string `"Hello, World!"`.

Likewise if you have a variable called `name` that has type `String`, the expression `"Hello, " + name` appends the value of `name` to the hello string, which creates a personalized greeting.

Since addition is defined for both numbers and strings, Java performs automatic conversions you may not expect:

```
System.out.println(1 + 2 + "Hello");
// the output is 3Hello

System.out.println("Hello" + 1 + 2);
// the output is Hello12
```

Java executes these operations from left to right. In the first line, `1 + 2` is `3`, and `3 + "Hello"` is `"3Hello"`. But in the second line, `"Hello" + 1` is `"Hello1"`, and `"Hello1" + 2` is `"Hello12"`.

When more than one operator appears in an expression, they are evaluated according to the **order of operations**. Generally speaking, Java evaluates operators from left to right (as you saw in the previous section). But for numeric operators, Java follows mathematical conventions:

- Multiplication and division take "precedence" over addition and subtraction, which means they happen first. So `1 + 2 * 3` yields 7, not 9, and `2 + 4 / 2` yields 4, not 3.
- If the operators have the same precedence, they are evaluated from left to right. So in the expression `minute * 100 / 60`, the multiplication happens first; if the value of `minute` is 59, we get `5900 / 60`, which yields 98. If these same operations had gone from right to left, the result would have been `59 * 1`, which is incorrect.
- Anytime you want to override the order of operations (or you are not sure what it is) you can use parentheses. Expressions in parentheses are evaluated first, so `(1 + 2) * 3` is 9. You can also use parentheses to make an expression easier to read, as in `(minute * 100) / 60`, even though it doesn't change the result.

See the official Java tutorials for a complete table of operator precedence (https://thinkjava.org/operators). If the order of operations is not obvious when looking at an expression, you can always add parentheses to make it more clear. But over time, you should internalize these kinds of details about the Java language.

2.9 Compiler Error Messages

Three kinds of errors can occur in a program: compile-time errors, run-time errors, and logic errors. It is useful to distinguish among them in order to track them down more quickly.

Compile-time errors occur when you violate the rules of the Java language. For example, parentheses and braces have to come in matching pairs. So `(1 + 2)` is legal, but `8)` is not. In the latter case, the program cannot be compiled, and the compiler displays a "syntax error".

Error messages from the compiler usually indicate where in the program the error occurred. Sometimes they can tell you exactly what the error is. As an example, let's get back to the Hello World program from Section 1.3:

```
public class Hello {

    public static void main(String[] args) {
        // generate some simple output
        System.out.println("Hello, World!");
    }
}
```

If you forget the semicolon at the end of the print statement, you might get an error message like this:

```
File: Hello.java  [line: 5]
Error: ';' expected
```

That's pretty good: the location of the error is correct, and the error message tells you what's wrong. But error messages are not always easy to understand. Sometimes the compiler reports the place in the program where the error was

detected, not where it actually occurred. And sometimes the description of the problem is more confusing than helpful.

For example, if you forget the closing brace at the end of `main` (line 6), you might get a message like this:

```
File: Hello.java  [line: 7]
Error: reached end of file while parsing
```

There are two problems here. First, the error message is written from the compiler's point of view, not yours. **Parsing** is the process of reading a program before translating; if the compiler gets to the end of the file while still parsing, that means something was omitted. But the compiler doesn't know what. It also doesn't know where. The compiler discovers the error at the end of the program (line 7), but the missing brace should be on the previous line.

Error messages contain useful information, so you should make an effort to read and understand them. But don't take them too literally. During the first few weeks of your programming career, you will probably spend a lot of time tracking down syntax and other compile-time errors. As you gain experience, you will make fewer mistakes and find them more quickly.

2.10 Other Types of Errors

The second type of error is a **run-time error**, so-called because it does not appear until after the program has started running. In Java, these errors occur while the interpreter is executing byte code and something goes wrong. These errors are also called "exceptions" because they usually indicate that something unexpected has happened.

Run-time errors are rare in the simple programs you will see in the first few chapters, so it might be a while before you encounter one. When a run-time error occurs, the program "crashes" (terminates) and displays an error message that explains what happened and where. For example, if you accidentally divide by zero, you will get a message like this:

```
Exception in thread "main" java.lang.ArithmeticException: / by zero
    at Hello.main(Hello.java:5)
```

Error messages are very useful for debugging. The first line includes the name of the exception, `ArithmeticException`, and a message that indicates more specifically what happened, division by zero. The next line shows the method where the error occurred; `Hello.main` indicates the method `main` in the class `Hello`. It also reports the file where the method is defined, `Hello.java`, and the line number where the error occurred, `5`.

The third type of error is a **logic error**. If your program has a logic error, it will compile and run without generating error messages, but it will not do the right thing. Instead, it will do exactly what you told it to do. For example, here is a version of the Hello World program with a logic error:

```
public class Hello {

    public static void main(String[] args) {
        System.out.println("Hello, ");
        System.out.println("World!");
    }
}
```

This program compiles and runs just fine, but the output is as follows:

```
Hello,
World!
```

Assuming that we wanted the output on one line, this is not correct. The problem is that the first line uses `println`, when we probably meant to use `print` (see the "Goodbye, cruel world" example of Section 1.5).

Identifying logic errors can be hard because you have to work backward, looking at the output of the program, trying to figure out why it is doing the wrong thing, and how to make it do the right thing. Usually, the compiler and the interpreter can't help you, since they don't know what the right thing is.

2.11 Vocabulary

variable: A named storage location for values. All variables have a type, which is declared when the variable is created.

value: A number, string, or other data that can be stored in a variable. Every value belongs to a type (e.g., `int` or `String`).

type: Mathematically speaking, a set of values. The type of a variable determines which values it can have.

declaration: A statement that creates a new variable and specifies its type.

keyword: A reserved word used by the compiler to analyze programs. You cannot use keywords (like `public`, `class`, and `void`) as variable names.

assignment: A statement that gives a value to a variable.

initialize: To assign a variable for the first time.

state: The variables in a program and their current values.

memory diagram: A graphical representation of the state of a program at a point in time.

operator: A symbol that represents a computation like addition, multiplication, or string concatenation.

operand: One of the values on which an operator operates. Most operators in Java require two operands.

expression: A combination of variables, operators, and values that represents a single value. Expressions also have types, as determined by their operators and operands.

floating-point: A data type that represents numbers with an integer part and a fractional part. In Java, the default floating-point type is `double`.

rounding error: The difference between the number we want to represent and the nearest floating-point number.

concatenate: To join two values, often strings, end to end.

order of operations: The rules that determine in what order expressions are evaluated. Also known as "operator precedence".

compile-time error: An error in the source code that makes it impossible to compile. Also called a "syntax error".

parse: To analyze the structure of a program; what the compiler does first.

run-time error: An error in a program that makes it impossible to run to completion. Also called an "exception".

logic error: An error in a program that makes it do something other than what the programmer intended.

2.12 Exercises

The code for this chapter is in the *ch02* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you have not already read Appendix A.2, now might be a good time. It describes the DrJava Interactions pane, which is a useful way to develop and test short fragments of code without writing a complete class definition.

Exercise 2.1 If you are using this book in a class, you might enjoy this exercise. Find a partner and play *Stump the Chump*:

Start with a program that compiles and runs correctly. One player looks away, while the other player adds an error to the program. Then the first player tries to find and fix the error. You get two points if you find the error without compiling the program, one point if you find it using the compiler, and your opponent gets a point if you don't find it.

Exercise 2.2 The point of this exercise is (1) to use string concatenation to display values with different types (`int` and `String`), and (2) to practice developing programs gradually by adding a few statements at a time.

1. Create a new program named *Date.java*. Copy or type in something like the Hello World program and make sure you can compile and run it.

2. Following the example in Section 2.4, write a program that creates variables named `day`, `date`, `month`, and `year`. The variable `day` will contain the day of the week (like Friday), and `date` will contain the day of the month (like the 13th). Assign values to those variables that represent today's date.

3. Display the value of each variable on a line by itself. This is an intermediate step that is useful for checking that everything is working so far. Compile and run your program before moving on.

4. Modify the program so that it displays the date in standard American format; for example: `Thursday, July 18, 2019`.

5. Modify the program so it also displays the date in European format. The final output should be as follows:

```
American format: Thursday, July 18, 2019
European format: Thursday 18 July 2019
```

Exercise 2.3 The point of this exercise is to (1) use some of the arithmetic operators, and (2) start thinking about compound entities (like time of day) that are represented with multiple values.

1. Create a new program called *Time.java*. From now on, we won't remind you to start with a small, working program, but you should.

2. Following the example program in Section 2.4, create variables named `hour`, `minute`, and `second`. Assign values that are roughly the current time. Use a 24-hour clock so that at 2:00 PM the value of `hour` is `14`.

3. Make the program calculate and display the number of seconds since midnight.

4. Calculate and display the number of seconds remaining in the day.

5. Calculate and display the percentage of the day that has passed. You might run into problems when computing percentages with integers, so consider using floating-point.

6. Change the values of `hour`, `minute`, and `second` to reflect the current time. Then write code to compute the elapsed time since you started working on this exercise.

Hint: You might want to use additional variables to hold values during the computation. Variables that are used in a computation but never displayed are sometimes called "intermediate" or "temporary" variables.

Chapter 3

Input and Output

The programs you've looked at so far simply display messages, which doesn't really involve that much computation. This chapter shows you how to read input from the keyboard, use that input to calculate a result, and then format that result for output.

3.1 The System Class

We have been using `System.out.println` for a while, but you might not have thought about what it means. `System` is a class that provides methods related to the "system", or environment, where programs run. It also provides `System.out`, which is a special value that has additional methods (like `println`) for displaying output.

In fact, we can use `System.out.println` to display the value of `System.out`:

```
System.out.println(System.out);
```

The result is shown here:

```
java.io.PrintStream@685d72cd
```

This output indicates that `System.out` is a `PrintStream`, which is defined in a package called `java.io`. A **package** is a collection of related classes; `java.io` contains classes for I/O which stands for "input and output".

The numbers and letters after the `@` sign are the **address** of `System.out`, represented as a hexadecimal (base 16) number. The address of a value is its location in the computer's memory, which might be different on different computers. In this example, the address is `685d72cd`, but if you run the same code, you will likely get something else.

As shown in Figure 3.1, `System` is defined in a file called *System.java*, and `PrintStream` is defined in *PrintStream.java*. These files are part of the Java **library**, which is an extensive collection of classes that you can use in your programs. The source code for these classes is usually included with the compiler (see Section 10.6).

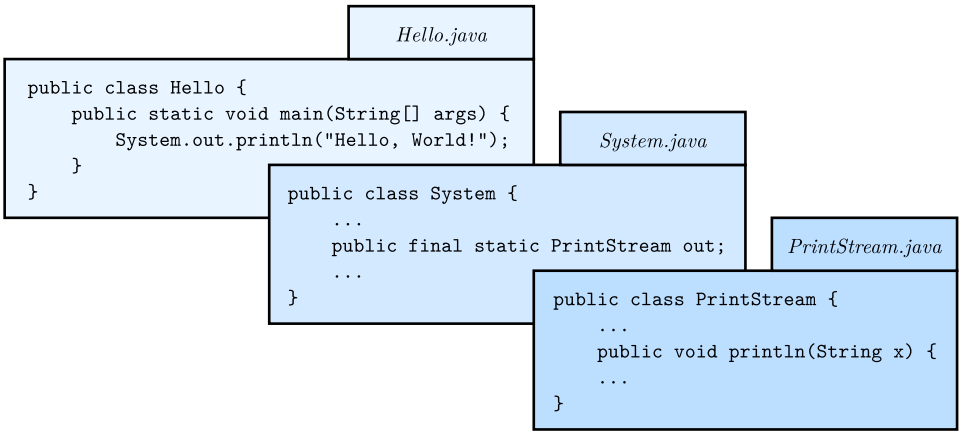


Figure 3.1: `System.out.println` refers to the `out` variable of the `System` class, which is a `PrintStream` that provides a method called `println`.

3.2 The Scanner Class

The `System` class also provides the special value `System.in`, which is an `InputStream` that has methods for reading input from the keyboard. These methods are not convenient to use, but fortunately Java provides other classes that make it easy to handle common input tasks.

For example, `Scanner` is a class that provides methods for inputting words, numbers, and other data. `Scanner` is provided by `java.util`, which is a package that contains various "utility classes". Before you can use `Scanner`, you have to import it like this:

```
import java.util.Scanner;
```

This **import statement** tells the compiler that when you refer to `Scanner`, you mean the one defined in `java.util`. Using an import statement is necessary because there might be another class named `Scanner` in another package.

Next you have to initialize the `Scanner`. This line declares a `Scanner` variable named `in` and creates a `Scanner` that reads input from `System.in`:

```
Scanner in = new Scanner(System.in);
```

The `Scanner` class provides a method called `nextLine` that reads a line of input from the keyboard and returns a `String`. Here's a complete example that reads two lines and repeats them back to the user:

```
import java.util.Scanner;

public class Echo {

    public static void main(String[] args) {
        String line;
        Scanner in = new Scanner(System.in);

        System.out.print("Type something: ");
        line = in.nextLine();
        System.out.println("You said: " + line);

        System.out.print("Type something else: ");
        line = in.nextLine();
        System.out.println("You also said: " + line);
    }
}
```

Import statements can't be inside a class definition. By convention, they are usually at the beginning of the file. If you omit the import statement, you get a compiler error like "cannot find symbol". That means the compiler doesn't know where to find the definition for `Scanner`.

You might wonder why we can use the `System` class without importing it. `System` belongs to the `java.lang` package, which is imported automatically.

According to the documentation, `java.lang` "provides classes that are fundamental to the design of the Java programming language." The `String` class is also part of `java.lang`.

3.3 Language Elements

At this point, we have seen nearly all of the organizational units that make up Java programs. Figure 3.2 shows how these "language elements" are related.

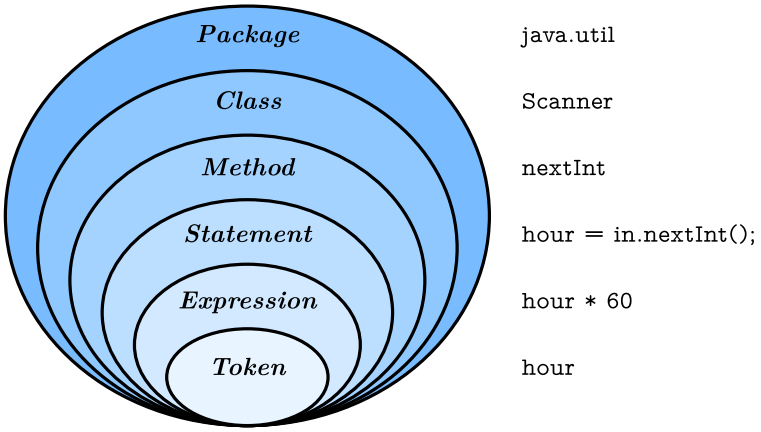


Figure 3.2: Elements of the Java language, from largest to smallest.

Java applications are typically organized into packages (like `java.io` and `java.util`) that include multiple classes (like `PrintStream` and `Scanner`). Each class defines its own methods (like `println` and `nextLine`), and each method is a sequence of statements.

Each statement performs one or more computations, depending on how many expressions it has, and each expression represents a single value to compute. For example, the assignment statement `hours = minutes / 60.0;` contains a single expression: `minutes / 60.0`.

Tokens are the most basic elements of a program, including numbers, variable names, operators, keywords, parentheses, braces, and semicolons. In the previous example, the tokens are `hours`, `=`, `minutes`, `/`, `60.0`, and `;` (spaces are ignored by the compiler).

Knowing this terminology is helpful, because error messages often say things like "not a statement" or "illegal start of expression" or "unexpected token". Comparing Java to English, statements are complete sentences, expressions are phrases, and tokens are individual words and punctuation marks.

Note there is a big difference between the Java *language*, which defines the elements in Figure 3.2, and the Java *library*, which provides the built-in classes that you can import. For example, the keywords `public` and `class` are part of the Java language, but the names `PrintStream` and `Scanner` are not.

The standard edition of Java comes with *several thousand* classes you can use, which can be both exciting and intimidating. You can browse this library on Oracle's website (https://thinkjava.org/apidoc). Interestingly, most of the Java library is written in Java.

3.4 Literals and Constants

Although most of the world has adopted the metric system for weights and measures, some countries are stuck with imperial units. For example, when talking with friends in Europe about the weather, people in the United States might have to convert from Celsius to Fahrenheit and back. Or they might want to convert height in inches to centimeters.

We can write a program to help. We'll use a `Scanner` to input a measurement in inches, convert to centimeters, and then display the results. The following lines declare the variables and create the `Scanner`:

```
int inch;
double cm;
Scanner in = new Scanner(System.in);
```

The next step is to prompt the user for the input. We'll use `print` instead of `println` so the user can enter the input on the same line as the **prompt**. And we'll use the `Scanner` method `nextInt`, which reads input from the keyboard and converts it to an integer:

```
System.out.print("How many inches? ");
inch = in.nextInt();
```

Next we multiply the number of inches by 2.54, since that's how many centimeters there are per inch, and display the results:

```
cm = inch * 2.54;
System.out.print(inch + " in = ");
System.out.println(cm + " cm");
```

This code works correctly, but it has a minor problem. If another programmer reads this code, they might wonder where 2.54 comes from. For the benefit of others (and yourself in the future), it would be better to assign this value to a variable with a meaningful name.

A value that appears in a program, like the number 2.54, is called a **literal**. In general, there's nothing wrong with literals. But when numbers like 2.54 appear in an expression with no explanation, they make the code hard to read. And if the same value appears many times and could change in the future, it makes the code hard to maintain.

Values like 2.54 are sometimes called **magic numbers** (with the implication that being magic is not a good thing). A good practice is to assign magic numbers to variables with meaningful names, like this:

```
double cmPerInch = 2.54;
cm = inch * cmPerInch;
```

This version is easier to read and less error-prone, but it still has a problem. Variables can vary (hence the term), but the number of centimeters in an inch does not. Once we assign a value to `cmPerInch`, it should never change. Java provides the keyword `final`, a language feature that enforces this rule:

```
final double CM_PER_INCH = 2.54;
```

Declaring that a variable is `final` means that it cannot be reassigned once it has been initialized. If you try, the compiler gives an error.

Variables declared as `final` are called **constants**. By convention, names for constants are all uppercase, with the underscore character (_) between words.

3.5 Formatting Output

When you output a `double` by using `print` or `println`, it displays up to 16 decimal places:

```
System.out.print(4.0 / 3.0);
```

The result is as follows:

```
1.3333333333333333
```

That might be more than you want. `System.out` provides another method, called `printf`, that gives you more control of the format. The "f" in `printf` stands for "formatted". Here's an example:

```
System.out.printf("Four thirds = %.3f", 4.0 / 3.0);
```

The first value in the parentheses is a **format string** that specifies how the output should be displayed. This format string contains ordinary text followed by a **format specifier**, which is a special sequence that starts with a percent sign. The format specifier `%.3f` indicates that the following value should be displayed as floating-point, rounded to three decimal places:

```
Four thirds = 1.333
```

The format string can contain any number of format specifiers; here's an example with two of them:

```
int inch = 100;
double cm = inch * CM_PER_INCH;
System.out.printf("%d in = %f cm\n", inch, cm);
```

The result is as follows:

```
100 in = 254.000000 cm
```

Like `print`, `printf` does not append a newline. So format strings often end with a newline character.

The format specifier `%d` displays integer values ("d" stands for "decimal", meaning base 10 integer). The values are matched up with the format specifiers in order, so `inch` is displayed using `%d`, and `cm` is displayed using `%f`.

Learning about format strings is like learning a sublanguage within Java. There are many options, and the details can be overwhelming. Table 3.1 lists a few common uses, to give you an idea of how things work.

`%d`	Integer in base 10 ("decimal")	`12345`
`%,d`	Integer with comma separators	`12,345`
`%08d`	Padded with zeros, at least 8 digits wide	`00012345`
`%f`	Floating-point number	`6.789000`
`%.2f`	Rounded to 2 decimal places	`6.79`
`%s`	String of characters	`"Hello"`
`%x`	Integer in base 16 ("hexadecimal")	`bc614e`

Table 3.1: Example format specifiers

For more details, refer to the documentation of `java.util.Formatter`. The easiest way to find documentation for Java classes is to do a web search for "Java" and the name of the class.

3.6 Reading Error Messages

Notice that the values you pass to `printf` are separated by commas. If you are used to using the `+` operator to concatenate strings, you might write something like this by accident:

```
System.out.printf("inches = %d" + inch);  // error
```

This line of code is legal, so the compiler won't catch the mistake. Instead, when you run the program, it causes an exception:

```
Exception in thread "main" java.util.MissingFormatArgumentException:
Format specifier '%d'
    at java.util.Formatter.format(Formatter.java:2519)
    at java.io.PrintStream.format(PrintStream.java:970)
    at java.io.PrintStream.printf(PrintStream.java:871)
    at Example.main(Example.java:10)
```

As you saw in Section 2.10, the error message includes the name of the exception, `MissingFormatArgumentException`, followed by additional details, `Format specifier '%d'`. That means it doesn't know what value to substitute for `%d`.

The problem is that concatenation happens first, before `printf` executes. If the value of `inch` is `100`, the result of concatenation is `"inches = %d100"`. So `printf` gets the format string, but it doesn't get any values to format.

The error message also includes a **stack trace** that shows the method that was running when the error was detected, `java.util.Formatter.format`; the method that ran it, `java.io.PrintStream.format`; the method that ran *that*, `java.io.PrintStream.printf`; and finally the method you actually wrote, `Example.main`.

Each line also names the source file of the method and the line it was on (e.g., `Example.java:10`). That's a lot of information, and it includes method names and filenames you have no reason to know at this point. But don't be overwhelmed.

When you see an error message like this, read the first line carefully to see *what* happened. Then read the last line to see *where* it happened. In some IDEs, you can click the error message, and it will take you to the line of code that was running. But remember that where the error is discovered is not always where it was caused.

3.7 Type Cast Operators

Now suppose we have a measurement in centimeters, and we want to round it off to the nearest inch. It is tempting to write this:

```
inch = cm / CM_PER_INCH;  // syntax error
```

But the result is an error—you get something like, "incompatible types: possible lossy conversion from double to int". The problem is that the value on the right is floating-point, and the variable on the left is an integer.

Java converts an `int` to a `double` automatically, since no information is lost in the process. On the other hand, going from `double` to `int` would lose the

decimal places. Java doesn't perform this operation automatically in order to ensure that you are aware of the loss of the fractional part of the number.

The simplest way to convert a floating-point value to an integer is to use a **type cast**, so called because it molds, or "casts", a value from one type to another. The syntax for type casting is to put the name of the type in parentheses and use it as an operator:

```
double pi = 3.14159;
int x = (int) pi;
```

The `(int)` operator has the effect of converting what follows into an integer. In this example, `x` gets the value `3`. Like integer division, casting to an integer always rounds toward zero, even if the fractional part is `0.999999` (or `-0.999999`). In other words, it simply throws away the fractional part.

In order to use a cast operator, the types must be compatible. For example, you can't cast a `String` to an `int` because a string is not a number:

```
String str = "3";
int x = (int) str;  // error: incompatible types
```

Type casting takes precedence over arithmetic operations. In the following example, the value of `pi` gets converted to an integer before the multiplication:

```
double pi = 3.14159;
double x = (int) pi * 20.0;  // result is 60.0, not 62.0
```

Keeping that in mind, here's how we can convert centimeters to inches:

```
inch = (int) (cm / CM_PER_INCH);
System.out.printf("%f cm = %d in\n", cm, inch);
```

The parentheses after the cast operator require the division to happen before the type cast. And the result is rounded toward zero. You will see in the next chapter how to round floating-point numbers to the closest integer.

3.8 Remainder Operator

Let's take the example one step further: suppose you have a measurement in inches and you want to convert to feet and inches. The goal is divide by 12 (the number of inches in a foot) and keep the remainder.

You have already seen the division operation (`/`), which computes the quotient of two numbers. If the numbers are integers, the operation is integer division. Java also provides the **modulo** operation (`%`), which divides two numbers and computes the remainder.

Using division and modulo, we can convert to feet and inches like this:

```
feet = 76 / 12;    // quotient
inches = 76 % 12;  // remainder
```

The first line yields 6. The second line, which is pronounced "76 mod 12", yields 4. So 76 inches is 6 feet, 4 inches.

Many people (and textbooks) incorrectly refer to `%` as the "modulus operator". In mathematics, however, **modulus** is the number you're dividing by. In the previous example, the modulus is 12.

The Java language specification refers to `%` as the "remainder operator". The remainder operator looks like a percent sign, but you might find it helpful to think of it as a division sign (÷) rotated to the left.

Modular arithmetic turns out to be surprisingly useful. For example, you can check whether one number is divisible by another: if `x % y` is `0`, then `x` is divisible by `y`. You can use the remainder operator to "extract" digits from a number: `x % 10` yields the rightmost digit of `x`, and `x % 100` yields the last two digits. And many encryption algorithms use remainders extensively.

3.9 Putting It All Together

At this point, you have seen enough Java to write useful programs that solve everyday problems. You can (1) import Java library classes, (2) create a `Scanner`, (3) get input from the keyboard, (4) format output with `printf`, and (5) divide and mod integers. Now we will put everything together in a complete program:

```
import java.util.Scanner;

/**
 * Converts centimeters to feet and inches.
 */
public class Convert {

    public static void main(String[] args) {
        double cm;
        int feet, inches, remainder;
        final double CM_PER_INCH = 2.54;
        final int IN_PER_FOOT = 12;
        Scanner in = new Scanner(System.in);

        // prompt the user and get the value
        System.out.print("Exactly how many cm? ");
        cm = in.nextDouble();

        // convert and output the result
        inches = (int) (cm / CM_PER_INCH);
        feet = inches / IN_PER_FOOT;
        remainder = inches % IN_PER_FOOT;
        System.out.printf("%.2f cm = %d ft, %d in\n",
                          cm, feet, remainder);
    }
}
```

Although not required, all variables and constants are declared at the top of `main`. This practice makes it easier to find their types later on, and it helps the reader know what data is involved in the algorithm.

For readability, each major step of the algorithm is separated by a blank line and begins with a comment. The class also includes a documentation comment (`/**`), which you can learn more about in Appendix B.

Many algorithms, including the `Convert` program, perform division and modulo together. In both steps, you divide by the same number (`IN_PER_FOOT`).

When statements including `System.out.printf` get long (generally wider

than 80 characters), a common style convention is to break them across multiple lines. The reader should never have to scroll horizontally.

3.10 The Scanner Bug

Now that you've had some experience with `Scanner`, we want to warn you about an unexpected behavior. The following code fragment asks users for their name and age:

```
System.out.print("What is your name? ");
name = in.nextLine();
System.out.print("What is your age? ");
age = in.nextInt();
System.out.printf("Hello %s, age %d\n", name, age);
```

The output might look something like this:

```
Hello Grace Hopper, age 45
```

When you read a `String` followed by an `int`, everything works just fine. But when you read an `int` followed by a `String`, something strange happens:

```
System.out.print("What is your age? ");
age = in.nextInt();
System.out.print("What is your name? ");
name = in.nextLine();
System.out.printf("Hello %s, age %d\n", name, age);
```

Try running this example code. It doesn't let you input your name, and it immediately displays the output:

```
What is your name? Hello , age 45
```

To understand what is happening, you need to realize that `Scanner` doesn't see input as multiple lines as we do. Instead, it gets a *stream of characters* as shown in Figure 3.3.

The arrow indicates the next character to be read by `Scanner`. When you run `nextInt`, it reads characters until it gets to a non-digit. Figure 3.4 shows the state of the stream after `nextInt` runs.

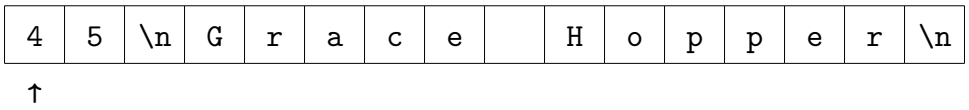


Figure 3.3: A stream of characters as seen by a `Scanner`.

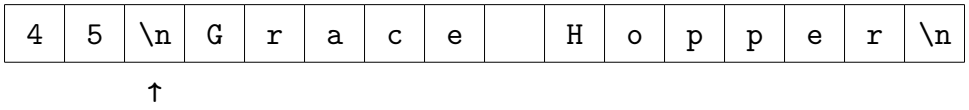


Figure 3.4: A stream of characters after `nextInt` runs.

At this point, `nextInt` returns the value `45`. The program then displays the prompt `"What is your name? "` and runs `nextLine`, which reads characters until it gets to a newline. But since the next character is already a newline, `nextLine` returns the empty string `""`.

To solve this problem, you need an extra `nextLine` after `nextInt`:

```
System.out.print("What is your age? ");
age = in.nextInt();
in.nextLine();  // read the newline
System.out.print("What is your name? ");
name = in.nextLine();
System.out.printf("Hello %s, age %d\n", name, age);
```

This technique is common when reading `int` or `double` values that appear on their own line. First you read the number, and then you read the rest of the line, which is just a newline character.

3.11 Vocabulary

package: A directory of classes that are related to each other.

address: The location of a value in computer memory, often represented as a hexadecimal integer.

library: A collection of packages and classes that are available for use in other programs.

import statement: A statement that allows programs to use classes defined in other packages.

token: The smallest unit of source code, such as an individual word, literal value, or symbol.

literal: A value that appears in source code. For example, `"Hello"` is a string literal, and `74` is an integer literal.

prompt: A brief message displayed in a print statement that asks the user for input.

magic number: A number that appears without explanation as part of an expression. It should generally be replaced with a constant.

constant: A variable, declared as `final`, whose value cannot be changed.

format string: The string in `System.out.printf` that specifies the format of the output.

format specifier: A special code that begins with a percent sign and specifies the data type and format of the corresponding value.

stack trace: An error message that shows the methods that were running when an exception occurs.

type cast: An operation that explicitly converts one data type into another. In Java, it appears as a type name in parentheses, like `(int)`.

modulo: An operation that yields the remainder when one integer is divided by another. In Java, it is denoted with a percent sign: `5 % 2` is `1`.

modulus: The value of `b` in the expression `a % b`. It often represents unit conversions, such as 24 hours in a day, 60 minutes in an hour, etc.

3.12 Exercises

The code for this chapter is in the *ch03* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you have not already read Appendix A.3, now might be a good time. It describes the command-line interface, which is a powerful and efficient way to interact with your computer.

Exercise 3.1 When you use `printf`, the Java compiler does not check your format string. See what happens if you try to display a value with type `int` using `%f`. And what happens if you display a `double` using `%d`? What if you use two format specifiers, but then provide only one value?

Exercise 3.2 Write a program that converts a temperature from Celsius to Fahrenheit. It should (1) prompt the user for input, (2) read a `double` value from the keyboard, (3) calculate the result, and (4) format the output to one decimal place. When it's finished, it should work like this:

```
Enter a temperature in Celsius: 24
24.0 C = 75.2 F
```

Here is the formula to do the conversion:

$$F = C \times \frac{9}{5} + 32$$

Hint: Be careful not to use integer division!

Exercise 3.3 Write a program that converts a total number of seconds to hours, minutes, and seconds. It should (1) prompt the user for input, (2) read an integer from the keyboard, (3) calculate the result, and (4) use `printf` to display the output. For example, `"5000 seconds = 1 hours, 23 minutes, and 20 seconds"`.

Hint: Use the remainder operator.

Exercise 3.4 The goal of this exercise is to program a *Guess My Number* game. When it's finished, it should work like this:

```
I'm thinking of a number between 1 and 100
(including both). Can you guess what it is?
Type a number: 45
Your guess is: 45
The number I was thinking of is: 14
You were off by: 31
```

To choose a random number, you can use the `Random` class in `java.util`. Here's how it works:

```
import java.util.Random;

public class GuessStarter {

    public static void main(String[] args) {
        // pick a random number
        Random random = new Random();
        int number = random.nextInt(100) + 1;
        System.out.println(number);
    }
}
```

Like the `Scanner` class in this chapter, `Random` has to be imported before we can use it. And as with `Scanner`, we have to use the `new` operator to create a `Random` (number generator).

Then we can use the method `nextInt` to generate a random number. In this example, the result of `nextInt(100)` will be between 0 and 99, including both. Adding 1 yields a number between 1 and 100, including both.

1. The definition of `GuessStarter` is in a file called *GuessStarter.java*, in the directory called *ch03*, in the repository for this book.

2. Compile and run this program.

3. Modify the program to prompt the user; then use a `Scanner` to read a line of user input. Compile and test the program.

4. Read the user input as an integer and display the result. Again, compile and test.

5. Compute and display the difference between the user's guess and the number that was generated.

Chapter 4

Methods and Testing

So far, we've written programs that have only one method, named `main`. In this chapter, we'll show you how to organize programs into multiple methods. We'll also take a look at the `Math` class, which provides methods for common mathematical operations. Finally, we'll discuss strategies for incrementally developing and testing your code.

4.1 Defining New Methods

Some methods perform a computation and return a result. For example, `nextDouble` reads input from the keyboard and returns it as a `double`. Other methods, like `println`, carry out a sequence of actions without returning a result. Java uses the keyword `void` to define such methods:

```
public static void newLine() {
    System.out.println();
}

public static void main(String[] args) {
    System.out.println("First line.");
    newLine();
    System.out.println("Second line.");
}
```

In this example, the `newLine` and `main` methods are both `public`, which means they can be **invoked** (or "called") from other classes. And they are both `void`, which means that they don't return a result (in contrast to `nextDouble`). The output of the program is shown here:

```
First line.

Second line.
```

Notice the extra space between the lines. If we wanted more space between them, we could invoke the same method repeatedly. Or we could write yet another method (named `threeLine`) that displays three blank lines:

```
public class NewLine {

    public static void newLine() {
        System.out.println();
    }

    public static void threeLine() {
        newLine();
        newLine();
        newLine();
    }

    public static void main(String[] args) {
        System.out.println("First line.");
        threeLine();
        System.out.println("Second line.");
    }
}
```

In this example, the name of the class is `NewLine`. By convention, class names begin with a capital letter. `NewLine` contains three methods, `newLine`, `threeLine`, and `main`. Remember that Java is case-sensitive, so `NewLine` and `newLine` are not the same.

By convention, method names begin with a lowercase letter and use "camel case", which is a cute name for `jammingWordsTogetherLikeThis`. You can use any name you want for methods, except `main` or any of the Java keywords.

4.2 Flow of Execution

When you look at a class definition that contains several methods, it is tempting to read it from top to bottom. But that is *not* the **flow of execution**, or the order the program actually runs. The `NewLine` program runs methods in the opposite order than they are listed.

Programs always begin at the first statement of `main`, regardless of where it is in the source file. Statements are executed one at a time, in order, until you reach a method invocation, which you can think of as a detour. Instead of going to the next statement, you jump to the first line of the invoked method, execute all the statements there, and then come back and pick up exactly where you left off.

That sounds simple enough, but remember that one method can invoke another one. In the middle of `main`, the previous example goes off to execute the statements in `threeLine`. While in `threeLine`, it goes off to execute `newLine`. Then `newLine` invokes `println`, which causes yet another detour.

Fortunately, Java is good at keeping track of which methods are running. So when `println` completes, it picks up where it left off in `newLine`; when `newLine` completes, it goes back to `threeLine`; and when `threeLine` completes, it gets back to `main`.

Beginners often wonder why it's worth the trouble to write other methods, when they could just do everything in `main`. The `NewLine` example demonstrates a few reasons:

- Creating a new method allows you to *name a block of statements*, which makes the code easier to read and understand.
- Introducing new methods can *make the program shorter* by eliminating repetitive code. For example, to display nine consecutive newlines, you could invoke `threeLine` three times.
- A common problem-solving technique is to *break problems down* into subproblems. Methods allow you to focus on each subproblem in isolation, and then compose them into a complete solution.

Perhaps most importantly, organizing your code into multiple methods allows you to test individual parts of your program separately. It's easier to get a complex program working if you know that each method works correctly.

4.3 Parameters and Arguments

Some of the methods we have used require **arguments**, which are the values you provide in parentheses when you invoke the method.

For example, the `println` method takes a `String` argument. To display a message, you have to provide the message: `System.out.println("Hello")`. Similarly, the `printf` method can take multiple arguments. The statement `System.out.printf("%d in = %f cm\n", inch, cm)` has three arguments: the format string, the `inch` value, and the `cm` value.

When you invoke a method, you provide the arguments. When you define a method, you name the **parameters**, which are variables that indicate what arguments are required. The following class shows an example:

```
public class PrintTwice {

    public static void printTwice(String s) {
        System.out.println(s);
        System.out.println(s);
    }

    public static void main(String[] args) {
        printTwice("Don't make me say this twice!");
    }
}
```

The `printTwice` method has a parameter named `s` with type `String`. When you invoke `printTwice`, you have to provide an argument with type `String`.

Before the method executes, the argument gets assigned to the parameter. In the `printTwice` example, the argument `"Don't make me say this twice!"` gets assigned to the parameter `s`.

This process is called **parameter passing**, because the value gets passed from outside the method to the inside. An argument can be any kind of expression, so if you have a `String` variable, you can use its value as an argument:

```
String message = "Never say never.";
printTwice(message);
```

The value you provide as an argument must have the same (or compatible) type as the parameter. For example, if you try this:

```
printTwice(17);  // syntax error
```

You will get an error message like this:

```
File: Test.java  [line: 10]
Error: method printTwice in class Test cannot be applied
       to given types;
  required: java.lang.String
  found: int
  reason: actual argument int cannot be converted to
          java.lang.String by method invocation conversion
```

This error message says that it found an `int` argument, but the required parameter should be a `String`. In the case of `printTwice`, Java won't convert the integer `17` to the string `"17"` automatically.

Sometimes Java can convert an argument from one type to another automatically. For example, `Math.sqrt` requires a `double`, but if you invoke `Math.sqrt(25)`, the integer value `25` is automatically converted to the floating-point value `25.0`.

Parameters and other variables exist only inside their own methods. In the `printTwice` example, there is no such thing as `s` in the `main` method. If you try to use it there, you'll get a compiler error.

Similarly, inside `printTwice` there is no such thing as `message`. That variable belongs to `main`. Because variables exist only inside the methods where they are defined, they are often called **local variables**.

4.4 Multiple Parameters

Here is an example of a method that takes two parameters:

```
public static void printTime(int hour, int minute) {
    System.out.print(hour);
    System.out.print(":");
    System.out.println(minute);
}
```

To invoke this method, we have to provide two integers as arguments:

```
int hour = 11;
int minute = 59;
printTime(hour, minute);
```

Beginners sometimes make the mistake of declaring the arguments:

```
int hour = 11;
int minute = 59;
printTime(int hour, int minute);  // syntax error
```

That's a syntax error, because the compiler sees `int hour` and `int minute` as variable declarations, not expressions that represent values. You wouldn't declare the types of the arguments if they were simply integers:

```
printTime(int 11, int 59);  // syntax error
```

Pulling together the code fragments, here is the complete program:

```
public class PrintTime {

    public static void printTime(int hour, int minute) {
        System.out.print(hour);
        System.out.print(":");
        System.out.println(minute);
    }

    public static void main(String[] args) {
        int hour = 11;
        int minute = 59;
        printTime(hour, minute);
    }
}
```

`printTime` has two parameters, named `hour` and `minute`. And `main` has two variables, also named `hour` and `minute`. Although they have the same names, these variables are *not* the same. The `hour` in `printTime` and the `hour` in `main` refer to different memory locations, and they can have different values.

For example, you could invoke `printTime` like this:

```
int hour = 11;
int minute = 59;
printTime(hour + 1, 0);
```

Before the method is invoked, Java evaluates the arguments; in this example, the results are `12` and `0`. Then it assigns those values to the parameters. Inside `printTime`, the value of `hour` is `12`, not `11`, and the value of `minute` is `0`, not `59`. Furthermore, if `printTime` modifies one of its parameters, that change has no effect on the variables in `main`.

4.5 Stack Diagrams

One way to keep track of variables is to draw a **stack diagram**, which is a memory diagram (see Section 2.3) that shows currently running methods. For each method there is a box, called a **frame**, that contains the method's parameters and local variables. The name of the method appears outside the frame; the variables and parameters appear inside.

As with memory diagrams, stack diagrams show variables and methods at a particular point in time. Figure 4.1 is a stack diagram at the beginning of the `printTime` method. Notice that `main` is on top, because it executed first.

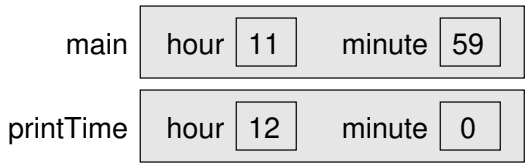


Figure 4.1: Stack diagram for `printTime(hour + 1, 0)`.

Stack diagrams help you to visualize the **scope** of a variable, which is the area of a program where a variable can be used.

Stack diagrams are a good mental model for how variables and methods work at run-time. Learning to trace the execution of a program on paper (or on a whiteboard) is a useful skill for communicating with other programmers.

Educational tools can automatically draw stack diagrams for you. For example, Java Tutor (https://thinkjava.org/javatutor) allows you to step

through an entire program, both forward and backward, and see the stack frames and variables at each step. If you haven't already, you should check out the Java examples on that website.

4.6 Math Methods

You don't always have to write new methods to get work done. As a reminder, the Java library contains thousands of classes you can use. For example, the `Math` class provides common mathematical operations:

```
double root = Math.sqrt(17.0);
double angle = 1.5;
double height = Math.sin(angle);
```

The first line sets `root` to the square root of 17. The third line finds the sine of 1.5 (the value of `angle`). `Math` is in the `java.lang` package, so you don't have to import it.

Values for the trigonometric functions—`sin`, `cos`, and `tan`—must be in *radians*. To convert from degrees to radians, you divide by 180 and multiply by π. Conveniently, the `Math` class provides a constant named `PI` that contains an approximation of π:

```
double degrees = 90;
double angle = degrees / 180.0 * Math.PI;
```

Notice that `PI` is in capital letters. Java does not recognize `Pi`, `pi`, or `pie`. Also, `PI` is the name of a constant, not a method, so it doesn't have parentheses. The same is true for the constant `Math.E`, which approximates Euler's number.

Converting to and from radians is a common operation, so the `Math` class provides methods that do that for you:

```
double radians = Math.toRadians(180.0);
double degrees = Math.toDegrees(Math.PI);
```

Another useful method is `round`, which rounds a floating-point value to the nearest integer and returns a `long`. The following result is 63 (rounded up from 62.8319):

```
long x = Math.round(Math.PI * 20.0);
```

A `long` is like an `int`, but bigger. More specifically, an `int` uses 32 bits of memory; the largest value it can hold is $2^{31} - 1$, which is about 2 billion. A `long` uses 64 bits, so the largest value is $2^{63} - 1$, which is about 9 quintillion.

Take a minute to read the documentation for these and other methods in the `Math` class. The easiest way to find documentation for Java classes is to do a web search for "Java" and the name of the class.

4.7 Composition

You have probably learned how to evaluate simple expressions like $\sin(\pi/2)$ and $\log(1/x)$. First, you evaluate the expression in parentheses, which is the argument of the function. Then you can evaluate the function itself, either by hand or by punching it into a calculator.

This process can be applied repeatedly to evaluate more-complex expressions like $\log(1/\sin(\pi/2))$. First we evaluate the argument of the innermost function ($\pi/2 = 1.57$), then evaluate the function itself ($\sin(1.57) = 1.0$), and so on.

Just as with mathematical functions, Java methods can be **composed** to solve complex problems. That means you can use one method as part of another. In fact, you can use any expression as an argument to a method, as long as the resulting value has the correct type:

```
double x = Math.cos(angle + Math.PI / 2.0);
```

This statement divides `Math.PI` by `2.0`, adds the result to `angle`, and computes the cosine of the sum. You can also take the result of one method and pass it as an argument to another:

```
double x = Math.exp(Math.log(10.0));
```

In Java, the `log` method always uses base e. So this statement finds the log base e of 10, and then raises e to that power. The result gets assigned to `x`.

Some math methods take more than one argument. For example, `Math.pow` takes two arguments and raises the first to the power of the second. This line computes 2^{10} and assigns the value `1024.0` to the variable `x`:

```
double x = Math.pow(2.0, 10.0);
```

When using `Math` methods, beginners often forget the word `Math`. For example, if you just write `x = pow(2.0, 10.0)`, you will get a compiler error:

```
File: Test.java  [line: 5]
Error: cannot find symbol
  symbol:   method pow(double,double)
  location: class Test
```

The message "cannot find symbol" is confusing, but the last two lines provide a useful hint. The compiler is looking for a method named `pow` in the file `Test.java` (the file for this example). If you don't specify a class name when referring to a method, the compiler looks in the current class by default.

4.8 Return Values

When you invoke a `void` method, the invocation is usually on a line all by itself. For example:

```
printTime(hour + 1, 0);
```

On the other hand, when you invoke a value-returning method, you have to do something with the return value. We usually assign it to a variable or use it as part of an expression, like this:

```
double error = Math.abs(expect - actual);
double height = radius * Math.sin(angle);
```

Compared to `void` methods, value-returning methods differ in two ways:

- They declare the type of the return value (the **return type**).
- They use at least one `return` statement to provide a **return value**.

Here's an example from a program named *Circle.java*. The `calculateArea` method takes a `double` as a parameter and returns the area of a circle with that radius (i.e., πr^2):

```
public static double calculateArea(double radius) {
    double result = Math.PI * radius * radius;
    return result;
}
```

As usual, this method is `public` and `static`. But in the place where we are used to seeing `void`, we see `double`, which means that the return value from this method is a `double`.

The last line is a new form of the `return` statement that means, "Return immediately from this method, and use the following expression as the return value." The expression you provide can be arbitrarily complex, so we could have written this method more concisely:

```
public static double calculateArea(double radius) {
    return Math.PI * radius * radius;
}
```

On the other hand, **temporary variables** like `result` often make debugging easier, especially when you are stepping through code by using an interactive debugger (see Appendix A.6).

Figure 4.2 illustrates how data values flows through the program. When the `main` method invokes `calculateArea`, the value `5.0` is assigned to the parameter `radius`. `calculateArea` then returns the value `78.54`, which is assigned to the variable `area`.

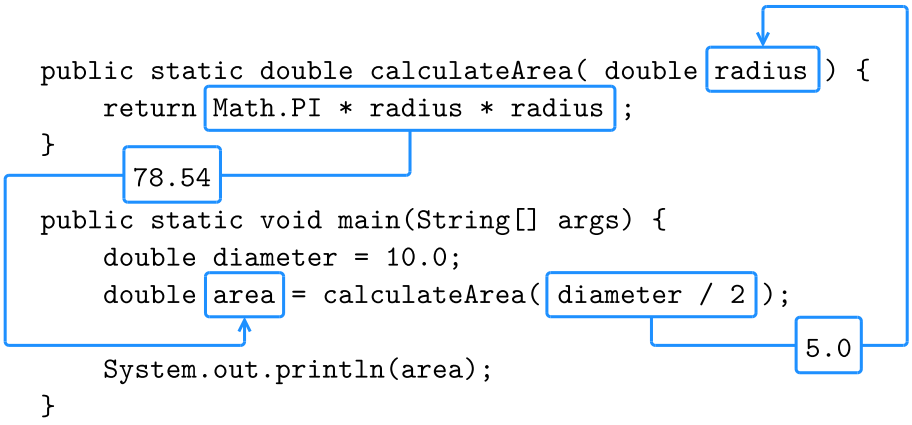


Figure 4.2: Passing a parameter and saving the return value.

The type of the expression in the `return` statement must match the return type of the method itself. When you declare that the return type is `double`, you are making a promise that this method will eventually produce a `double` value. If you try to `return` with no expression, or `return` an expression with the wrong type, the compiler will give an error.

4.9 Incremental Development

People often make the mistake of writing a lot of code before they try to compile and run it. Then they spend way too much time debugging. A better approach is **incremental development**. Its key aspects are as follows:

- Start with a working program and make small, incremental changes. At any point, if there is an error, you will know where to look.
- Use variables to hold intermediate values so you can check them, either with print statements or by using a debugger.
- Once the program is working, you can consolidate multiple statements into compound expressions (but only if it does not make the program more difficult to read).

As an example, suppose you want to find the distance between two points, given by the coordinates (x_1, y_1) and (x_2, y_2). By the usual definition:

$$distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

The first step is to consider what a `distance` method should look like in Java. In other words, what are the inputs (parameters) and what is the output (return value)? For this method, the parameters are the two points, and it is natural to represent them using four `double` values. The return value is the distance, which should also have type `double`.

Already we can write an outline for the method, which is sometimes called a **stub**. The stub includes the method declaration and a `return` statement:

```
public static double distance
        (double x1, double y1, double x2, double y2) {
    return 0.0;  // stub
}
```

The `return` statement is a placeholder that is necessary only for the program to compile. At this stage, the program doesn't do anything useful, but it is good to compile it so we can find any syntax errors before we add more code.

It's usually a good idea to think about testing *before* you develop new methods; doing so can help you figure out how to implement them. To test the method, we can invoke it from `main` by using the sample values:

```
double dist = distance(1.0, 2.0, 4.0, 6.0);
```

With these values, the horizontal distance is 3.0 and the vertical distance is 4.0. So the result should be 5.0, the hypotenuse of a 3-4-5 triangle. When you are testing a method, it is necessary to know the right answer.

Once we have compiled the stub, we can start adding code one line at a time. After each incremental change, we recompile and run the program. If there is an error, we have a good idea of where to look: the lines we just added.

The next step is to find the differences, $x_2 - x_1$ and $y_2 - y_1$. We store those values in temporary variables named `dx` and `dy`, so that we can examine them with print statements before proceeding. They should be 3.0 and 4.0:

```
public static double distance
        (double x1, double y1, double x2, double y2) {
    double dx = x2 - x1;
    double dy = y2 - y1;
    System.out.println("dx is " + dx);
    System.out.println("dy is " + dy);
    return 0.0;  // stub
}
```

We will remove the print statements when the method is finished. Code like that is called **scaffolding**, because it is helpful for building the program but is not part of the final product.

The next step is to square `dx` and `dy`. We could use the `Math.pow` method, but it is simpler (and more efficient) to multiply each term by itself. Then we add the squares and print the result so far:

```
public static double distance
        (double x1, double y1, double x2, double y2) {
    double dx = x2 - x1;
    double dy = y2 - y1;
    double dsquared = dx * dx + dy * dy;
    System.out.println("dsquared is " + dsquared);
    return 0.0;  // stub
}
```

Again, you should compile and run the program at this stage and check the intermediate value, which should be 25.0. Finally, we can use `Math.sqrt` to compute and return the result:

```
public static double distance
        (double x1, double y1, double x2, double y2) {
    double dx = x2 - x1;
    double dy = y2 - y1;
    double dsquared = dx * dx + dy * dy;
    double result = Math.sqrt(dsquared);
    return result;
}
```

As you gain more experience programming, you might write and debug more than one line at a time. But if you find yourself spending a lot of time debugging, consider taking smaller steps.

4.10 Vocabulary

void: A special return type indicating the method does not return a value.

invoke: To cause a method to execute. Also known as "calling" a method.

flow of execution: The order in which Java executes methods and statements. It may not necessarily be from top to bottom in the source file.

argument: A value that you provide when you call a method. This value must have the type that the method expects.

parameter: A piece of information that a method requires before it can run. Parameters are variables: they contain values and have types.

parameter passing: The process of assigning an argument value to a parameter variable.

local variable: A variable declared inside a method. Local variables cannot be accessed from outside their method.

stack diagram: A graphical representation of the variables belonging to each method. The method calls are "stacked" from top to bottom, in the flow of execution.

frame: In a stack diagram, a representation of the variables and parameters for a method, along with their current values.

scope: The area of a program where a variable can be used.

composition: The ability to combine simple expressions and statements into compound expressions and statements.

return type: The type of value a method returns.

return value: The value provided as the result of a method invocation.

temporary variable: A short-lived variable, often used for debugging.

incremental development: A process for creating programs by writing a few lines at a time, compiling, and testing.

stub: A placeholder for an incomplete method so that the class will compile.

scaffolding: Code that is used during program development but is not part of the final version.

4.11 Exercises

The code for this chapter is in the *ch04* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you have not already read Appendix A.4, now might be a good time. It describes an efficient way to test programs that take input from the user and display specific output.

Exercise 4.1 The purpose of this exercise is to take code from a previous exercise and redesign it as a method that takes parameters. Start with a working solution to Exercise 2.2.

1. Write a method called `printAmerican` that takes the day, date, month, and year as parameters and displays them in American format.

2. Test your method by invoking it from `main` and passing appropriate arguments. The output should look something like this (except the date might be different):

   ```
   Monday, July 22, 2019
   ```

3. Once you have debugged `printAmerican`, write another method called `printEuropean` that displays the date in European format.

Exercise 4.2 This exercise reviews the flow of execution through a program with multiple methods. Read the following code and answer the questions:

```
public static void main(String[] args) {
    zippo("rattle", 13);
}
```

```
public static void baffle(String blimp) {
    System.out.println(blimp);
    zippo("ping", -5);
}
```

```
public static void zippo(String quince, int flag) {
    if (flag < 0) {
        System.out.println(quince + " zoop");
    } else {
        System.out.println("ik");
        baffle(quince);
        System.out.println("boo-wa-ha-ha");
    }
}
```

1. Write the number 1 next to the first line of code in this program that will execute.

2. Write the number 2 next to the second line of code, and so on until the end of the program. If a line is executed more than once, it might end up with more than one number next to it.

3. What is the value of the parameter `blimp` when `baffle` gets invoked?

4. What is the output of this program?

Exercise 4.3 Answer the following questions without running the program on a computer.

1. Draw a stack diagram that shows the state of the program the first time `ping` is invoked.

2. What is output by the following program? Be precise about the placement of spaces and newlines.

```
public static void zoop() {
    baffle();
    System.out.print("You wugga ");
    baffle();
}
```

```
public static void main(String[] args) {
    System.out.print("No, I ");
    zoop();
    System.out.print("I ");
    baffle();
}
```

```
public static void baffle() {
    System.out.print("wug");
    ping();
}
```

```
public static void ping() {
    System.out.println(".");
}
```

Exercise 4.4 If you have a question about whether something is legal, and what happens if it is not, a good way to find out is to ask the compiler. Answer the following questions by trying them out.

1. What happens if you invoke a value method and don't do anything with the result; that is, if you don't assign it to a variable or use it as part of a larger expression?

2. What happens if you use a void method as part of an expression? For example, try `System.out.println("boo!") + 7;`.

Exercise 4.5 Draw a stack diagram that shows the state of the program the *second* time `zoop` is invoked. What is the complete output?

```
public static void zoop(String fred, int bob) {
    System.out.println(fred);
    if (bob == 5) {
        ping("not ");
    } else {
        System.out.println("!");
    }
}
```

```
public static void main(String[] args) {
    int bizz = 5;
    int buzz = 2;
    zoop("just for", bizz);
    clink(2 * buzz);
}
```

```
public static void clink(int fork) {
    System.out.print("It's ");
    zoop("breakfast ", fork);
}
```

```
public static void ping(String strangStrung) {
    System.out.println("any " + strangStrung + "more ");
}
```

Exercise 4.6 Many computations can be expressed more concisely using the "multadd" operation, which takes three operands and computes `a * b + c`. Some processors even provide a hardware implementation of this operation for floating-point numbers.

1. Create a new program called *Multadd.java*.
2. Write a method called `multadd` that takes three `doubles` as parameters and returns `a * b + c`.
3. Write a `main` method that tests `multadd` by invoking it with a few simple parameters, like `1.0, 2.0, 3.0`.
4. Also in `main`, use `multadd` to compute the following values:

$$\sin\frac{\pi}{4} + \frac{\cos\frac{\pi}{4}}{2}$$
$$\log 10 + \log 20$$

5. Write a method called `expSum` that takes a double as a parameter and uses `multadd` to calculate:

$$xe^{-x} + \sqrt{1 - e^{-x}}$$

   Hint: The method for raising e to a power is `Math.exp`.

In the last part of this exercise, you need to write a method that invokes another method you wrote. Whenever you do that, it is a good idea to test the first method carefully before working on the second. Otherwise, you might find yourself debugging two methods at the same time, which can be difficult.

One of the purposes of this exercise is to practice pattern-matching: the ability to recognize a specific problem as an instance of a general category of problems.

Chapter 5

Conditionals and Logic

The programs in the previous chapters do the same thing every time they are run, regardless of the input. For more-complex computations, programs usually react to inputs, check for certain conditions, and generate applicable results. This chapter introduces Java language features for expressing logic and making decisions.

5.1 Relational Operators

Java has six **relational operators** that test the relationship between two values (e.g., whether they are equal, or whether one is greater than the other). The following expressions show how they are used:

```
x == y          // x is equal to y
x != y          // x is not equal to y
x > y           // x is greater than y
x < y           // x is less than y
x >= y          // x is greater than or equal to y
x <= y          // x is less than or equal to y
```

The result of a relational operator is one of two special values: `true` or `false`. These values belong to the data type `boolean`, named after the mathematician George Boole. He developed an algebraic way of representing logic.

You are probably familiar with these operators, but notice how Java is different from mathematical symbols like $=$, $\neq$, and $\geq$. A common error is to use a single `=` instead of a double `==` when comparing values. Remember that `=` is the *assignment* operator, and `==` is a *relational* operator. Also, the operators `=<` and `=>` do not exist.

The two sides of a relational operator have to be compatible. For example, the expression `5 < "6"` is invalid because `5` is an `int` and `"6"` is a `String`. When comparing values of different numeric types, Java applies the same conversion rules you saw previously with the assignment operator. For example, when evaluating the expression `5 < 6.0`, Java automatically converts the `5` to `5.0`.

5.2 The if-else Statement

To write useful programs, we almost always need to check conditions and react accordingly. **Conditional statements** give us this ability. The simplest conditional statement in Java is the `if` statement:

```
if (x > 0) {
    System.out.println("x is positive");
}
```

The expression in parentheses is called the *condition*. If it is true, the statements in braces get executed. If the condition is false, execution skips over that **block** of code. The condition in parentheses can be any `boolean` expression.

A second form of conditional statement has two possibilities, indicated by `if` and `else`. The possibilities are called **branches**, and the condition determines which branch gets executed:

```
if (x % 2 == 0) {
    System.out.println("x is even");
} else {
    System.out.println("x is odd");
}
```

If the remainder when `x` is divided by 2 is 0, we know that `x` is even, and the program displays a message to that effect. If the condition is false, the second

print statement is executed instead. Since the condition must be true or false, exactly one of the branches will run.

The braces are optional for branches that have only one statement. So we could have written the previous example this way:

```
if (x % 2 == 0)
    System.out.println("x is even");
else
    System.out.println("x is odd");
```

However, it's better to use braces—even when they are optional—to avoid making the mistake of adding statements to a one-line `if` or `else` block. This code is misleading because it's not indented correctly:

```
if (x > 0)
    System.out.println("x is positive");
    System.out.println("x is not zero");
```

Since there are no braces, only the first `println` is part of the `if` statement. Here is what the compiler actually sees:

```
if (x > 0) {
    System.out.println("x is positive");
}
    System.out.println("x is not zero");
```

As a result, the second `println` runs no matter what. Even experienced programmers make this mistake; search the web for Apple's "goto fail" bug.

In all previous examples, notice that there is no semicolon at the end of the `if` or `else` lines. Instead, a new block should be defined using braces. Another common mistake is to put a semicolon after the condition, like this:

```
int x = 1;
if (x % 2 == 0); {  // incorrect semicolon
    System.out.println("x is even");
}
```

This code will compile, but the program will output `"x is even"` regardless of the value of `x`. Here is the same incorrect code with better formatting:

```
int x = 1;
if (x % 2 == 0)
    ;  // empty statement
{
    System.out.println("x is even");
}
```

Because of the semicolon, the `if` statement compiles as if there are no braces, and the subsequent block runs independently. As a general rule, each line of Java code should end with a semicolon or brace—but not both.

The compiler won't complain if you omit optional braces or write empty statements. Doing so is allowed by the Java language, but it often results in bugs that are difficult to find. Development tools like Checkstyle (see Appendix A.5) can warn you about these and other kinds of programming mistakes.

5.3 Chaining and Nesting

Sometimes you want to check related conditions and choose one of several actions. One way to do this is by **chaining** a series of `if` and `else` blocks:

```
if (x > 0) {
    System.out.println("x is positive");
} else if (x < 0) {
    System.out.println("x is negative");
} else {
    System.out.println("x is zero");
}
```

These chains can be as long as you want, although they can be difficult to read if they get out of hand. One way to make them easier to read is to use standard indentation, as demonstrated in these examples. If you keep all the statements and braces lined up, you are less likely to make syntax errors.

Notice that the last branch is simply `else`, not `else if (x == 0)`. At this point in the chain, we know that `x` is not positive and `x` is not negative. There is no need to test whether `x` is 0, because there is no other possibility.

In addition to chaining, you can also make complex decisions by **nesting** one conditional statement inside another. We could have written the previous example as follows:

```
if (x > 0) {
    System.out.println("x is positive");
} else {
    if (x < 0) {
        System.out.println("x is negative");
    } else {
        System.out.println("x is zero");
    }
}
```

The outer conditional has two branches. The first branch contains a print statement, and the second branch contains another conditional statement, which has two branches of its own. These two branches are also print statements, but they could have been conditional statements as well.

These kinds of nested structures are common, but they can become difficult to read very quickly. Good indentation is essential to make the structure (or intended structure) apparent to the reader.

5.4 The switch Statement

If you need to make a series of decisions, chaining `else if` blocks can get long and redundant. For example, consider a program that converts integers like 1, 2, and 3 into words like `"one"`, `"two"`, and `"three"`:

```
if (number == 1) {
    word = "one";
} else if (number == 2) {
    word = "two";
} else if (number == 3) {
    word = "three";
} else {
    word = "unknown";
}
```

This chain could go on and on, especially for banking programs that write numbers in long form (e.g., "one hundred twenty-three and 45/100 dollars"). An alternative way to evaluate many possible values of an expression is to use a `switch` statement:

```
switch (number) {
    case 1:
        word = "one";
        break;
    case 2:
        word = "two";
        break;
    case 3:
        word = "three";
        break;
    default:
        word = "unknown";
        break;
}
```

The body of a `switch` statement is organized into one or more `case` blocks. Each `case` ends with a `break` statement, which exits the `switch` body. The `default` block is optional and executed only if none of the cases apply.

Although `switch` statements appear longer than chained `else if` blocks, they are particularly useful when multiple cases can be grouped:

```
switch (food) {
    case "apple":
    case "banana":
    case "cherry":
        System.out.println("Fruit!");
        break;
    case "asparagus":
    case "broccoli":
    case "carrot":
        System.out.println("Vegetable!");
        break;
}
```

5.5 Logical Operators

In addition to the relational operators, Java also has three **logical operators**: `&&`, `||`, and `!`, which respectively stand for *and*, *or*, and *not*. The results of these operators are similar to their meanings in English. For example:

- `x > 0 && x < 10` is true when `x` is greater than 0 *and* less than 10.
- `x < 0 || x > 10` is true if either condition is true; that is, if `x` is less than 0 *or* greater than 10.
- `!(x > 0)` is true if `x` is *not* greater than 0. The parentheses are necessary in this example because, in the order of operations, `!` comes before `>`.

In order for an expression with `&&` to be true, both sides of the `&&` operator must be true. And in order for an expression with `||` to be false, both sides of the `||` operator must be false.

The `&&` operator can be used to simplify nested `if` statements. For example, the following code can be rewritten with a single condition:

```
if (x == 0) {
    if (y == 0) {
        System.out.println("Both x and y are zero");
    }
}
```

```
// combined
if (x == 0 && y == 0) {
    System.out.println("Both x and y are zero");
}
```

Likewise, the `||` operator can simplify chained `if` statements. Since the branches are the same, there is no need to duplicate that code:

```
if (x == 0) {
    System.out.println("Either x or y is zero");
} else if (y == 0) {
    System.out.println("Either x or y is zero");
}
```

```
// combined
if (x == 0 || y == 0) {
    System.out.println("Either x or y is zero");
}
```

Then again, if the statements in the branches were different, we could not combine them into one block. But it's useful to explore different ways of representing the same logic, especially when it's complex.

Logical operators evaluate the second expression *only when necessary*. For example, `true || anything` is always true, so Java does not need to evaluate the expression `anything`. Likewise, `false && anything` is always false.

Ignoring the second operand, when possible, is called **short-circuit** evaluation, by analogy with an electrical circuit. Short-circuit evaluation can save time, especially if `anything` takes a long time to evaluate. It can also avoid unnecessary errors, if `anything` might fail.

5.6 De Morgan's Laws

Sometimes you need to negate an expression containing a mix of relational and logical operators. For example, to test if `x` and `y` are both nonzero, you could write the following:

```
if (!(x == 0 || y == 0)) {
    System.out.println("Neither x nor y is zero");
}
```

This condition is difficult to read because of the `!` and parentheses. A better way to negate logic expressions is to apply **De Morgan's laws**:

- `!(A && B)` is the same as `!A || !B`
- `!(A || B)` is the same as `!A && !B`

In words, negating a logical expression is the same as negating each term and changing the operator. The `!` operator takes precedence over `&&` and `||`, so you don't have to put parentheses around the individual terms `!A` and `!B`.

De Morgan's laws also apply to the relational operators. In this case, negating each term means using the "opposite" relational operator:

- `!(x < 5 && y == 3)` is the same as `x >= 5 || y != 3`
- `!(x >= 1 || y != 7)` is the same as `x < 1 && y == 7`

It may help to read these examples out loud in English. For instance, "If I don't want the case where x is less than 5 and y is 3, then I need x to be greater than or equal to 5, or I need y to be anything but 3."

Returning to the previous example, here is the revised condition. In English, it reads, "If x is not zero and y is not zero." The logic is the same, and the source code is easier to read:

```
if (x != 0 && y != 0) {
    System.out.println("Neither x nor y is zero");
}
```

5.7 Boolean Variables

To store a `true` or `false` value, you need a `boolean` variable. You can declare and assign them like other variables. In this example, the first line is a variable declaration, the second is an assignment, and the third is both:

```
boolean flag;
flag = true;
boolean testResult = false;
```

Since relational and logical operators evaluate to a `boolean` value, you can store the result of a comparison in a variable:

```
boolean evenFlag = (x % 2 == 0);     // true if x is even
boolean positiveFlag = (x > 0);      // true if x is positive
```

The parentheses are unnecessary, but they make the code easier to understand. A variable defined in this way is called a **flag**, because it signals, or "flags", the presence or absence of a condition.

You can use flag variables as part of a conditional statement:

```
if (evenFlag) {
    System.out.println("n was even when I checked it");
}
```

Flags may not seem that useful at this point, but they will help simplify complex conditions later. Each part of a condition can be stored in a separate flag, and these flags can be combined with logical operators.

Notice that we didn't have to write `if (evenFlag == true)`. Since `evenFlag` is a `boolean`, it's already a condition. To check if a flag is `false`, we simply negate the flag:

```
if (!evenFlag) {
    System.out.println("n was odd when I checked it");
}
```

In general, you should never compare anything to `true` or `false`. Doing so makes the code more verbose and awkward to read out loud.

5.8 Boolean Methods

Methods can return `boolean` values, just like any other type, which is often convenient for hiding tests inside methods. For example:

```
public static boolean isSingleDigit(int x) {
    if (x > -10 && x < 10) {
        return true;
    } else {
        return false;
    }
}
```

The name of this method is `isSingleDigit`. It is common to give `boolean` methods names that sound like yes/no questions. Since the return type is `boolean`, the return statement has to provide a boolean expression.

The code itself is straightforward, although it is longer than it needs to be. Remember that the expression `x > -10 && x < 10` has type `boolean`, so there is nothing wrong with returning it directly (without the `if` statement):

```
public static boolean isSingleDigit(int x) {
    return x > -10 && x < 10;
}
```

In `main`, you can invoke the method in the usual ways:

```
System.out.println(isSingleDigit(2));
boolean bigFlag = !isSingleDigit(17);
```

The first line displays `true` because 2 is a single-digit number. The second line sets `bigFlag` to `true`, because 17 is *not* a single-digit number.

Conditional statements often invoke `boolean` methods and use the result as the condition:

```
if (isSingleDigit(z)) {
    System.out.println("z is small");
} else {
    System.out.println("z is big");
}
```

Examples like this one almost read like English: "If is single digit z, print z is small else print z is big."

5.9 Validating Input

One of the most important tasks in any computer program is to **validate** input from the user. People often make mistakes while typing, especially on smartphones, and incorrect inputs may cause your program to fail.

Even worse, someone (i.e., a **hacker**) may intentionally try to break into your system by entering unexpected inputs. You should never assume that users will input the right kind of data.

Consider this simple program that prompts the user for a number and computes its logarithm:

```
Scanner in = new Scanner(System.in);
System.out.print("Enter a number: ");
double x = in.nextDouble();
double y = Math.log(x);
System.out.println("The log is " + y);
```

In mathematics, the natural logarithm (base e) is undefined when $x \leq 0$. In Java, if you ask for `Math.log(-1)`, it returns **NaN**, which stands for "not a number". We can check for this condition and print an appropriate message:

```
if (x > 0) {
    double y = Math.log(x);
    System.out.println("The log is " + y);
} else {
    System.out.println("The log is undefined");
}
```

The output is better now, but there is another problem. What if the user doesn't enter a number at all? What would happen if they typed the word "hello", either by accident or on purpose?

```
Exception in thread "main" java.util.InputMismatchException
    at java.util.Scanner.throwFor(Scanner.java:864)
    at java.util.Scanner.next(Scanner.java:1485)
    at java.util.Scanner.nextDouble(Scanner.java:2413)
    at Logarithm.main(Logarithm.java:8)
```

If the user inputs a `String` when we expect a `double`, Java reports an "input mismatch" exception. We can prevent this run-time error from happening by testing the input first.

The `Scanner` class provides `hasNextDouble`, which checks whether the next input can be interpreted as a `double`. If not, we can display an error message:

```
if (!in.hasNextDouble()) {
    String word = in.next();
    System.err.println(word + "is not a number");
}
```

In contrast to `in.nextLine`, which returns an entire line of input, the `in.next` method returns only the next token of input. We can use `in.next` to show the user exactly which word they typed was not a number.

This example also uses `System.err`, which is an `OutputStream` for error messages and warnings. Some development environments display output to `System.err` with a different color or in a separate window.

5.10 Example Program

In this chapter, you have seen relational and logical operators, `if` statements, boolean methods, and validating input. The following program shows how the individual code examples in the previous section fit together:

```
import java.util.Scanner;

/**
 * Demonstrates input validation using if statements.
 */
public class Logarithm {

    public static void main(String[] args) {

        // prompt for input
        Scanner in = new Scanner(System.in);
        System.out.print("Enter a number: ");

        // check the format
        if (!in.hasNextDouble()) {
            String word = in.next();
            System.err.println(word + " is not a number");
            return;
        }

        // check the range
        double x = in.nextDouble();
        if (x > 0) {
            double y = Math.log(x);
            System.out.println("The log is " + y);
        } else {
            System.out.println("The log is undefined");
        }
    }
}
```

Notice that the `return` statement allows you to exit a method before you reach the end of it. Returning from `main` terminates the program.

What started as five lines of code at the beginning of Section 5.9 is now a 30-line program. Making programs robust (and secure) often requires a lot of additional checking, as shown in this example.

It's important to write comments every few lines to make your code easier to understand. Comments not only help other people read your code, but also help you document what you're trying to do. If there's a mistake in the code, finding it will be a lot easier when there are good comments.

5.11 Vocabulary

boolean: A data type with only two possible values, `true` and `false`.

relational operator: An operator that compares two values and produces a `boolean` indicating the relationship between them.

conditional statement: A statement that uses a condition to determine which statements to execute.

block: A sequence of statements, surrounded by braces, that generally runs as the result of a condition.

branch: One of the alternative blocks after a conditional statement. For example, an `if-else` statement has two branches.

chaining: A way of joining several conditional statements in sequence.

nesting: Putting a conditional statement inside one or both branches of another conditional statement.

logical operator: An operator that combines boolean values and produces a boolean value.

short circuit: A way of evaluating logical operators that evaluates the second operand only if necessary.

De Morgan's laws: Mathematical rules that show how to negate a logical expression.

flag: A variable (usually `boolean`) that represents a condition or status.

validate: To confirm that an input value is of the correct type and within the expected range.

hacker: A programmer who breaks into computer systems. The term hacker may also apply to someone who enjoys writing code.

NaN: A special floating-point value that stands for "not a number".

5.12 Exercises

The code for this chapter is in the *ch05* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you have not already read Appendix A.5, now might be a good time. It describes Checkstyle, a tool that analyzes many aspects of your source code.

Exercise 5.1 Rewrite the following code by using a single `if` statement:

```
if (x > 0) {
    if (x < 10) {
        System.out.println("positive single digit number.");
    }
}
```

Exercise 5.2 Now that we have conditional statements, we can get back to the *Guess My Number* game from Exercise 3.4.

You should already have a program that chooses a random number, prompts the user to guess it, and displays the difference between the guess and the chosen number.

By adding a small amount of code at a time and testing as you go, modify the program so it tells the user whether the guess is too high or too low, and then prompts the user for another guess.

The program should continue until the user gets it right or guesses incorrectly three times. If the user guesses the correct number, display a message and terminate the program.

Exercise 5.3 Fermat's Last Theorem says that there are no integers a, b, c, and n such that $a^n + b^n = c^n$, except when $n \leq 2$.

Write a program named *Fermat.java* that inputs four integers (`a`, `b`, `c`, and `n`) and checks to see if Fermat's theorem holds. If n is greater than 2 and $a^n + b^n = c^n$, the program should display "Holy smokes, Fermat was wrong!" Otherwise, the program should display "No, that doesn't work."

Hint: You might want to use `Math.pow`.

Exercise 5.4 Using the following variables, evaluate the logic expressions in the table that follows. Write your answers as true, false, or error.

```
boolean yes = true;
boolean no = false;
int loVal = -999;
int hiVal = 999;
double grade = 87.5;
double amount = 50.0;
String hello = "world";
```

Expression	Result
`yes == no || grade > amount`	
`amount == 40.0 || 50.0`	
`hiVal != loVal || loVal < 0`	
`True || hello.length() > 0`	
`hello.isEmpty() && yes`	
`grade <= 100 && !false`	
`!yes || no`	
`grade > 75 > amount`	
`amount <= hiVal && amount >= loVal`	
`no && !no || yes && !yes`	

Exercise 5.5 What is the output of the following program? Determine the answer without using a computer.

```
public static void main(String[] args) {
    boolean flag1 = isHoopy(202);
    boolean flag2 = isFrabjuous(202);
    System.out.println(flag1);
    System.out.println(flag2);
    if (flag1 && flag2) {
        System.out.println("ping!");
    }
    if (flag1 || flag2) {
        System.out.println("pong!");
    }
}
```

```
public static boolean isHoopy(int x) {
    boolean hoopyFlag;
    if (x % 2 == 0) {
        hoopyFlag = true;
    } else {
        hoopyFlag = false;
    }
    return hoopyFlag;
}
```

```
public static boolean isFrabjuous(int x) {
    boolean frabjuousFlag;
    if (x > 0) {
        frabjuousFlag = true;
    } else {
        frabjuousFlag = false;
    }
    return frabjuousFlag;
}
```

The purpose of this exercise is to make sure you understand logical operators and the flow of execution through methods.

Exercise 5.6 Write a program named *Quadratic.java* that finds the roots of $ax^2 + bx + c = 0$ using the quadratic formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Prompt the user to input integers for a, b, and c. Compute the two solutions for x, and display the results.

Your program should be able to handle inputs for which there is only one or no solution. Specifically, it should not divide by zero or take the square root of a negative number.

Be sure to validate all inputs. The user should never see an input mismatch exception. Display specific error messages that include the invalid input.

Exercise 5.7 If you are given three sticks, you may or may not be able to arrange them in a triangle. For example, if one of the sticks is 12 inches long and the other two are 1 inch long, you will not be able to get the short sticks to meet in the middle. For any three lengths, there is a simple test to see if it is possible to form a triangle:

> If any of the three lengths is greater than the sum of the other two, you cannot form a triangle.

Write a program named *Triangle.java* that inputs three integers, and then outputs whether you can (or cannot) form a triangle from the given lengths. Reuse your code from the previous exercise to validate the inputs. Display an error if any of the lengths are negative or zero.

Chapter 6

Loops and Strings

Computers are often used to automate repetitive tasks, such as searching for text in documents. Repeating tasks without making errors is something that computers do well and people do poorly.

In this chapter, you'll learn how to use `while` and `for` loops to add repetition to your code. We'll also take a first look at `String` methods and solve some interesting problems.

6.1 The while Statement

Using a `while` statement, we can repeat the same code multiple times:

```
int n = 3;
while (n > 0) {
    System.out.println(n);
    n = n - 1;
}
System.out.println("Blastoff!");
```

Reading the code in English sounds like this: "Start with `n` set to 3. While `n` is greater than 0, print the value of `n`, and reduce the value of `n` by 1. When you get to 0, print Blastoff!"

The output is shown here:

```
3
2
1
Blastoff!
```

The flow of execution for a `while` statement is as follows:

1. Evaluate the condition in parentheses, yielding `true` or `false`.
2. If the condition is `false`, skip the following statements in braces.
3. If the condition is `true`, execute the statements and go back to step 1.

This type of flow is called a **loop**, because the last step "loops back around" to the first. Figure 6.1 shows this idea using a flowchart.

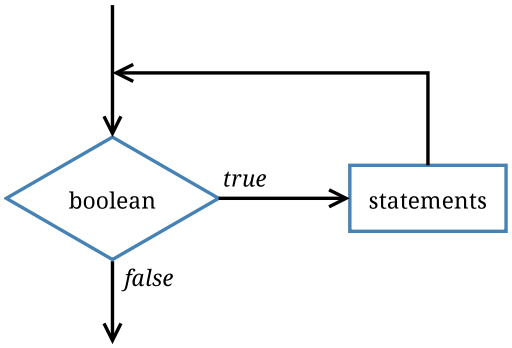


Figure 6.1: Flow of execution for a `while` loop.

The **body** of the loop should change the value of one or more variables so that, eventually, the condition becomes `false` and the loop terminates. Otherwise, the loop will repeat forever, which is called an **infinite loop**:

```
int n = 3;
while (n > 0) {
    System.out.println(n);
    // n never changes
}
```

This example will print the number 3 forever, or at least until you terminate the program. An endless source of amusement for computer scientists is the

observation that the directions on shampoo, "Lather, rinse, repeat," are an infinite loop.

In the first example, we can prove that the loop terminates when `n` is positive. But in general, it is not so easy to tell whether a loop terminates. For example, this loop continues until `n` is 1 (which makes the condition `false`):

```
while (n != 1) {
    System.out.println(n);
    if (n % 2 == 0) {          // n is even
        n = n / 2;
    } else {                   // n is odd
        n = 3 * n + 1;
    }
}
```

Each time through the loop, the program displays the value of `n` and then checks whether it is even or odd. If it is even, the value of `n` is divided by 2. If it is odd, the value is replaced by $3n + 1$. For example, if the starting value is 3, the resulting sequence is 3, 10, 5, 16, 8, 4, 2, 1.

Since `n` sometimes increases and sometimes decreases, there is no obvious proof that `n` will ever reach 1 and that the program will ever terminate. For some values of `n`, such as the powers of two, we can prove that it terminates. The previous example ends with such a sequence, starting when `n` is 16 (or 2^4).

The hard question is whether this program terminates for *all* values of `n`. So far, no one has been able to prove it *or* disprove it! For more information, see https://en.wikipedia.org/wiki/Collatz_conjecture.

6.2 Increment and Decrement

Here is another `while` loop example; this one displays the numbers 1 to 5:

```
int i = 1;
while (i <= 5) {
    System.out.println(i);
    i++;  // add 1 to i
}
```

Assignments like `i = i + 1` don't often appear in loops, because Java provides a more concise way to add and subtract by one. Specifically, `++` is the **increment** operator; it has the same effect as `i = i + 1`. And `--` is the **decrement** operator; it has the same effect as `i = i - 1`.

If you want to increment or decrement a variable by an amount other than `1`, you can use `+=` and `-=`. For example, `i += 2` increments `i` by `2`:

```
int i = 2;
while (i <= 8) {
    System.out.print(i + ", ");
    i += 2;  // add 2 to i
}
System.out.println("Who do we appreciate?");
```

And the output is as follows:

```
2, 4, 6, 8, Who do we appreciate?
```

6.3 The for Statement

The loops we have written so far have three parts in common. They start by initializing a variable, they have a condition that depends on that variable, and they do something inside the loop to update that variable.

Running the same code multiple times is called **iteration**. It's so common that there is another statement, the `for` loop, that expresses it more concisely. For example, we can rewrite the 2-4-6-8 loop this way:

```
for (int i = 2; i <= 8; i += 2) {
    System.out.print(i + ", ");
}
System.out.println("Who do we appreciate?");
```

`for` loops have three components in parentheses, separated by semicolons: the initializer, the condition, and the update:

1. The *initializer* runs once at the very beginning of the loop. It is equivalent to the line before the `while` statement.

2. The *condition* is checked each time through the loop. If it is `false`, the loop ends. Otherwise, the body of the loop is executed (again).

3. At the end of each iteration, the *update* runs, and we go back to step 2.

The `for` loop is often easier to read because it puts all the loop-related statements at the top of the loop. Doing so allows you to focus on the statements inside the loop body. Figure 6.2 illustrates `for` loops with a flowchart.

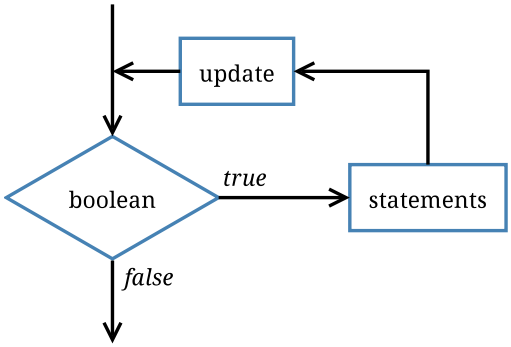


Figure 6.2: Flow of execution for a `for` loop.

There is another difference between `for` loops and `while` loops: if you declare a variable in the initializer, it exists only *inside* the `for` loop. For example:

```
for (int n = 3; n > 0; n--) {
    System.out.println(n);
}
System.out.println("n is now " + n);  // compiler error
```

The last line tries to display `n` (for no reason other than demonstration), but it won't work. If you need to use a loop variable outside the loop, you have to declare it *outside* the loop, like this:

```
int n;
for (n = 3; n > 0; n--) {
    System.out.println(n);
}
System.out.println("n is now " + n);
```

Notice that the `for` statement does not say `int n = 3`. Rather, it simply initializes the existing variable `n`.

6.4 Nested Loops

Like conditional statements, loops can be nested one inside the other. Nested loops allow you to iterate over two variables. For example, we can generate a "multiplication table" like this:

```
for (int x = 1; x <= 10; x++) {
    for (int y = 1; y <= 10; y++) {
        System.out.printf("%4d", x * y);
    }
    System.out.println();
}
```

Variables like `x` and `y` are called **loop variables**, because they control the execution of a loop. In this example, the first loop (`for x`) is known as the "outer loop", and the second loop (`for y`) is known as the "inner loop".

Each loop repeats its corresponding statements 10 times. The outer loop iterates from 1 to 10 only once, but the inner loop iterates from 1 to 10 each of those 10 times. As a result, the `printf` method is invoked 100 times.

The format specifier `%4d` displays the value of `x * y` padded with spaces so it's four characters wide. Doing so causes the output to align vertically, regardless of how many digits the numbers have:

```
   1   2   3   4   5   6   7   8   9  10
   2   4   6   8  10  12  14  16  18  20
   3   6   9  12  15  18  21  24  27  30
   4   8  12  16  20  24  28  32  36  40
   5  10  15  20  25  30  35  40  45  50
   6  12  18  24  30  36  42  48  54  60
   7  14  21  28  35  42  49  56  63  70
   8  16  24  32  40  48  56  64  72  80
   9  18  27  36  45  54  63  72  81  90
  10  20  30  40  50  60  70  80  90 100
```

It's important to realize that the output is displayed row by row. The inner loop displays a single row of output, followed by a newline. The outer loop iterates over the rows themselves. Another way to read nested loops, like the ones in this example, is: "For each row `x`, and for each column `y`, . . . "

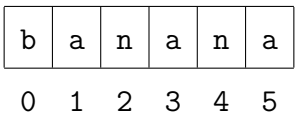
6.5 Characters

Some of the most interesting problems in computer science involve searching and manipulating text. In the next few sections, we'll discuss how to apply loops to strings. Although the examples are short, the techniques work the same whether you have one word or one million words.

Strings provide a method named `charAt`. It returns a `char`, a data type that stores an individual character (as opposed to strings of them):

```
String fruit = "banana";
char letter = fruit.charAt(0);
```

The argument `0` means that we want the character at **index** 0. String indexes range from 0 to $n - 1$, where n is the length of the string. So the character assigned to `letter` is `'b'`:



Characters work like the other data types you have seen. You can compare them using relational operators:

```
if (letter == 'A') {
    System.out.println("It's an A!");
}
```

Character literals, like `'A'`, appear in single quotes. Unlike string literals, which appear in double quotes, character literals can contain only a single character. Escape sequences, like `'\t'`, are legal because they represent a single character.

The increment and decrement operators also work with characters. So this loop displays the letters of the alphabet:

```
System.out.print("Roman alphabet: ");
for (char c = 'A'; c <= 'Z'; c++) {
    System.out.print(c);
}
System.out.println();
```

The output is shown here:

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ
```

Java uses **Unicode** to represent characters, so strings can store text in other alphabets like Cyrillic and Greek, and non-alphabetic languages like Chinese. You can read more about it at the Unicode website (https://unicode.org/).

In Unicode, each character is represented by a "code point", which you can think of as an integer. The code points for uppercase Greek letters run from 913 to 937, so we can display the Greek alphabet like this:

```
System.out.print("Greek alphabet: ");
for (int i = 913; i <= 937; i++) {
    System.out.print((char) i);
}
System.out.println();
```

This example uses a type cast to convert each integer (in the range) to the corresponding character. Try running the code and see what happens.

6.6 Which Loop to Use

`for` and `while` loops have the same capabilities; any `for` loop can be rewritten as a `while` loop, and vice versa. For example, we could have printed letters of the alphabet by using a `while` loop:

```
System.out.print("Roman alphabet: ");
char c = 'A';
while (c <= 'Z') {
    System.out.print(c);
    c++;
}
System.out.println();
```

You might wonder when to use one or the other. It depends on whether you know how many times the loop will repeat.

A `for` loop is "definite", which means we know, at the beginning of the loop, how many times it will repeat. In the alphabet example, we know it will run

26 times. In that case, it's better to use a `for` loop, which puts all of the loop control code on one line.

A `while` loop is "indefinite", which means we don't know how many times it will repeat. For example, when validating user input as in Section 5.9, it's impossible to know how many times the user will enter a wrong value. In this case, a `while` loop is more appropriate:

```
System.out.print("Enter a number: ");
while (!in.hasNextDouble()) {
    String word = in.next();
    System.err.println(word + " is not a number");
    System.out.print("Enter a number: ");
}
double number = in.nextDouble();
```

It's easier to read the `Scanner` method calls when they're not all on one line of code.

6.7 String Iteration

Strings provide a method called `length` that returns the number of characters in the string. The following loop iterates the characters in `fruit` and displays them, one on each line:

```
for (int i = 0; i < fruit.length(); i++) {
    char letter = fruit.charAt(i);
    System.out.println(letter);
}
```

Because `length` is a method, you have to invoke it with parentheses (there are no arguments). When `i` is equal to the length of the string, the condition becomes `false` and the loop terminates.

To find the last letter of a string, you might be tempted to do something like the following:

```
int length = fruit.length();
char last = fruit.charAt(length);      // wrong!
```

This code compiles and runs, but invoking the `charAt` method throws a `StringIndexOutOfBoundsException`. The problem is that there is no sixth letter in `"banana"`. Since we started counting at 0, the six letters are indexed from 0 to 5. To get the last character, you have to subtract 1 from `length`:

```
int length = fruit.length();
char last = fruit.charAt(length - 1);  // correct
```

Many string algorithms involve reading one string and building another. For example, to reverse a string, we can concatenate one character at a time:

```
public static String reverse(String s) {
    String r = "";
    for (int i = s.length() - 1; i >= 0; i--) {
        r += s.charAt(i);
    }
    return r;
}
```

The initial value of `r` is `""`, which is an **empty string**. The loop iterates the indexes of `s` in reverse order. Each time through the loop, the `+=` operator appends the next character to `r`. When the loop exits, `r` contains the characters from `s` in reverse order. So the result of `reverse("banana")` is `"ananab"`.

6.8 The indexOf Method

To search for a specific character in a string, you could write a `for` loop and use `charAt` as in the previous section. However, the `String` class already provides a method for doing just that:

```
String fruit = "banana";
int index = fruit.indexOf('a');      // returns 1
```

This example finds the index of `'a'` in the string. But the letter appears three times, so it's not obvious what `indexOf` might do. According to the documentation, it returns the index of the *first* appearance.

To find subsequent appearances, you can use another version of `indexOf`, which takes a second argument that indicates where in the string to start looking:

```
int index = fruit.indexOf('a', 2);  // returns 3
```

To visualize how `indexOf` and other `String` methods work, it helps to draw a picture like Figure 6.3. The previous code starts at index 2 (the first `'n'`) and finds the next `'a'`, which is at index 3.

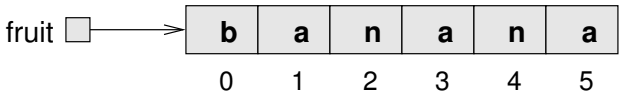


Figure 6.3: Memory diagram for a `String` of six characters.

If the character happens to appear at the starting index, the starting index is the answer. So `fruit.indexOf('a', 5)` returns `5`. If the character does not appear in the string, `indexOf` returns `-1`. Since indexes cannot be negative, this value indicates the character was not found.

You can also use `indexOf` to search for an entire string, not just a single character. For example, the expression `fruit.indexOf("nan")` returns `2`.

6.9 Substrings

In addition to searching strings, we often need to extract parts of strings. The `substring` method returns a new string that copies letters from an existing string, given a pair of indexes:

- `fruit.substring(0, 3)` returns `"ban"`
- `fruit.substring(2, 5)` returns `"nan"`
- `fruit.substring(6, 6)` returns `""`

Notice that the character indicated by the second index is *not* included. Defining `substring` this way simplifies some common operations. For example, to select a substring with length `len`, starting at index `i`, you could write `fruit.substring(i, i + len)`.

Like most string methods, `substring` is **overloaded**. That is, there are other versions of `substring` that have different parameters. If it's invoked with one argument, it returns the letters from that index to the end:

- `fruit.substring(0)` returns `"banana"`
- `fruit.substring(2)` returns `"nana"`
- `fruit.substring(6)` returns `""`

The first example returns a copy of the entire string. The second example returns all but the first two characters. As the last example shows, `substring` returns the empty string if the argument is the length of the string.

We could also use `fruit.substring(2, fruit.length() - 1)` to get the result `"nana"`. But calling `substring` with one argument is more convenient when you want the end of the string.

6.10 String Comparison

When comparing strings, it might be tempting to use the `==` and `!=` operators. But that will almost never work. The following code compiles and runs, but it always displays `Goodbye!` regardless what the user types.

```
System.out.print("Play again? ");
String answer = in.nextLine();
if (answer == "yes") {                  // wrong!
    System.out.println("Let's go!");
} else {
    System.out.println("Goodbye!");
}
```

The problem is that the `==` operator checks whether the two operands refer to the *same object*. Even if the answer is `"yes"`, it will refer to a different object in memory than the literal string `"yes"` in the code. You'll learn more about objects and references in the next chapter.

The correct way to compare strings is with the `equals` method, like this:

```
if (answer.equals("yes")) {
    System.out.println("Let's go!");
}
```

This example invokes `equals` on `answer` and passes `"yes"` as an argument. The `equals` method returns `true` if the strings contain the same characters; otherwise, it returns `false`.

If two strings differ, we can use `compareTo` to see which comes first in alphabetical order:

```
String name1 = "Alan Turing";
String name2 = "Ada Lovelace";
int diff = name1.compareTo(name2);
if (diff < 0) {
    System.out.println("name1 comes before name2.");
} else if (diff > 0) {
    System.out.println("name2 comes before name1.");
} else {
    System.out.println("The names are the same.");
}
```

The return value from `compareTo` is the difference between the first characters in the strings that are not the same. In the preceding code, `compareTo` returns positive `8`, because the second letter of `"Ada"` comes before the second letter of `"Alan"` by eight letters.

If the first string (the one on which the method is invoked) comes earlier in the alphabet, the difference is negative. If it comes later in the alphabet, the difference is positive. If the strings are equal, their difference is zero.

Both `equals` and `compareTo` are case-sensitive. In Unicode, uppercase letters come before lowercase letters. So `"Ada"` comes before `"ada"`.

6.11 String Formatting

In Section 3.5, we learned how to use `System.out.printf` to display formatted output. Sometimes programs need to create strings that are formatted a certain way, but not display them immediately (or ever). For example, the following method returns a time string in 12-hour format:

```
public static String timeString(int hour, int minute) {
    String ampm;
    if (hour < 12) {
        ampm = "AM";
        if (hour == 0) {
            hour = 12;  // midnight
        }
    } else {
        ampm = "PM";
        hour = hour - 12;
    }
    return String.format("%02d:%02d %s", hour, minute, ampm);
}
```

`String.format` takes the same arguments as `System.out.printf`: a format specifier followed by a sequence of values. The main difference is that `System.out.printf` *displays* the result on the screen. `String.format` creates a new string but does not display anything.

In this example, the format specifier `%02d` means "two-digit integer padded with zeros", so `timeString(19, 5)` returns the string `"07:05 PM"`. As an exercise, try writing two nested `for` loops (in `main`) that invoke `timeString` and display all possible times over a 24-hour period.

Be sure to skim through the documentation for `String`. Knowing what other methods are there will help you avoid reinventing the wheel. The easiest way to find documentation for Java classes is to do a web search for "Java" and the name of the class.

6.12 Vocabulary

loop: A statement that executes a sequence of statements repeatedly.

loop body: The statements inside the loop.

infinite loop: A loop whose condition is always true.

increment: Increase the value of a variable.

decrement: Decrease the value of a variable.

iteration: Executing a sequence of statements repeatedly.

loop variable: A variable that is initialized, tested, and updated in order to control a loop.

index: An integer variable or value used to indicate a character in a string.

Unicode: An international standard for representing characters in most of the world's languages.

empty string: The string `""`, which contains no characters and has a length of zero.

overloaded: Two or more methods with the same name but different parameters.

6.13 Exercises

The code for this chapter is in the *ch06* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you have not already read Appendix A.6, now might be a good time. It describes the DrJava debugger, which is a useful tool for visualizing the flow of execution through loops.

Exercise 6.1 Consider the following methods (`main` and `loop`):

1. Draw a table that shows the value of the variables `i` and `n` during the execution of `loop`. The table should contain one column for each variable and one line for each iteration.

2. What is the output of this program?

3. Can you prove that this loop terminates for any positive value of `n`?

```
public static void main(String[] args) {
    loop(10);
}

public static void loop(int n) {
    int i = n;
    while (i > 1) {
        System.out.println(i);
        if (i % 2 == 0) {
            i = i / 2;
        } else {
            i = i + 1;
        }
    }
}
```

Exercise 6.2 Let's say you are given a number, a, and you want to find its square root. One way to do that is to start with a rough guess about the answer, x_0, and then improve the guess by using this formula:

$$x_1 = (x_0 + a/x_0)/2$$

For example, if we want to find the square root of 9, and we start with $x_0 = 6$, then $x_1 = (6 + 9/6)/2 = 3.75$, which is closer. We can repeat the procedure, using x_1 to calculate x_2, and so on. In this case, $x_2 = 3.075$ and $x_3 = 3.00091$. So the repetition converges quickly on the correct answer.

Write a method called `squareRoot` that takes a `double` and returns an approximation of the square root of the parameter, using this technique. You should not use `Math.sqrt`.

As your initial guess, you should use $a/2$. Your method should iterate until it gets two consecutive estimates that differ by less than 0.0001. You can use `Math.abs` to calculate the absolute value of the difference.

Exercise 6.3 One way to evaluate $\exp(-x^2)$ is to use the infinite series expansion:

$$\exp(-x^2) = 1 - x^2 + x^4/2 - x^6/6 + \ldots$$

The ith term in this series is $(-1)^i x^{2i}/i!$. Write a method named `gauss` that

takes `x` and `n` as arguments and returns the sum of the first `n` terms of the series. You should not use `factorial` or `pow`.

Exercise 6.4 A word is said to be "abecedarian" if the letters in the word appear in alphabetical order. For example, the following are all six-letter English abecedarian words:

> abdest, acknow, acorsy, adempt, adipsy, agnosy, befist, behint, beknow, bijoux, biopsy, cestuy, chintz, deflux, dehors, dehort, deinos, diluvy, dimpsy

Write a method called `isAbecedarian` that takes a `String` and returns a `boolean` indicating whether the word is abecedarian.

Exercise 6.5 A word is said to be a "doubloon" if every letter that appears in the word appears exactly twice. Here are some example doubloons found in the dictionary:

> Abba, Anna, appall, appearer, appeases, arraigning, beriberi, bilabial, boob, Caucasus, coco, Dada, deed, Emmett, Hannah, horseshoer, intestines, Isis, mama, Mimi, murmur, noon, Otto, papa, peep, reappear, redder, sees, Shanghaiings, Toto

Write a method called `isDoubloon` that takes a string and checks whether it is a doubloon. To ignore case, invoke the `toLowerCase` method before checking.

Exercise 6.6 In Scrabble[1] each player has a set of tiles with letters on them. The object of the game is to use those letters to spell words. The scoring system is complex, but longer words are usually worth more than shorter words.

Imagine you are given your set of tiles as a string, like `"quijibo"`, and you are given another string to test, like `"jib"`.

Write a method called `canSpell` that takes two strings and checks whether the set of tiles can spell the word. You might have more than one tile with the same letter, but you can use each tile only once.

[1] Scrabble is a registered trademark owned in the USA and Canada by Hasbro Inc., and in the rest of the world by J. W. Spear & Sons Limited of Maidenhead, Berkshire, England, a subsidiary of Mattel Inc.

Chapter 7

Arrays and References

Up to this point, the only variables we have used were for individual values such as numbers or strings. In this chapter, you'll learn how to store multiple values of the same type by using a single variable. This language feature will enable you to write programs that manipulate larger amounts of data.

For example, Exercise 6.5 asked you to check whether every letter in a string appears exactly twice. One algorithm (which hopefully you already discovered) loops through the string 26 times, once for each lowercase letter:

```
// outer loop: for each lowercase letter
for (char c = 'a'; c <= 'z'; c++) {
    // inner loop: count how many times the letter appears
    for (int i = 0; i < str.length(); i++) {
        ...
    // if the count is not 0 or 2, return false
```

This "nested loops" approach is inefficient, especially when the string is long. For example, there are more than 3 million characters in *War and Peace*; to process the whole book, the nested loop would run about 80 million times.

Another algorithm would initialize 26 variables to zero, loop through the string *one time*, and use a giant `if` statement to update the variable for each letter. But who wants to declare 26 variables?

That's where arrays come in. We can use a single variable to store 26 integers. Rather than use an `if` statement to update each value, we can use arithmetic

to update the nth value directly. We will present this algorithm at the end of the chapter.

7.1 Creating Arrays

An **array** is a sequence of values; the values in the array are called **elements**. You can make an array of `int`s, `double`s, `String`s, or any other type, but all the values in an array must have the same type.

To create an array, you have to declare a variable with an *array type* and then create the array itself. Array types look like other Java types, except they are followed by square brackets (`[]`). For example, the following lines declare that `counts` is an "integer array" and `values` is a "double array":

```
int[] counts;
double[] values;
```

To create the array itself, you have to use the `new` operator, which you first saw in Section 3.2. The `new` operator **allocates** memory for the array and automatically initializes all of its elements to zero:

```
counts = new int[4];
values = new double[size];
```

The first assignment makes `counts` refer to an array of four integers. The second makes `values` refer to an array of `double`s, but the number of elements depends on the value of `size` (at the time the array is created).

Of course, you can also declare the variable and create the array with a single line of code:

```
int[] counts = new int[4];
double[] values = new double[size];
```

You can use any integer expression for the size of an array, as long as the value is nonnegative. If you try to create an array with `-4` elements, for example, you will get a `NegativeArraySizeException`. An array with zero elements is allowed, and there are special uses for such arrays.

You can initialize an array with a comma-separated sequence of elements enclosed in braces, like this:

```
int[] a = {1, 2, 3, 4};
```

This statement creates an array variable, `a`, and makes it refer to an array with four elements.

7.2 Accessing Elements

When you create an array with the `new` operator, the elements are initialized to zero. Figure 7.1 shows a memory diagram of the `counts` array so far.

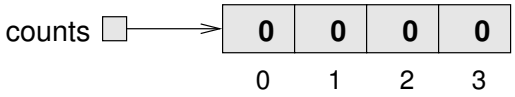


Figure 7.1: Memory diagram of an `int` array.

The arrow indicates that the value of `counts` is a **reference** to the array. You should think of *the array* and *the variable* that refers to it as two different things. As you'll soon see, we can assign a different variable to refer to the same array, and we can change the value of `counts` to refer to a different array.

The boldface numbers inside the boxes are the elements of the array. The lighter numbers outside the boxes are the **indexes** used to identify each location in the array. As with strings, the index of the first element is 0, not 1. For this reason, we sometimes refer to the first element as the "zeroth" element.

The `[]` operator selects elements from an array:

```
System.out.println("The zeroth element is " + counts[0]);
```

You can use the `[]` operator anywhere in an expression:

```
counts[0] = 7;
counts[1] = counts[0] * 2;
counts[2]++;
counts[3] -= 60;
```

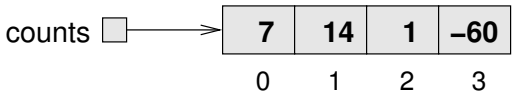


Figure 7.2: Memory diagram after several assignment statements.

Figure 7.2 shows the result of these statements.

You can use any expression as an index, as long as it has type `int`. One of the most common ways to index an array is with a loop variable. For example:

```
int i = 0;
while (i < 4) {
    System.out.println(counts[i]);
    i++;
}
```

This `while` loop counts up from 0 to 4. When `i` is 4, the condition fails and the loop terminates. So the body of the loop is executed only when `i` is 0, 1, 2, or 3. In this context, the variable name `i` is short for "index".

Each time through the loop, we use `i` as an index into the array, displaying the ith element. This type of array processing is usually written as a `for` loop:

```
for (int i = 0; i < 4; i++) {
    System.out.println(counts[i]);
}
```

For the `counts` array, the only legal indexes are 0, 1, 2, and 3. If the index is negative or greater than 3, the result is an `ArrayIndexOutOfBoundsException`.

7.3 Displaying Arrays

You can use `println` to display an array, but it probably doesn't do what you would like. For example, say you print an array like this:

```
int[] a = {1, 2, 3, 4};
System.out.println(a);
```

The output is something like this:

```
[I@bf3f7e0
```

The bracket indicates that the value is an array, `I` stands for "integer", and the rest represents the address of the array in memory.

If we want to display the elements of the array, we can do it ourselves:

```
public static void printArray(int[] a) {
    System.out.print("{" + a[0]);
    for (int i = 1; i < a.length; i++) {
        System.out.print(", " + a[i]);
    }
    System.out.println("}");
}
```

Given the previous array, the output of `printArray` is as follows:

```
{1, 2, 3, 4}
```

The Java library includes a class, `java.util.Arrays`, that provides methods for working with arrays. One of them, `toString`, returns a string representation of an array. After importing `Arrays`, we can invoke `toString` like this:

```
System.out.println(Arrays.toString(a));
```

And the output is shown here:

```
[1, 2, 3, 4]
```

Notice that `Arrays.toString` uses square brackets instead of curly braces. But it beats writing your own `printArray` method.

7.4 Copying Arrays

As explained in Section 7.2, array variables contain *references* to arrays. When you make an assignment to an array variable, it simply copies the reference. But it doesn't copy the array itself. For example:

```
double[] a = new double[3];
double[] b = a;
```

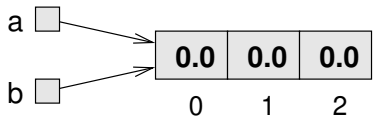


Figure 7.3: Memory diagram of two variables referring to the same array.

These statements create an array of three `double`s and make two different variables refer to it, as shown in Figure 7.3.

Any changes made through either variable will be seen by the other. For example, if we set `a[0] = 17.0`, and then display `b[0]`, the result is `17.0`. Because `a` and `b` are different names for the same thing, they are sometimes called **aliases**.

If you actually want to copy the array, not just the reference, you have to create a new array and copy the elements from one to the other, like this:

```
double[] b = new double[3];
for (int i = 0; i < 3; i++) {
    b[i] = a[i];
}
```

`java.util.Arrays` provides a method named `copyOf` that performs this task for you. So you can replace the previous code with one line:

```
double[] b = Arrays.copyOf(a, 3);
```

The second parameter is the number of elements you want to copy, so `copyOf` can also be used to copy part of an array. Figure 7.4 shows the state of the array variables after invoking `Arrays.copyOf`.

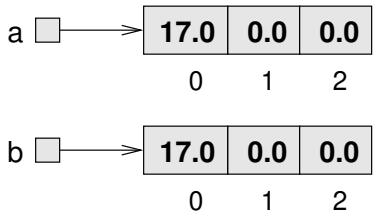


Figure 7.4: Memory diagram of two variables referring to different arrays.

The examples so far work only if the array has three elements. It is better to generalize the code to work with arrays of any size. We can do that by replacing the magic number, 3, with `a.length`:

```
double[] b = new double[a.length];
for (int i = 0; i < a.length; i++) {
    b[i] = a[i];
}
```

All arrays have a built-in constant, `length`, that stores the number of elements. In contrast to `String.length()`, which is a method, `a.length` is a constant. The expression `a.length` may look like a method invocation, but there are no parentheses and no arguments.

The last time the loop gets executed, `i` is `a.length - 1`, which is the index of the last element. When `i` is equal to `a.length`, the condition fails and the body is not executed—which is a good thing, because trying to access `a[a.length]` would throw an exception.

Of course, we can replace the loop altogether by using `Arrays.copyOf` and `a.length` for the second argument. The following line produces the same result shown in Figure 7.4:

```
double[] b = Arrays.copyOf(a, a.length);
```

The `Arrays` class provides many other useful methods like `Arrays.compare`, `Arrays.equals`, `Arrays.fill`, and `Arrays.sort`. Take a moment to read the documentation by searching the web for `java.util.Arrays`.

7.5 Traversing Arrays

Many computations can be implemented by looping through the elements of an array and performing an operation on each element. Looping through the elements of an array is called a **traversal**:

```
int[] a = {1, 2, 3, 4, 5};
for (int i = 0; i < a.length; i++) {
    a[i] *= a[i];
}
```

This example traverses an array and squares each element. At the end of the loop, the array has the values `{1, 4, 9, 16, 25}`.

Another common pattern is a **search**, which involves traversing an array and "searching" for a particular element. For example, the following method takes an array and a value, and it returns the index where the value appears:

```
public static int search(double[] array, double target) {
    for (int i = 0; i < array.length; i++) {
        if (array[i] == target) {
            return i;
        }
    }
    return -1;  // not found
}
```

If we find the target value in the array, we return its index immediately. If the loop exits without finding the target, it returns `-1`, a special value chosen to indicate a failed search. (This code is essentially what the `String.indexOf` method does.)

The following code searches an array for the value `1.23`, which is the third element. Because array indexes start at 0, the output is 2:

```
double[] array = {3.14, -55.0, 1.23, -0.8};
int index = search(array, 1.23);
System.out.println(index);
```

Another common traversal is a **reduce** operation, which "reduces" an array of values down to a single value. Examples include the sum or product of the elements, the minimum, and the maximum. The following method takes an array and returns the sum of its elements:

```
public static double sum(double[] array) {
    double total = 0.0;
    for (int i = 0; i < array.length; i++) {
        total += array[i];
    }
    return total;
}
```

Before the loop, we initialize `total` to `0`. Each time through the loop, we update `total` by adding one element from the array. At the end of the loop, `total` contains the sum of the elements. A variable used this way is sometimes called an **accumulator**, because it "accumulates" the running total.

7.6 Random Numbers

Most computer programs do the same thing every time they run; programs like that are called **deterministic**. Usually, determinism is a good thing, since we expect the same calculation to yield the same result. But for some applications, we want the computer to be unpredictable. Games are an obvious example, but there are many others, like scientific simulations.

Making a program **nondeterministic** turns out to be hard, because it's impossible for a computer to generate truly random numbers. But there are algorithms that generate unpredictable sequences called **pseudorandom** numbers. For most applications, they are as good as random.

If you did Exercise 3.4, you have already seen `java.util.Random`, which generates pseudorandom numbers. The method `nextInt` takes an integer argument, `n`, and returns a random integer between `0` and `n - 1` (inclusive).

If you generate a long series of random numbers, every value should appear, at least approximately, the same number of times. One way to test this behavior of `nextInt` is to generate a large number of values, store them in an array, and count the number of times each value occurs.

The following method creates an `int` array and fills it with random numbers between 0 and 99. The argument specifies the desired size of the array, and the return value is a reference to the new array:

```
public static int[] randomArray(int size) {
    Random random = new Random();
    int[] a = new int[size];
    for (int i = 0; i < a.length; i++) {
        a[i] = random.nextInt(100);
    }
    return a;
}
```

The following `main` method generates an array and displays it by using the `printArray` method from Section 7.3. We could have used `Arrays.toString`, but we like seeing curly braces instead of square brackets:

```
public static void main(String[] args) {
    int[] array = randomArray(8);
    printArray(array);
}
```

Each time you run the program, you should get different values. The output will look something like this:

```
{15, 62, 46, 74, 67, 52, 51, 10}
```

7.7 Building a Histogram

If these values were exam scores—and they would be pretty bad exam scores in that case—the teacher might present them to the class in the form of a **histogram**. In statistics, a histogram is a set of counters that keeps track of the number of times each value appears.

For exam scores, we might have 10 counters to keep track of how many students scored in the 90s, the 80s, etc. To do that, we can traverse the array and count the number of elements that fall in a given range.

The following method takes an array and two integers. It returns the number of elements that fall in the range from `low` to `high - 1`:

```
public static int inRange(int[] a, int low, int high) {
    int count = 0;
    for (int i = 0; i < a.length; i++) {
        if (a[i] >= low && a[i] < high) {
            count++;
        }
    }
    return count;
}
```

This pattern should look familiar: it is another reduce operation. Notice that `low` is included in the range (`>=`), but `high` is excluded (`<`). This design keeps us from counting any scores twice.

Now we can count the number of scores in each grade range. We add the following code to our `main` method:

```
int[] scores = randomArray(30);
int a = inRange(scores, 90, 100);
int b = inRange(scores, 80, 90);
int c = inRange(scores, 70, 80);
int d = inRange(scores, 60, 70);
int f = inRange(scores, 0, 60);
```

This code is repetitive, but it is acceptable as long as the number of ranges is small. Suppose we wanted to keep track of the number of times each individual score appears. Then we would have to write 100 lines of code:

```
int count0 = inRange(scores, 0, 1);
int count1 = inRange(scores, 1, 2);
int count2 = inRange(scores, 2, 3);
...
int count99 = inRange(scores, 99, 100);
```

What we need is a way to store 100 counters, preferably so we can use an index to access them. Wait a minute—that's exactly what an array does.

The following fragment creates an array of 100 counters, one for each possible score. It loops through the scores and uses `inRange` to count how many times each score appears. Then it stores the results in the `counts` array:

```
int[] counts = new int[100];
for (int i = 0; i < counts.length; i++) {
    counts[i] = inRange(scores, i, i + 1);
}
```

Notice that we are using the loop variable `i` three times: as an index into the `counts` array, and in the last two arguments of `inRange`.

The code works, but it is not as efficient as it could be. Every time the loop invokes `inRange`, it traverses the entire array. It would be better to make a single pass through the `scores` array.

For each score, we already know which range it falls in—the score itself. We can use that value to increment the corresponding counter. This code traverses the array of scores *only once* to generate the histogram:

```
int[] counts = new int[100];
for (int i = 0; i < scores.length; i++) {
    int index = scores[i];
    counts[index]++;
}
```

Each time through the loop, it selects one element from `scores` and uses it as an index to increment the corresponding element of `counts`. Because this code traverses the array of scores only once, it is much more efficient.

7.8 The Enhanced for Loop

Since traversing arrays is so common, Java provides an alternative syntax that makes the code more compact. Consider a `for` loop that displays the elements of an array on separate lines:

```
for (int i = 0; i < values.length; i++) {
    int value = values[i];
    System.out.println(value);
}
```

We could rewrite the loop like this:

```
for (int value : values) {
    System.out.println(value);
}
```

This statement is called an **enhanced for loop**, also known as the "for each" loop. You can read the code as, "for each `value` in `values`". It's conventional to use plural nouns for array variables and singular nouns for element variables.

Notice how the single line `for (int value : values)` replaces the first two lines of the standard `for` loop. It hides the details of iterating each index of the array, and instead, focuses on the values themselves.

Using the enhanced `for` loop, and removing the temporary variable, we can write the histogram code from the previous section more concisely:

```
int[] counts = new int[100];
for (int score : scores) {
    counts[score]++;
}
```

Enhanced `for` loops often make the code more readable, especially for accumulating values. But they are not helpful when you need to refer to the index, as in search operations:

```
for (double d : array) {
    if (d == target) {
        // array contains d, but we don't know where
    }
}
```

7.9 Counting Characters

We now return to the example from the beginning of the chapter and present a solution to Exercise 6.5 using arrays. Here is the problem again:

> A word is said to be a "doubloon" if every letter that appears in the word appears exactly twice. Write a method called `isDoubloon` that takes a string and checks whether it is a doubloon. To ignore case, invoke the `toLowerCase` method before checking.

Based on the approach from Section 7.7, we will create an array of 26 integers to count how many times each letter appears. We convert the string to lowercase, so that we can treat `'A'` and `'a'` (for example) as the same letter.

```
int[] counts = new int[26];
String lower = s.toLowerCase();
```

We can use a `for` loop to iterate each character in the string. To update the `counts` array, we need to compute the index that corresponds to each character. Fortunately, Java allows you to perform arithmetic on characters:

```
for (int i = 0; i < lower.length(); i++) {
    char letter = lower.charAt(i);
    int index = letter - 'a';
    counts[index]++;
}
```

If `letter` is `'a'`, the value of `index` is `0`; if `letter` is `'b'`, the value of `index` is `1`, and so on.

Then we use `index` to increment the corresponding element of `counts`. At the end of the loop, `counts` contains a histogram of the letters in the string `lower`.

We can simplify this code with an enhanced `for` loop, but it doesn't work with strings; we have to convert `lower` to an array of characters, like this:

```
for (char letter : lower.toCharArray()) {
    int index = letter - 'a';
    counts[index]++;
}
```

Once we have the counts, we can use a second `for` loop to check whether each letter appears zero or two times:

```
for (int count : counts) {
    if (count != 0 && count != 2) {
        return false;  // not a doubloon
    }
}
return true;  // is a doubloon
```

If we find a count that is neither 0 or 2, we know the word is not a doubloon and we can return immediately. If we make it all the way through the `for` loop, we know that all counts are 0 or 2, which means the word is a doubloon.

Pulling together the code fragments, and adding some comments and test cases, here's the entire program:

```
public class Doubloon {

    public static boolean isDoubloon(String s) {
        // count the number of times each letter appears
        int[] counts = new int[26];
        String lower = s.toLowerCase();
        for (char letter : lower.toCharArray()) {
            int index = letter - 'a';
            counts[index]++;
        }
        // determine whether the given word is a doubloon
        for (int count : counts) {
            if (count != 0 && count != 2) {
                return false;
            }
        }
        return true;
    }

    public static void main(String[] args) {
        System.out.println(isDoubloon("Mama"));  // true
        System.out.println(isDoubloon("Lama"));  // false
    }
}
```

This example uses methods, `if` statements, `for` loops, arithmetic and logical operators, integers, characters, strings, booleans, and arrays. We hope you'll take a second to appreciate how much you've learned!

7.10 Vocabulary

array: A collection of values in which all the values have the same type, and each value is identified by an index.

element: One of the values in an array. The `[]` operator selects elements.

index: An integer variable or value used to indicate an element of an array.

allocate: To reserve memory for an array or other object. In Java, the `new` operator allocates memory.

reference: A value that indicates a storage location. In a memory diagram, a reference appears as an arrow.

alias: A variable that refers to the same object as another variable.

traversal: Looping through the elements of an array (or other collection).

search: A traversal pattern used to find a particular element of an array.

reduce: A traversal pattern that combines the elements of an array into a single value.

accumulator: A variable used to accumulate results during a traversal.

deterministic: A program that does the same thing every time it is run.

nondeterministic: A program that always behaves differently, even when run multiple times with the same input.

pseudorandom: A sequence of numbers that appear to be random but are actually the product of a deterministic computation.

histogram: An array of integers in which each integer counts the number of values that fall into a certain range.

enhanced for loop: An alternative syntax for traversing the elements of an array (or other collection).

7.11 Exercises

The code for this chapter is in the *ch07* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you haven't already, take a look at Appendix D, where we've collected some of our favorite debugging advice. It refers to language features we haven't yet covered, but it's good for you to know what's available when you need it.

Exercise 7.1 The purpose of this exercise is to practice reading code and recognizing the traversal patterns in this chapter. The following methods are hard to read, because instead of using meaningful names for the variables and methods, they use names of fruit.

For each method, write one sentence that describes what the method does, without getting into the details of how it works. And for each variable, identify the role it plays.

```
public static int banana(int[] a) {
    int kiwi = 1;
    int i = 0;
    while (i < a.length) {
        kiwi = kiwi * a[i];
        i++;
    }
    return kiwi;
}
```

```
public static int grapefruit(int[] a, int grape) {
    for (int i = 0; i < a.length; i++) {
        if (a[i] == grape) {
            return i;
        }
    }
    return -1;
}
```

```
public static int pineapple(int[] a, int apple) {
    int pear = 0;
    for (int pine: a) {
        if (pine == apple) {
            pear++;
        }
    }
    return pear;
}
```

Exercise 7.2 What is the output of the following program? Describe in a few words what `mus` does. Draw a stack diagram just before `mus` returns.

```
public static int[] make(int n) {
    int[] a = new int[n];
    for (int i = 0; i < n; i++) {
        a[i] = i + 1;
    }
    return a;
}
```

```
public static void dub(int[] jub) {
    for (int i = 0; i < jub.length; i++) {
        jub[i] *= 2;
    }
}
```

```
public static int mus(int[] zoo) {
    int fus = 0;
    for (int i = 0; i < zoo.length; i++) {
        fus += zoo[i];
    }
    return fus;
}
```

```
public static void main(String[] args) {
    int[] bob = make(5);
    dub(bob);
    System.out.println(mus(bob));
}
```

Exercise 7.3 Write a method called `indexOfMax` that takes an array of integers and returns the index of the largest element. Can you write this method by using an enhanced `for` loop? Why or why not?

Exercise 7.4 The Sieve of Eratosthenes is "a simple, ancient algorithm for finding all prime numbers up to any given limit" (https://en.wikipedia.org/wiki/Sieve_of_Eratosthenes).

Write a method called `sieve` that takes an integer parameter, `n`, and returns a `boolean` array that indicates, for each number from `0` to `n - 1`, whether the number is prime.

Exercise 7.5 Write a method named `areFactors` that takes an integer `n` and an array of integers, and returns `true` if the numbers in the array are all factors of `n` (which is to say that `n` is divisible by all of them).

Exercise 7.6 Write a method named `arePrimeFactors` that takes an integer `n` and an array of integers, and that returns `true` if the numbers in the array are all prime *and* their product is `n`.

Exercise 7.7 Write a method called `letterHist` that takes a string as a parameter and returns a histogram of the letters in the string. The zeroth element of the histogram should contain the number of a's in the string (upper- and lowercase); the 25th element should contain the number of z's. Your solution should traverse the string only once.

Exercise 7.8 Two words are anagrams if they contain the same letters and the same number of each letter. For example, "stop" is an anagram of "pots", "allen downey" is an anagram of "well annoyed", and "christopher mayfield" is an anagram of "hi prof the camel is dry". Write a method that takes two strings and checks whether they are anagrams of each other.

Chapter 8

Recursive Methods

Up to this point, we've been using `while` and `for` loops whenever we've needed to repeat something. Methods that use iteration are called **iterative**. They are straight-forward, but sometimes more-elegant solutions exist.

In this chapter, we explore one of the most magical things that a method can do: invoke *itself* to solve a smaller version of the *same* problem. A method that invokes itself is called **recursive**.

8.1 Recursive Void Methods

Consider the following example:

```
public static void countdown(int n) {
    if (n == 0) {
        System.out.println("Blastoff!");
    } else {
        System.out.println(n);
        countdown(n - 1);
    }
}
```

The name of the method is `countdown`; it takes a single integer as a parameter. If the parameter is 0, it displays the word `Blastoff!`. Otherwise, it displays the number and then invokes itself, passing `n - 1` as the argument.

What happens if we invoke `countdown(3)` from `main`?

> The execution of `countdown` begins with `n == 3`, and since `n` is not 0, it displays the value 3, and then invokes itself...
>
> > The execution of `countdown` begins with `n == 2`, and since `n` is not 0, it displays the value 2, and then invokes itself...
> >
> > > The execution of `countdown` begins with `n == 1`, and since `n` is not 0, it displays the value 1, and then invokes itself...
> > >
> > > > The execution of `countdown` begins with `n == 0`, and since `n` is 0, it displays the word `Blastoff!` and then returns.
> > >
> > > The `countdown` that got `n == 1` returns.
> >
> > The `countdown` that got `n == 2` returns.
>
> The `countdown` that got `n == 3` returns.

And then you're back in `main`. So the total output looks like this:

```
3
2
1
Blastoff!
```

As a second example, we'll rewrite the methods `newLine` and `threeLine` from Section 4.1. Here they are again:

```
public static void newLine() {
    System.out.println();
}

public static void threeLine() {
    newLine();
    newLine();
    newLine();
}
```

Although these methods work, they would not help if we wanted to display two newlines, or maybe 100. A more general alternative would be the following:

```
public static void nLines(int n) {
    if (n > 0) {
        System.out.println();
        nLines(n - 1);
    }
}
```

This method takes an integer, `n`, as a parameter and displays `n` newlines. The structure is similar to `countdown`. As long as n is greater than 0, it displays a newline and then invokes itself to display $(n - 1)$ additional newlines. The total number of newlines is $1 + (n - 1)$, which is just what we wanted: n.

8.2 Recursive Stack Diagrams

In Section 4.5, we used a stack diagram to represent the state of a program during a method invocation. The same kind of diagram can make it easier to interpret a recursive method.

Remember that every time a method gets called, Java creates a new frame that contains the method's parameters and variables. Figure 8.1 is a stack diagram for `countdown`, called with `n == 3`.

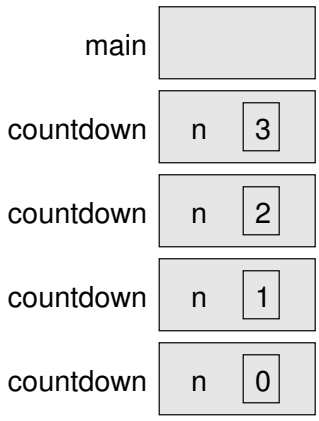


Figure 8.1: Stack diagram for the `countdown` program.

By convention, the frame for `main` is at the top, and the stack of other frames grows down. That way, we can draw stack diagrams on paper without needing to guess how far they will grow. The frame for `main` is empty because `main`

does not have any variables. (It has the parameter `args`, but since we're not using it, we left it out of the diagram.)

There are four frames for `countdown`, each with a different value for the parameter `n`. The last frame, with `n == 0`, is called the **base case**. It does not make a recursive call, so there are no more frames below it.

If there is no base case in a recursive method, or if the base case is never reached, the stack would grow forever—at least in theory. In practice, the size of the stack is limited. If you exceed the limit, you get a `StackOverflowError`.

For example, here is a recursive method without a base case:

```
public static void forever(String s) {
    System.out.println(s);
    forever(s);
}
```

This method displays the given string until the stack overflows, at which point it throws an error. Try this example on your computer—you might be surprised by how long the error message is!

8.3 Value-Returning Methods

To give you an idea of what you can do with the tools you have learned, let's look at methods that evaluate recursively defined mathematical functions.

A recursive definition is similar to a "circular" definition, in the sense that the definition refers to the thing being defined. Of course, a truly circular definition is not very useful:

> **recursive:**
> An adjective used to describe a method that is recursive.

If you saw that definition in the dictionary, you might be annoyed. Then again, if you search for "recursion" on Google, it displays "Did you mean: recursion" as an inside joke. People fall for that link all the time.

Many mathematical functions are defined recursively, because that is often the simplest way. For example, the **factorial** of an integer n, which is written $n!$, is defined like this:

$$0! = 1$$
$$n! = n \cdot (n-1)!$$

Don't confuse the mathematical symbol !, which means *factorial*, with the Java operator `!`, which means *not*. This definition says that `factorial(0)` is `1`, and `factorial(n)` is `n * factorial(n - 1)`.

So `factorial(3)` is `3 * factorial(2)`; `factorial(2)` is `2 * factorial(1)`; `factorial(1)` is `1 * factorial(0)`; and `factorial(0)` is `1`. Putting it all together, we get `3 * 2 * 1 * 1`, which is 6.

If you can formulate a recursive definition of something, you can easily write a Java method to evaluate it. The first step is to decide what the parameters and return type are. Since `factorial` is defined for integers, the method takes an `int` as a parameter and returns an `int`:

```
public static int factorial(int n) {
    return 0;  // stub
}
```

Next, we think about the base case. If the argument happens to be 0, we return 1:

```
public static int factorial(int n) {
    if (n == 0) {
        return 1;
    }
    return 0;  // stub
}
```

Otherwise, and this is the interesting part, we have to make a recursive call to find the factorial of $n-1$, and then multiply it by n:

```
public static int factorial(int n) {
    if (n == 0) {
        return 1;
    }
    int recurse = factorial(n - 1);
    int result = n * recurse;
    return result;
}
```

To illustrate what is happening, we'll use the temporary variables `recurse` and `result`. In each method call, `recurse` stores the factorial of $n - 1$, and `result` stores the factorial of n.

The flow of execution for this program is similar to `countdown` from Section 8.1. If we invoke `factorial` with the value `3`:

> Since 3 is not 0, we skip the first branch and calculate the factorial of $n - 1$...
>
> > Since 2 is not 0, we skip the first branch and calculate the factorial of $n - 1$...
> >
> > > Since 1 is not 0, we skip the first branch and calculate the factorial of $n - 1$...
> > >
> > > > Since 0 *is* 0, we take the first branch and return the value 1 immediately.
> > >
> > > The return value (1) gets multiplied by `n`, which is 1, and the result is returned.
> >
> > The return value (1) gets multiplied by `n`, which is 2, and the result is returned.
>
> The return value (2) gets multiplied by `n`, which is 3, and the result, 6, is returned to whatever invoked `factorial(3)`.

Figure 8.2 shows what the stack diagram looks like for this sequence of method invocations. The return values are shown being passed up the stack. Notice that `recurse` and `result` do not exist in the last frame, because when `n == 0`, the code that declares them does not execute.

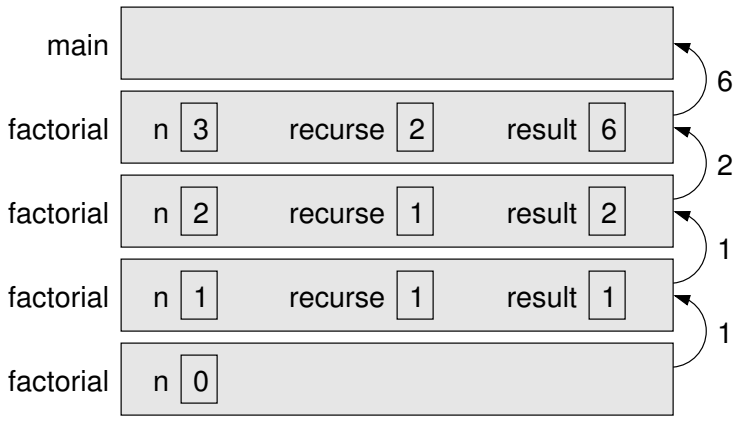


Figure 8.2: Stack diagram for the `factorial` method.

8.4 The Leap of Faith

Following the flow of execution is one way to read programs, but it can quickly become overwhelming. Another way to understand recursion is the **leap of faith**: when you come to a method invocation, instead of following the flow of execution, you *assume* that the method works correctly and returns the appropriate value.

In fact, you are already practicing this leap of faith when you use methods in the Java library. When you invoke `Math.cos` or `System.out.println`, you don't think about the implementations of those methods. You just assume that they work properly.

The same is true of other methods. For example, consider the method from Section 5.8 that determines whether an integer has only one digit:

```
public static boolean isSingleDigit(int x) {
    return x > -10 && x < 10;
}
```

Once you convince yourself that this method is correct—by examining and testing the code—you can just use the method without ever looking at the implementation again.

Recursive methods are no different. When you get to a recursive call, don't think about the flow of execution. Instead, *assume* that the recursive call produces the desired result.

For example, "Assuming that I can find the factorial of $n-1$, can I compute the factorial of n?" Yes you can, by multiplying by n. Here's an implementation of `factorial` with the temporary variables removed:

```
public static int factorial(int n) {
    if (n == 0) {
        return 1;
    }
    return n * factorial(n - 1);
}
```

Notice how similar this version is to the original mathematical definition:

$$0! = 1$$
$$n! = n \cdot (n-1)!$$

Of course, it is strange to assume that the method works correctly when you have not finished writing it. But that's why it's called a leap of faith!

Another common recursively defined mathematical function is the Fibonacci sequence, which has the following definition:

$$fibonacci(1) = 1$$
$$fibonacci(2) = 1$$
$$fibonacci(n) = fibonacci(n-1) + fibonacci(n-2)$$

Notice that each Fibonacci number is the sum of the two preceding Fibonacci numbers. Translated into Java, this function is as follows:

```
public static int fibonacci(int n) {
    if (n == 1 || n == 2) {
        return 1;
    }
    return fibonacci(n - 1) + fibonacci(n - 2);
}
```

If you try to follow the flow of execution here, even for small values of `n`, your head will explode. But if we take a leap of faith and assume that the two recursive invocations work correctly, then it is clear, looking at the definition, that our implementation is correct.

8.5 Counting Up Recursively

The `countdown` example in Section 8.1 has three parts: (1) it checks the base case, (2) it displays something, and (3) it makes a recursive call. What do you think happens if you reverse steps 2 and 3, making the recursive call *before* displaying?

```
public static void countup(int n) {
    if (n == 0) {
        System.out.println("Blastoff!");
    } else {
        countup(n - 1);
        System.out.println(n);
    }
}
```

The stack diagram is the same as before, and the method is still called n times. But now the `System.out.println` happens just before each recursive call returns. As a result, it counts *up* instead of down:

```
Blastoff!
1
2
3
```

Keep this in mind for the next example, which displays numbers in binary.

8.6 Binary Number System

You are probably aware that computers can store only 1s and 0s. That's because processors and memory are made up of billions of tiny on-off switches.

The value 1 means a switch is on; the value 0 means a switch is off. All types of data, whether integer, floating-point, text, audio, video, or something else, are represented by 1s and 0s.

Fortunately, we can represent any integer as a **binary** number. Table 8.1 shows the first eight numbers in binary and decimal.

Binary	Decimal
0	0
1	1
10	2
11	3
100	4
101	5
110	6
111	7

Table 8.1: The first eight binary numbers.

In decimal there are 10 digits, and the written representation of numbers is based on powers of 10. For example, the number 456 has 4 in the 100's place, 5 in the 10's place, and 6 in the 1's place. So the value is 400 + 50 + 6:

4	5	6
10^2	10^1	10^0

In binary there are two digits, and the written representation of numbers is based on powers of two. For example, the number 10111 has 1 in the 16's place, 0 in the 8's place, 1 in the 4's place, 1 in the 2's place, and 1 in the 1's place. So the value is 16 + 0 + 4 + 2 + 1, which is 23 in decimal.

1	0	1	1	1
2^4	2^3	2^2	2^1	2^0

To get the digits of a decimal number, we can use repeated division. For example, if we divide 456 by 10, we get 45 with remainder 6. The remainder is the rightmost digit of 456.

If we divide the result again, we get 4 with remainder 5. The remainder is the second rightmost digit of 456. And if we divide again, we get 0 with remainder 4. The remainder is the third rightmost digit of 456, and the result, 0, tells us that we're done.

We can do the same thing in binary if we divide by 2. When you divide by 2, the remainder is the right-most digit, either 0 or 1. If you divide the result again, you get the second rightmost digit. If you keep going, and write down the remainders, you'll have your number in binary:

```
23 / 2 is 11 remainder 1
11 / 2 is  5 remainder 1
 5 / 2 is  2 remainder 1
 2 / 2 is  1 remainder 0
 1 / 2 is  0 remainder 1
```

Reading these remainders from bottom to top, 23 in binary is 10111.

8.7 Recursive Binary Method

Now, to display a number in binary, we can combine the algorithm from the previous section and the "count up" pattern from Section 8.5.

Here is a recursive method that displays any positive integer in binary:

```
public static void displayBinary(int value) {
    if (value > 0) {
        displayBinary(value / 2);
        System.out.print(value % 2);
    }
}
```

If `value` is `0`, `displayBinary` does nothing (that's the base case). If the argument is positive, the method divides it by 2 and calls `displayBinary` recursively. When the recursive call returns, the method displays one digit of the result and returns (again). Figure 8.3 illustrates this process.

The leftmost digit is near the bottom of the stack, so it gets displayed first. The rightmost digit, near the top of the stack, gets displayed last. After invoking `displayBinary`, we use `println` to complete the output:

```
displayBinary(23);      // output is 10111
System.out.println();
```

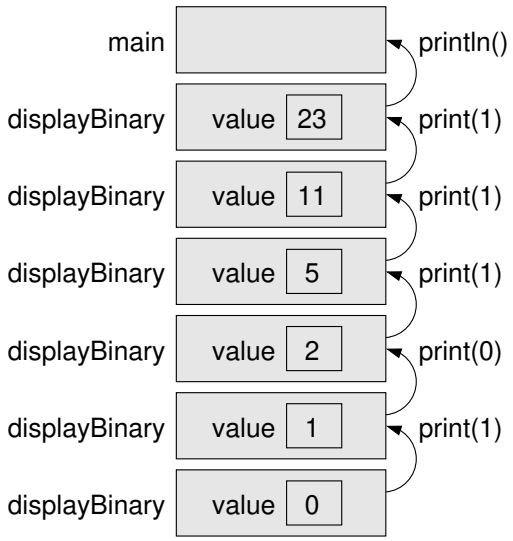


Figure 8.3: Stack diagram for the `displayBinary` method.

8.8 CodingBat Problems

In the past several chapters, you've seen methods, conditions, loops, strings, arrays, and recursion. A great resource for practicing all of these concepts is https://codingbat.com/.

CodingBat is a free website of programming problems developed by Nick Parlante, a computer science lecturer at Stanford University. As you work on these problems, CodingBat saves your progress (if you create an account).

To conclude this chapter, we consider two problems in the Recursion-1 section of CodingBat. One of them deals with strings, and the other deals with arrays. Both of them have the same recursive idea: check the base case, look at the current index, and recursively handle the rest.

The first problem is available at https://codingbat.com/prob/p118230:

> **Recursion-1 noX**
>
> Given a string, compute recursively a new string where all the `'x'` chars have been removed.
>
> ```
> noX("xaxb") → "ab"
> noX("abc") → "abc"
> noX("xx") → ""
> ```

When solving recursive problems, it helps to think about the base case first. The base case is the easiest version of the problem; for `noX`, it's the empty string. If the argument is an empty string, there are no `x`'s to be removed:

```
if (str.length() == 0) {
    return "";
}
```

Next comes the more difficult part. To solve a problem recursively, you need to think of a simpler instance of the same problem. For `noX`, it's removing all the `x`'s from a shorter string.

So let's split the string into two parts, the first letter and the rest:

```
char first = str.charAt(0);
String rest = str.substring(1);
```

Now we can make a recursive call to remove the `x`'s from `rest`:

```
String recurse = noX(rest);
```

If `first` happens to be an `x`, we're done; we just have to return `recurse`. Otherwise, we have to concatenate `first` and `recurse`. Here's the `if` statement we need:

```
if (first == 'x') {
    return recurse;
} else {
    return first + recurse;
}
```

You can run this solution on CodingBat by pasting these snippets into the provided method definition.

The second problem is available at https://codingbat.com/prob/p135988:

> **Recursion-1 array11**
>
> Given an array of ints, compute recursively the number of times that the value 11 appears in the array.
>
> `array11([1, 2, 11], 0)` → `1`
> `array11([11, 11], 0)` → `2`
> `array11([1, 2, 3, 4], 0)` → `0`

This problem uses the convention of passing the index as an argument. So the base case is when we've reached the end of the array. At that point, we know there are no more `11`s:

```
if (index >= nums.length) {
    return 0;
}
```

Next we look at the current number (based on the given index), and check if it's an `11`. After that, we can recursively check the rest of the array. Similar to the `noX` problem, we look at only one integer per method call:

```
int recurse = array11(nums, index + 1);
if (nums[index] == 11) {
    return recurse + 1;
} else {
    return recurse;
}
```

Again, you can run this solutions on CodingBat by pasting the snippets into the method definition.

To see how these solutions actually work, you might find it helpful to step through them with a debugger (see Appendix A.6) or Java Tutor (https://thinkjava.org/javatutor). Then try solving other CodingBat problems on your own.

Learning to think recursively is an important part of learning to think like a computer scientist. Many algorithms can be written concisely with recursive methods that perform computations on the way down, on the way up, or both.

8.9 Vocabulary

iterative: A method or algorithm that repeats steps by using one or more loops.

recursive: A method or algorithm that invokes itself one or more times with different arguments.

base case: A condition that causes a recursive method *not* to make another recursive call.

factorial: The product of all the integers up to and including a given integer.

leap of faith: A way to read recursive programs by assuming that the recursive call works, rather than following the flow of execution.

binary: A system that uses only zeros and ones to represent numbers. Also known as "base 2".

8.10 Exercises

The code for this chapter is in the *ch08* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

If you have not already read Appendix A.7, now might be a good time. It describes JUnit, a standard framework for writing test code.

Exercise 8.1 The purpose of this exercise is to take a problem and break it into smaller problems, and to solve the smaller problems by writing simple methods. Consider the first verse of the song "99 Bottles of Beer":

> 99 bottles of beer on the wall,
> 99 bottles of beer,
> ya' take one down, ya' pass it around,
> 98 bottles of beer on the wall.

Subsequent verses are identical except that the number of bottles gets smaller by one in each verse, until the last verse:

> No bottles of beer on the wall,
> no bottles of beer,
> ya' can't take one down, ya' can't pass it around,
> 'cause there are no more bottles of beer on the wall!

And then the song (finally) ends.

Write a program that displays the entire lyrics of "99 Bottles of Beer". Your program should include a recursive method that does the hard part, but you might want to write additional methods to separate other parts of the program. As you develop your code, test it with a small number of verses, like `3`.

Exercise 8.2 Write a recursive method named `oddSum` that takes a positive odd integer `n` and returns the sum of odd integers from 1 to `n`. Start with a base case, and use temporary variables to debug your solution. You might find it helpful to print the value of `n` each time `oddSum` is invoked.

Exercise 8.3 In this exercise, you will use a stack diagram to understand the execution of the following recursive method:

```
public static void main(String[] args) {
    System.out.println(prod(1, 4));
}

public static int prod(int m, int n) {
    if (m == n) {
        return n;
    } else {
        int recurse = prod(m, n - 1);
        int result = n * recurse;
        return result;
    }
}
```

1. Draw a stack diagram showing the state of the program just before the last invocation of `prod` completes.

2. What is the output of this program? (Try to answer this question on paper first; then run the code to check your answer.)

3. Explain in a few words what `prod` does (without getting into the details of how it works).

4. Rewrite `prod` without the temporary variables `recurse` and `result`. *Hint:* You need only one line for the `else` branch.

Exercise 8.4 The goal of this exercise is to translate a recursive definition into a Java method. The Ackermann function is defined for non-negative integers as follows:

$$A(m,n) = \begin{cases} n+1 & \text{if } m = 0 \\ A(m-1,1) & \text{if } m > 0 \text{ and } n = 0 \\ A(m-1, A(m,n-1)) & \text{if } m > 0 \text{ and } n > 0 \end{cases}$$

Write a recursive method called `ack` that takes two `int`s as parameters and that computes and returns the value of the Ackermann function.

Test your implementation of Ackermann by invoking it from `main` and displaying the return value. Note the return value gets very big very quickly. You should try it only for small values of m and n (not bigger than 3).

Exercise 8.5 Write a recursive method called `power` that takes a double `x` and an integer `n` and returns x^n.

Hint: A recursive definition of this operation is $x^n = x \cdot x^{n-1}$. Also, remember that anything raised to the zeroth power is 1.

Optional challenge: you can make this method more efficient, when `n` is even, using $x^n = \left(x^{n/2}\right)^2$.

Exercise 8.6 Many of the patterns you have seen for traversing arrays can also be written recursively. It is not common, but it is a useful exercise.

1. Write a method called `maxInRange` that takes an array of integers and two indexes, `lowIndex` and `highIndex`, and finds the maximum value in the array, but considering only the elements between `lowIndex` and `highIndex`, including both.

   This method should be recursive. If the length of the range is 1 (i.e., if `lowIndex == highIndex`), we know immediately that the sole element in the range must be the maximum. So that's the base case.

   If there is more than one element in the range, we can break the array into two pieces, find the maximum in each piece, and then find the maximum of the maxima.

2. Methods like `maxInRange` can be awkward to use. To find the largest element in an array, we have to provide the range for the entire array:

   ```
   double max = maxInRange(a, 0, a.length - 1);
   ```

   Write a method called `max` that takes an array and uses `maxInRange` to find and return the largest element.

Exercise 8.7 Create a program called *Recurse.java* and type in the following methods:

```
/**
 * Returns the first character of the given String.
 */
public static char first(String s) {
    return s.charAt(0);
}
```

```
/**
 * Returns all but the first letter of the given String.
 */
public static String rest(String s) {
    return s.substring(1);
}
```

```
/**
 * Returns all but the first and last letter of the String.
 */
public static String middle(String s) {
    return s.substring(1, s.length() - 1);
}
```

```
/**
 * Returns the length of the given String.
 */
public static int length(String s) {
    return s.length();
}
```

1. Write some code in `main` that tests each of these methods. Make sure they work, and you understand what they do.

2. Using these methods, and without using any other `String` methods, write a method called `printString` that takes a string as a parameter and displays the letters of the string, one on each line. It should be a `void` method.

3. Again using only these methods, write a method called `printBackward` that does the same thing as `printString` but displays the string backward (again, one character per line).

4. Now write a method called `reverseString` that takes a string as a parameter and returns a new string as a return value. The new string should contain the same letters as the parameter, but in reverse order:

   ```
   String backwards = reverseString("coffee");
   System.out.println(backwards);
   ```

   The output of this example code should be as follows:

   ```
   eeffoc
   ```

5. A palindrome is a word that reads the same both forward and backward, like "otto" and "palindromeemordnilap". Here's one way to test whether a string is a palindrome:

   > A single letter is a palindrome, a two-letter word is a palindrome if the letters are the same, and any other word is a palindrome if the first letter is the same as the last and the middle is a palindrome.

   Write a recursive method named `isPalindrome` that takes a `String` and returns a `boolean` indicating whether the word is a palindrome.

Chapter 9

Immutable Objects

Java is an **object-oriented** language, which means that it uses objects to (1) represent data and (2) provide methods related to them. This way of organizing programs is a powerful design concept, and we will introduce it gradually throughout the remainder of the book.

An **object** is a collection of data that provides a set of methods. For example, `Scanner`, which you saw in Section 3.2, is an object that provides methods for parsing input. `System.out` and `System.in` are also objects.

Strings are objects, too. They contain characters and provide methods for manipulating character data. Other data types, like `Integer`, contain numbers and provide methods for manipulating number data. We will explore some of these methods in this chapter.

9.1 Primitives vs Objects

Not everything in Java is an object: `int`, `double`, `char`, and `boolean` are **primitive** types. When you declare a variable with a primitive type, Java reserves a small amount of memory to store its value. Figure 9.1 shows how the following values are stored in memory:

```
int number = -2;
char symbol = '!';
```

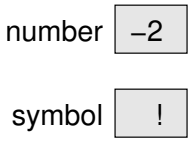


Figure 9.1: Memory diagram of two primitive variables.

As you learned in Section 7.2, an array variable stores a *reference* to an array. For example, the following line declares a variable named `array` and creates an array of three characters:

```
char[] array = {'c', 'a', 't'};
```

Figure 9.2 shows them both, with a box to represent the location of the variable and an arrow pointing to the location of the array.

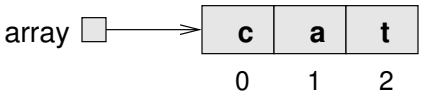


Figure 9.2: Memory diagram of an array of characters.

Objects work in a similar way. For example, this line declares a `String` variable named `word` and creates a `String` object, as shown in Figure 9.3:

```
String word = "dog";
```

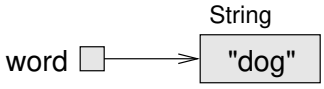


Figure 9.3: Memory diagram of a `String` object.

Objects and arrays are usually created with the `new` keyword, which allocates memory for them. For convenience, you don't have to use `new` to create strings:

```
String word1 = new String("dog");  // creates a string object
String word2 = "dog";   // implicitly creates a string object
```

Recall from Section 6.10 that you need to use the `equals` method to compare strings. The `equals` method traverses the `String` objects and tests whether they contain the same characters.

To test whether two integers or other primitive types are equal, you can simply use the == operator. But two `String` objects with the same characters would not be considered equal in the == sense. The == operator, when applied to string variables, tests only whether they refer to the *same* object.

9.2 The null Keyword

Often when you declare an object variable, you assign it to reference an object. But sometimes you want to declare a variable that doesn't refer to an object, at least initially.

In Java, the keyword `null` is a special value that means "no object". You can initialize object and array variables this way:

```
String name = null;
int[] combo = null;
```

The value `null` is represented in memory diagrams by a small box with no arrow, as in Figure 9.4.

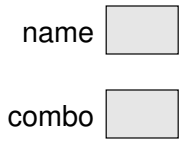


Figure 9.4: Memory diagram showing variables that are `null`.

If you try to use a variable that is `null` by invoking a method or accessing an element, Java throws a `NullPointerException`:

```
System.out.println(name.length());  // NullPointerException
System.out.println(combo[0]);       // NullPointerException
```

On the other hand, it is perfectly fine to pass a `null` reference as an argument to a method, or to receive one as a return value. In these situations, `null` is often used to represent a special condition or indicate an error.

9.3 Strings Are Immutable

If the Java library didn't have a `String` class, we would have to use character arrays to store and manipulate text. Operations like concatenation (`+`), `indexOf`, and `substring` would be difficult and inconvenient. Fortunately, Java does have a `String` class that provides these and other methods.

For example, the methods `toLowerCase` and `toUpperCase` convert uppercase letters to lowercase, and vice versa. These methods are often a source of confusion, because it sounds like they modify strings. But neither these methods nor any others can change a string, because strings are **immutable**.

When you invoke `toUpperCase` on a string, you get a new `String` object as a result. For example:

```
String name = "Alan Turing";
String upperName = name.toUpperCase();
```

After these statements run, `upperName` refers to the string `"ALAN TURING"`. But `name` still refers to `"Alan Turing"`. A common mistake is to assume that `toUpperCase` somehow affects the original string:

```
String name = "Alan Turing";
name.toUpperCase();           // ignores the return value
System.out.println(name);
```

The previous code displays `"Alan Turing"`, because the value of `name`, which refers to the original `String` object, never changes. If you want to change `name` to be uppercase, then you need to assign the return value:

```
String name = "Alan Turing";
name = name.toUpperCase();    // references the new string
System.out.println(name);
```

A similar method is `replace`, which finds and replaces instances of one string within another. This example replaces `"Computer Science"` with `"CS"`:

```
String text = "Computer Science is fun!";
text = text.replace("Computer Science", "CS");
```

As with `toUpperCase`, assigning the return value (to `text`) is important. If you don't assign the return value, invoking `text.replace` has no effect.

Strings are immutable by design, because it simplifies passing them as parameters and return values. And since the contents of a string can never change, two variables can reference the same string without one accidentally corrupting the other.

9.4 Wrapper Classes

Primitive types like `int`, `double`, and `char` cannot be `null`, and they do not provide methods. For example, you can't invoke `equals` on an `int`:

```
int i = 5;
System.out.println(i.equals(5));  // compiler error
```

But for each primitive type, there is a corresponding **wrapper class** in the Java library. The wrapper class for `int` is named `Integer`, with a capital `I`:

```
Integer i = Integer.valueOf(5);
System.out.println(i.equals(5));  // displays true
```

Other wrapper classes include `Boolean`, `Character`, `Double`, and `Long`. They are in the `java.lang` package, so you can use them without importing them.

Like strings, objects from wrapper classes are immutable, and you have to use the `equals` method to compare them:

```
Integer x = Integer.valueOf(123);
Integer y = Integer.valueOf(123);
if (x == y) {                     // false
    System.out.println("x and y are the same object");
}
if (x.equals(y)) {                // true
    System.out.println("x and y have the same value");
}
```

Because `x` and `y` refer to different objects, this code displays only "x and y have the same value".

Each wrapper class defines the constants `MIN_VALUE` and `MAX_VALUE`. For example, `Integer.MIN_VALUE` is `-2147483648`, and `Integer.MAX_VALUE` is

2147483647. Because these constants are available in wrapper classes, you don't have to remember them, and you don't have to write them yourself.

Wrapper classes also provide methods for converting strings to and from primitive types. For example, `Integer.parseInt` converts a string to an `int`. In this context, **parse** means "read and translate".

```
String str = "12345";
int num = Integer.parseInt(str);
```

Other wrapper classes provide similar methods, like `Double.parseDouble` and `Boolean.parseBoolean`. They also provide `toString`, which returns a string representation of a value:

```
int num = 12345;
String str = Integer.toString(num);
```

The result is the `String` object `"12345"`.

It's always possible to convert a primitive value to a string, but not the other way around. For example, say we try to parse an invalid string like this:

```
String str = "five";
int num = Integer.parseInt(str);  // NumberFormatException
```

`parseInt` throws a `NumberFormatException`, because the characters in the string `"five"` are not digits.

9.5 Command-Line Arguments

Now that you know about strings, arrays, and wrapper classes, we can *finally* explain the `args` parameter of the `main` method, which we have been ignoring since Chapter 1. If you are unfamiliar with the command-line interface, please read Appendix A.3.

Let's write a program to find the maximum value in a sequence of numbers. Rather than read the numbers from `System.in` by using a `Scanner`, we'll pass them as command-line arguments. Here is a starting point:

```
import java.util.Arrays;
public class Max {
    public static void main(String[] args) {
        System.out.println(Arrays.toString(args));
    }
}
```

You can run this program from the command line by typing this:

```
java Max
```

The output indicates that `args` is an **empty array**; that is, it has no elements:

```
[]
```

If you provide additional values on the command line, they are passed as arguments to `main`. For example, say you run the program like this:

```
java Max 10 -3 55 0 14
```

The output is shown here:

```
[10, -3, 55, 0, 14]
```

It's not clear from the output, but the elements of `args` are strings. So `args` is the array `{"10", "-3", "55", "0", "14"}`. To find the maximum number, we have to convert the arguments to integers.

The following code uses an enhanced `for` loop (see Section 7.8) to parse the arguments and find the largest value:

```
int max = Integer.MIN_VALUE;
for (String arg : args) {
    int value = Integer.parseInt(arg);
    if (value > max) {
        max = value;
    }
}
System.out.println("The max is " + max);
```

We begin by initializing `max` to the smallest (most negative) number an `int` can represent. That way, the first value we parse will replace `max`. As we find larger values, they will replace `max` as well.

If `args` is empty, the result will be `MIN_VALUE`. We can prevent this situation from happening by checking `args` at the beginning of the program:

```
if (args.length == 0) {
    System.err.println("Usage: java Max <numbers>");
    return;
}
```

It's customary for programs that require command-line arguments to display a "usage" message if the arguments are not valid. For example, if you run `javac` or `java` from the command line without any arguments, you will get a very long message.

9.6 Argument Validation

As we discussed in Section 5.9, you should never assume that program input will be in the correct format. Sometimes users make mistakes, such as pressing the wrong key or misreading instructions.

Or even worse, someone might make intentional "mistakes" to see what your program will do. One way hackers break into computer systems is by entering malicious input that causes a program to fail.

Programmers can make mistakes too. It's difficult to write bug-free software, especially when working in teams on large projects.

For all of these reasons, it's good practice to validate arguments passed to methods, including the `main` method. In the previous section, we did this by ensuring that `args.length` was not 0.

As a further example, consider a method that checks whether the first word of a sentence is capitalized. We can write this method using the `Character` wrapper class:

```
public static boolean isCapitalized(String str) {
    return Character.isUpperCase(str.charAt(0));
}
```

The expression `str.charAt(0)` makes two assumptions: the string object referenced by `str` exists, and it has at least one character. What if these assumptions don't hold at run-time?

- If `str` is `null`, invoking `charAt` will cause a `NullPointerException`, because you can't invoke a method on `null`.

- If `str` refers to an empty string, which is a `String` object with no characters, `charAt` will cause a `StringIndexOutOfBoundsException`, because there is no character at index `0`.

We can prevent these exceptions by validating `str` *at the start* of the method. If it's invalid, we return before executing the rest of the method:

```
public static boolean isCapitalized(String str) {
    if (str == null || str.isEmpty()) {
        return false;
    }
    return Character.isUpperCase(str.charAt(0));
}
```

Notice that `null` and *empty* are different concepts, as shown in Figure 9.5. The variable `str1` is `null`, meaning that it doesn't reference an object. The variable `str2` refers to the empty string, an object that exists.

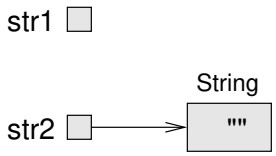


Figure 9.5: Memory diagram of `null` and empty string.

Beginners sometimes make the mistake of checking for empty first. Doing so causes a `NullPointerException`, because you can't invoke methods on variables that are `null`:

```
if (str.isEmpty() || str == null) {    // wrong!
```

Checking for `null` first prevents the `NullPointerException`. If `str` is `null`, the `||` operator will short circuit (see Section 5.5) and evaluate to `true` immediately. As a result, `str.isEmpty()` will not be called.

9.7 BigInteger Arithmetic

It might not be clear at this point why you would ever need an integer object when you can just use an `int` or `long`. One advantage is the variety of methods that `Integer` and `Long` provide. But there is another reason: when you need very large integers that exceed `Long.MAX_VALUE`.

`BigInteger` is a Java class that can represent arbitrarily large integers. There is no upper bound except the limitations of memory size and processing speed. Take a minute to read the documentation, which you can find by doing a web search for "Java BigInteger".

To use BigIntegers, you have to `import java.math.BigInteger` at the beginning of your program. There are several ways to create a BigInteger, but the simplest uses `valueOf`. The following code converts a `long` to a `BigInteger`:

```
long x = 17;
BigInteger big = BigInteger.valueOf(x);
```

You can also create BigIntegers from strings. For example, here is a 20-digit integer that is too big to store using a `long`:

```
String s = "12345678901234567890";
BigInteger bigger = new BigInteger(s);
```

Notice the difference in the previous two examples: you use `valueOf` to convert integers, and `new BigInteger` to convert strings.

Since BigIntegers are not primitive types, the usual math operators don't work. Instead, we have to use methods like `add`. To add two BigIntegers, we invoke `add` on one and pass the other as an argument:

```
BigInteger a = BigInteger.valueOf(17);
BigInteger b = BigInteger.valueOf(1700000000);
BigInteger c = a.add(b);
```

Like strings, `BigInteger` objects are immutable. Methods like `add`, `multiply`, and `pow` all return new BigIntegers, rather than modify an existing one.

Internally, a `BigInteger` is implemented using an array of `int`s, similar to the way a string is implemented using an array of `char`s. Each `int` in the array

stores a portion of the BigInteger. The methods of `BigInteger` traverse this array to perform addition, multiplication, etc.

For very long floating-point values, take a look at `java.math.BigDecimal`. Interestingly, `BigDecimal` objects represent floating-point numbers internally by using a `BigInteger`!

9.8 Incremental Design

One challenge of programming, especially for beginners, is figuring out how to divide a program into methods. In this section, we present a **design process** that allows you to divide a program into methods as you go along. The process is called "encapsulation and generalization". The essential steps are as follows:

1. Write a few lines of code in `main` or another method, and test them.
2. When they are working, wrap them in a new method and test again.
3. If it's appropriate, replace literal values with variables and parameters.

To demonstrate this process, we'll develop methods that display multiplication tables. We begin by writing and testing a few lines of code. Here is a loop that displays the multiples of two, all on one line:

```
for (int i = 1; i <= 6; i++) {
    System.out.printf("%4d", 2 * i);
}
System.out.println();
```

Each time through the loop, we display the value of `2 * i`, padded with spaces so it's four characters wide. Since we use `System.out.printf`, the output appears on a single line.

After the loop, we call `println` to print a newline character. Remember that in some environments, none of the output is displayed until the line is complete. The output of the code so far is shown here:

```
   2   4   6   8  10  12
```

The next step is to **encapsulate** the code; that is, we "wrap" the code in a method:

```
public static void printRow() {
    for (int i = 1; i <= 6; i++) {
        System.out.printf("%4d", 2 * i);
    }
    System.out.println();
}
```

Finally, we **generalize** the method to print multiples of other numbers by replacing the constant value 2 with a parameter `n`. This step is called "generalization", because it makes the method more general (less specific):

```
public static void printRow(int n) {
    for (int i = 1; i <= 6; i++) {
        System.out.printf("%4d", n * i);  // generalized n
    }
    System.out.println();
}
```

Invoking this method with the argument 2 yields the same output as before. With the argument 3, the output is as follows:

```
   3   6   9  12  15  18
```

By now, you can probably guess how we are going to display a multiplication table: we'll invoke `printRow` repeatedly with different arguments. In fact, we'll use another loop to iterate through the rows:

```
for (int i = 1; i <= 6; i++) {
    printRow(i);
}
```

And the output looks like this:

```
   1   2   3   4   5   6
   2   4   6   8  10  12
   3   6   9  12  15  18
   4   8  12  16  20  24
   5  10  15  20  25  30
   6  12  18  24  30  36
```

9.9 More Generalization

The previous result is similar to the "nested loops" approach in Section 6.4. However, the inner loop is now encapsulated in the `printRow` method. We can encapsulate the outer loop in a method too:

```
public static void printTable() {
    for (int i = 1; i <= 6; i++) {
        printRow(i);
    }
}
```

The initial version of `printTable` always displays six rows. We can generalize it by replacing the literal `6` with a parameter:

```
public static void printTable(int rows) {
    for (int i = 1; i <= rows; i++) {     // generalized rows
        printRow(i);
    }
}
```

Here is the output of `printTable(7)`:

```
  1   2   3   4   5   6
  2   4   6   8  10  12
  3   6   9  12  15  18
  4   8  12  16  20  24
  5  10  15  20  25  30
  6  12  18  24  30  36
  7  14  21  28  35  42
```

That's better, but it always displays the same number of columns. We can generalize more by adding a parameter to `printRow`:

```
public static void printRow(int n, int cols) {
    for (int i = 1; i <= cols; i++) {     // generalized cols
        System.out.printf("%4d", n * i);
    }
    System.out.println();
}
```

Now `printRow` takes two parameters: `n` is the value whose multiples should be displayed, and `cols` is the number of columns. Since we added a parameter to `printRow`, we also have to change the line in `printTable` where it is invoked:

```
public static void printTable(int rows) {
    for (int i = 1; i <= rows; i++) {
        printRow(i, rows);
    }
}
```

When this line executes, it evaluates `rows` and passes the value, which is `7` in this example, as an argument. In `printRow`, this value is assigned to `cols`. As a result, the number of columns equals the number of rows, so we get a square 7 x 7 table, instead of the previous 7 x 6 table.

When you generalize a method appropriately, you often find that it has capabilities you did not plan. For example, you might notice that the multiplication table is symmetric. Since $ab = ba$, all the entries in the table appear twice. You could save ink by printing half of the table, and you would have to change only *one line* of `printTable`:

```
printRow(i, i);  // using i for both n and cols
```

This means the length of each row is the same as its row number. The result is a triangular multiplication table:

```
1
2   4
3   6   9
4   8  12  16
5  10  15  20  25
6  12  18  24  30  36
7  14  21  28  35  42  49
```

Generalization makes code more versatile, more likely to be reused, and sometimes easier to write.

9.10 Vocabulary

object-oriented: A way of organizing code and data into objects, rather than independent methods.

object: A collection of related data that comes with a set of methods that operate on the data.

primitive: A data type that stores a single value and provides no methods.

immutable: An object that, once created, cannot be modified. Strings are immutable by design.

wrapper class: Classes in `java.lang` that provide constants and methods for working with primitive types.

parse: In Chapter 2, we defined *parse* as what the compiler does to analyze a program. Now you know that it means to read a string and interpret or translate it.

empty array: An array with no elements and a length of zero.

design process: A process for determining what methods a class or program should have.

encapsulate: To wrap data inside an object, or to wrap statements inside a method.

generalize: To replace something unnecessarily specific (like a constant value) with something appropriately general (like a variable or parameter).

9.11 Exercises

The code for this chapter is in the *ch09* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

Exercise 9.1 The point of this exercise is to explore Java types and fill in some of the details that aren't covered in the chapter.

1. Create a new program named *Test.java* and write a `main` method that contains expressions that combine various types using the `+` operator. For example, what happens when you "add" a `String` and a `char`? Does it perform character addition or string concatenation? What is the type of the result?

2. Make a bigger copy of the following table and fill it in. At the intersection of each pair of types, you should indicate whether it is legal to use the `+` operator with these types, the operation that is performed (addition or concatenation), and the type of the result.

	boolean	char	int	double	String
boolean					
char					
int					
double					
String					

3. Think about some of the choices the designers of Java made, based on this table. How many of the entries seem unavoidable, as if there was no other choice? How many seem like arbitrary choices from several equally reasonable possibilities? Which entries seem most problematic?

4. Here's a puzzler: normally, the statement `x++` is exactly equivalent to `x = x + 1`. But if `x` is a `char`, it's not exactly the same! In that case, `x++` is legal, but `x = x + 1` causes an error. Try it out. See what the error message is, and then see if you can figure out what is going on.

5. What happens when you add `""` (the empty string) to the other types; for example, `"" + 5`?

Exercise 9.2 You might be sick of the `factorial` method by now, but we're going to do one more version.

1. Create a new program called *Big.java* and write an iterative version of `factorial` (using a `for` loop).

2. Display a table of the integers from 0 to 30 along with their factorials. At some point around 15, you will probably see that the answers are not correct anymore. Why not?

3. Convert `factorial` so that it performs its calculation using BigIntegers and returns a `BigInteger` as a result. You can leave the parameter alone; it will still be an integer.

4. Try displaying the table again with your modified factorial method. Is it correct up to 30? How high can you make it go?

Exercise 9.3 Many encryption algorithms depend on the ability to raise large integers to a power. Here is a method that implements an efficient algorithm for integer exponentiation:

```
public static int pow(int x, int n) {
    if (n == 0) return 1;

    // find x to the n/2 recursively
    int t = pow(x, n / 2);

    // if n is even, the result is t squared
    // if n is odd, the result is t squared times x
    if (n % 2 == 0) {
        return t * t;
    } else {
        return t * t * x;
    }
}
```

The problem with this method is that it works only if the result is small enough to be represented by an `int`. Rewrite it so that the result is a `BigInteger`. The parameters should still be integers, though.

You should use the `BigInteger` methods `add` and `multiply`. But don't use `BigInteger.pow`; that would spoil the fun.

Exercise 9.4 One way to calculate e^x is to use the following infinite series expansion. The ith term in the series is $x^i/i!$.

$$e^x = 1 + x + x^2/2! + x^3/3! + x^4/4! + \ldots$$

1. Write a method called `myexp` that takes `x` and `n` as parameters and estimates e^x by adding the first `n` terms of this series. You can use the `factorial` method from Section 8.3 or your iterative version from the previous exercise.

2. You can make this method more efficient by observing that the numerator of each term is the same as its predecessor multiplied by `x`, and the denominator is the same as its predecessor multiplied by `i`.

   Use this observation to eliminate the use of `Math.pow` and `factorial`, and check that you get the same result.

3. Write a method called `check` that takes a parameter, `x`, and displays `x`, `myexp(x)`, and `Math.exp(x)`. The output should look like this:

   ```
   1.0     2.708333333333333     2.718281828459045
   ```

   Use the escape sequence `'\t'` to display a tab character between each of the values.

4. Vary the number of terms in the series (the second argument that `check` sends to `myexp`) and see the effect on the accuracy of the result. Adjust this value until the estimated value agrees with the correct answer when `x` is 1.

5. Write a loop in `main` that invokes `check` with the values 0.1, 1.0, 10.0, and 100.0. How does the accuracy of the result vary as `x` varies? Compare the number of digits of agreement rather than the difference between the actual and estimated values.

6. Add a loop in `main` that checks `myexp` with the values -0.1, -1.0, -10.0, and -100.0. Comment on the accuracy.

Exercise 9.5 The goal of this exercise is to practice encapsulation and generalization using some of the examples in previous chapters.

1. Starting with the code in Section 7.5, write a method called `powArray` that takes a `double` array, `a`, and returns a new array that contains the elements of `a` squared. Generalize it to take a second argument and raise the elements of `a` to the given power.

2. Starting with the code in Section 7.8, write a method called `histogram` that takes an `int` array of scores from 0 to (but not including) 100, and returns a histogram of 100 counters. Generalize it to take the number of counters as an argument.

Exercise 9.6 The following code fragment traverses a string and checks whether it has the same number of opening and closing parentheses:

```
String s = "((3 + 7) * 2)";
int count = 0;

for (int i = 0; i < s.length(); i++) {
    char c = s.charAt(i);
    if (c == '(') {
        count++;
    } else if (c == ')') {
        count--;
    }
}

System.out.println(count);
```

1. Encapsulate this fragment in a method that takes a string argument and returns the final value of `count`.

2. Test your method with multiple strings, including some that are balanced and some that are not.

3. Generalize the code so that it works on any string. What could you do to generalize it more?

Chapter 10

Mutable Objects

As you learned in the previous chapter, an *object* is a collection of data that provides a set of methods. For example, a `String` is a collection of characters that provides methods like `charAt` and `substring`.

This chapter explores two new types of objects: `Point` and `Rectangle`. You'll see how to write methods that take objects as parameters and produce objects as return values. You will also look at the source code for the Java library.

10.1 Point Objects

In math, 2D points are often written in parentheses with a comma separating the coordinates. For example, $(0, 0)$ indicates the origin, and (x, y) indicates the point x units to the right and y units up from the origin.

The `java.awt` package provides a class named `Point` that represents a location in a Cartesian plane. In order to use the `Point` class, you have to import it:

```
import java.awt.Point;
```

Then, to create a new point, you use the `new` operator:

```
Point blank;
blank = new Point(3, 4);
```

The first line declares that `blank` has type `Point`. The second line creates the new `Point` with the coordinates $x = 3$ and $y = 4$. The result of the `new` operator is a *reference* to the object. Figure 10.1 shows the result.

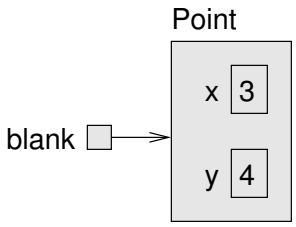


Figure 10.1: Memory diagram showing a variable that refers to a `Point` object.

As usual, the name of the variable `blank` appears outside the box, and its value appears inside the box. In this case, the value is a reference, which is represented with an arrow. The arrow points to the `Point` object, which contains two variables, `x` and `y`.

Variables that belong to an object are called **attributes**. In some documentation, you also see them called "fields". To access an attribute of an object, Java uses **dot notation**. For example:

```
int x = blank.x;
```

The expression `blank.x` means "go to the object `blank` refers to, and get the value of the attribute `x`." In this case, we assign that value to a local variable named `x`.

There is no conflict between the local variable `x` and the attribute `x`. The purpose of dot notation is to identify *which* variable you are referring to unambiguously.

You can use dot notation as part of an expression. For example:

```
System.out.println(blank.x + ", " + blank.y);
int sum = blank.x * blank.x + blank.y * blank.y;
```

The first line displays `3, 4`. The second line calculates the value `25`.

10.2 Objects as Parameters

You can pass objects as parameters in the usual way. For example:

```
public static void printPoint(Point p) {
    System.out.println("(" + p.x + ", " + p.y + ")");
}
```

This method takes a point as an argument and displays its attributes in parentheses. If you invoke `printPoint(blank)`, it displays `(3, 4)`.

As another example, we can rewrite the `distance` method from Section 4.9 so that it takes two `Point`s as parameters instead of four `double`s:

```
public static double distance(Point p1, Point p2) {
    int dx = p2.x - p1.x;
    int dy = p2.y - p1.y;
    return Math.sqrt(dx * dx + dy * dy);
}
```

Passing objects as parameters makes the source code more readable and less error-prone because related values are bundled together.

You actually don't need to write a `distance` method, because `Point` objects already have one. To compute the distance between two points, we invoke `distance` on one and pass the other as an argument:

```
Point p1 = new Point(0, 0);
Point p2 = new Point(3, 4);
double dist = p1.distance(p2);  // dist is 5.0
```

It turns out you don't need the `printPoint` method either. If you invoke `System.out.println(blank)`, it prints the type of the object and the values of the attributes:

```
java.awt.Point[x=3,y=4]
```

`Point` objects provide a method called `toString` that returns a string representation of a point. When you call `println` with objects, it *automatically* calls `toString` and displays the result.

10.3 Objects as Return Values

The `java.awt` package also provides a class named `Rectangle`. To use it, you have to import it:

```
import java.awt.Rectangle;
```

`Rectangle` objects are similar to points, but they have four attributes: `x`, `y`, `width`, and `height`. The following example creates a `Rectangle` object and makes the variable `box` refer to it:

```
Rectangle box = new Rectangle(0, 0, 100, 200);
```

Figure 10.2 shows the effect of this assignment.

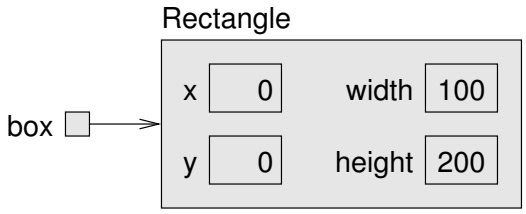


Figure 10.2: Memory diagram showing a `Rectangle` object.

If you run `System.out.println(box)`, you get this:

```
java.awt.Rectangle[x=0,y=0,width=100,height=200]
```

Again, `println` uses the `toString` method provided by `Rectangle`, which knows how to represent `Rectangle` objects as strings.

You can also write methods that return new objects. For example, `findCenter` takes a `Rectangle` as an argument and returns a `Point` with the coordinates of the center of the rectangle:

```
public static Point findCenter(Rectangle box) {
    int x = box.x + box.width / 2;
    int y = box.y + box.height / 2;
    return new Point(x, y);
}
```

The return type of this method is `Point`. The last line creates a new `Point` object and returns a reference to it.

10.4 Rectangles Are Mutable

You can change the contents of an object by making an assignment to one of its attributes. For example, to "move" a rectangle without changing its size, you can modify the `x` and `y` values:

```
Rectangle box = new Rectangle(0, 0, 100, 200);
box.x = box.x + 50;
box.y = box.y + 100;
```

The result is shown in Figure 10.3.

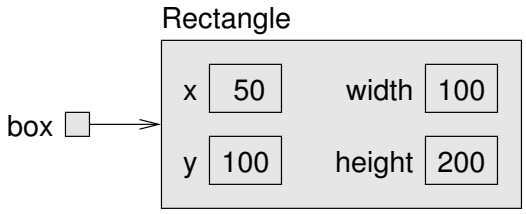


Figure 10.3: Memory diagram showing updated attributes.

We can encapsulate this code in a method and generalize it to move the rectangle by any amount:

```
public static void moveRect(Rectangle box, int dx, int dy) {
    box.x = box.x + dx;
    box.y = box.y + dy;
}
```

The variables `dx` and `dy` indicate how far to move the rectangle in each direction. Invoking this method has the effect of modifying the `Rectangle` that is passed as an argument:

```
Rectangle box = new Rectangle(0, 0, 100, 200);
moveRect(box, 50, 100);  // now at (50, 100, 100, 200)
```

Modifying objects by passing them as arguments to methods can be useful. But it can also make debugging difficult, because it is not always clear which method invocations modify their arguments.

Java provides a number of methods that operate on `Point`s and `Rectangle`s. For example, `translate` has the same effect as `moveRect`, but instead of passing the rectangle as an argument, you use dot notation:

```
box.translate(50, 100);
```

This line invokes the `translate` method on the object that `box` refers to, which modifies the object.

This syntax—using dot notation to invoke a method on an object, rather than passing it as a parameter—is more consistent with the style of object-oriented programming.

10.5 Aliasing Revisited

Remember that when you assign an object to a variable, you are assigning a *reference* to an object. It is possible to have multiple variables that refer to the same object. For example, this code creates two variables that refer to the same `Rectangle`:

```
Rectangle box1 = new Rectangle(0, 0, 100, 200);
Rectangle box2 = box1;
```

Figure 10.4 shows the result: `box1` and `box2` refer to the same object, so any changes that affect one variable also affect the other.

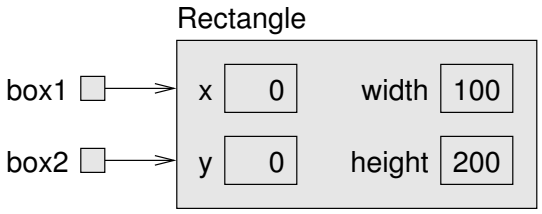


Figure 10.4: Memory diagram showing two variables that refer to the same `Rectangle` object.

For example, the following code uses `grow` to make `box1` bigger by 50 units in all directions. It decreases `x` and `y` by 50, and it increases `height` and `width` by 100:

```
box1.grow(50, 50);                  // grow box1 (alias)
```

The result is shown in Figure 10.5.

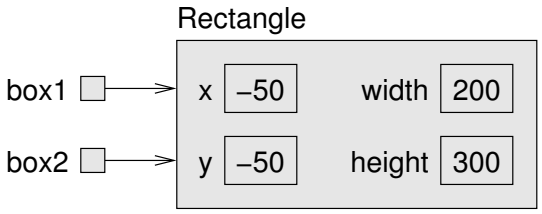


Figure 10.5: Memory diagram showing the effect of invoking `grow`.

Now, if we print `box1`, we are not surprised to see that it has changed:

```
java.awt.Rectangle[x=-50,y=-50,width=200,height=300]
```

And if we print `box2`, we should not be surprised to see that it has changed too, because it refers to the same object:

```
java.awt.Rectangle[x=-50,y=-50,width=200,height=300]
```

This scenario is called "aliasing" because a single object has multiple names, or aliases, that refer to it.

As you can tell from this simple example, code that involves aliasing can get confusing fast, and it can be difficult to debug.

10.6 Java Library Source

So far we have used several classes from the Java library, including `System`, `String`, `Scanner`, `Math`, and `Random`. These classes are written in Java, so you can read the source code to see how they work.

The Java library contains thousands of files, many of which are thousands of lines of code. That's more than one person could read and understand fully, but don't be intimidated!

Because it's so large, the library source code is stored in a ZIP archive named *src.zip*. If you have Java installed on your computer, you should already have this file somewhere:

- On Linux, it's likely under: `/usr/lib/jvm/.../lib`
  If not, you might have to install the *openjdk-...-source* package.

- On macOS, it's likely under:
  `/Library/Java/JavaVirtualMachines/.../Contents/Home/lib`
- On Windows, it's likely under: `C:\Program Files\Java\...\lib`

When you open (or unzip) the file, you will see folders that correspond to Java packages. For example, open the *java* folder, and then open the *awt* folder. (If you don't see a *java* folder at first, open the *java.desktop* folder.) You should now see *Point.java* and *Rectangle.java*, along with the other classes in the `java.awt` package.

Open *Point.java* in your editor and skim through the file. It uses language features we haven't discussed yet, so you probably won't understand every line. But you can get a sense of what professional Java source code looks like by browsing through the library.

Notice how much of *Point.java* is documentation (see Appendix B). Each method includes comments and tags like `@param` and `@return`. Javadoc reads these comments and generates documentation in HTML. You can see the same documentation online by doing a web search for "Java Point".

Now take a look at the `grow` and `translate` methods in the `Rectangle` class. There is more to them than you may have expected.

10.7 Class Diagrams

To summarize what you've learned so far, `Point` and `Rectangle` objects have attributes and methods. Attributes are an object's *data*; methods are an object's *code*. An object's *class* definition specifies the attributes and methods that it has.

Unified Modeling Language (UML) defines a graphical way to summarize this information. Figure 10.6 shows two examples, the UML **class diagrams** for the `Point` and `Rectangle` classes.

Each class is represented by a box with the name of the class, a list of attributes, and a list of methods.

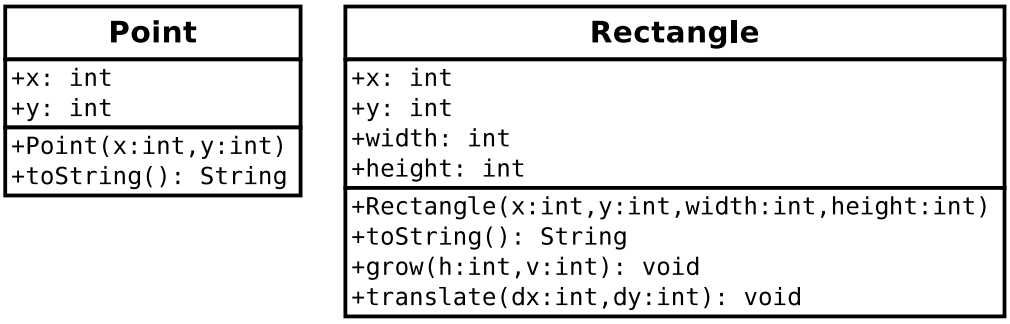


Figure 10.6: UML class diagrams for `Point` and `Rectangle`.

To identify the types of attributes and parameters, UML uses a language-independent syntax, like `x: int` rather than Java syntax, `int x`.

The plus sign (`+`) identifies `public` attributes and methods. A minus sign (`-`) identifies `private` attributes and methods, which we discuss in the next chapter.

Both `Point` and `Rectangle` have additional methods; we show only the ones introduced in this chapter.

In contrast to memory diagrams, which visualize objects (and variables) at run-time, a class diagram visualizes the source code at compile-time.

10.8 Scope Revisited

In Section 4.5, we introduced the idea that variables have scope. The scope of a variable is the part of a program where a variable can be used.

Consider the first few lines of the `Rectangle.translate` method from the Java library source code:

```
public void translate(int dx, int dy) {
    int oldv = this.x;
    int newv = oldv + dx;
    if (dx < 0) {
    ...
```

This example uses three kinds of variables:

- Parameters (`dx` and `dy`)
- Local variables (`oldv` and `newv`)
- Attributes (`this.x`)

Parameters and local variables are created when a method is invoked, and they disappear when the method returns. They can be used anywhere inside the method, but not in other methods and not in other classes.

Attributes are created when an object is created, and they disappear when the object is destroyed. They can be used in any of the object's methods, using the keyword `this`. And if they are public, they can be used in other classes via references to the object, `box1.x`.

When the Java compiler encounters a variable name, it searches backward for its declaration. The compiler first looks for local variables, then parameters, then attributes.

10.9 Garbage Collection

In the previous section, we said that attributes exist as long as the object exists. But when does an object cease to exist? Here is a simple example:

```
Point blank = new Point(3, 4);
blank = null;
```

The first line creates a new `Point` object and makes `blank` refer to it. The second line changes `blank` so that instead of referring to the object, it refers to nothing. As shown in Figure 10.7, after the second assignment, there are no references to the `Point` object.

If there are no references to an object, there is no way to access its attributes or invoke a method on it. From the program's point of view, it ceases to exist. However, it's still present in the computer's memory, taking up space.

As your program runs, the system automatically looks for stranded objects and deletes them; then the space can be reused for new objects. This process is called **garbage collection**.

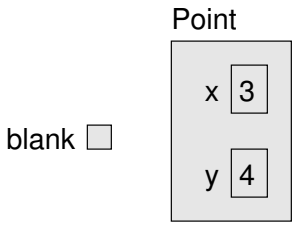


Figure 10.7: Memory diagram showing the effect of setting a variable to `null`.

You don't have to do anything to make garbage collection happen, and in general, you don't have to be aware of it. But in high-performance applications, you may notice a slight delay every now and then while Java reclaims space from discarded objects.

10.10 Mutable vs Immutable

`Point`s and `Rectangle`s are **mutable** objects, because their attributes can be modified. You can modify their attributes directly, like `box.x = 15`, or you can invoke methods that modify their attributes, like `box.translate(15, 0)`.

In contrast, immutable objects like `String`s and `Integer`s cannot be modified. They don't allow direct access to their attributes or provide methods that change them.

Immutable objects have advantages that help improve the reliability and performance of programs. You can pass strings (and other immutable objects) to methods without worrying about their contents changing as a side-effect of the method. That makes programs easier to debug and more reliable.

Also, two strings that contain the same characters can be stored in memory only once. That can reduce the amount of memory the program uses and can speed it up.

In the following example, `s1` and `s2` are created differently, but they refer to equivalent strings; that is, the two strings contain the same characters:

```
public class Surprise {
    public static void main(String[] args) {
        String s1 = "Hi, Mom!";
        String s2 = "Hi, " + "Mom!";
        if (s1 == s2) {                 // true!
            System.out.println("s1 and s2 are the same");
        }
    }
}
```

Because both strings are specified at compile time, the compiler can tell that they are equivalent. And because strings are immutable, there is no need to make two copies; the compiler can create one `String` and make both variables refer to it.

As a result, the test `s1 == s2` turns out to be true, which means that `s1` and `s2` refer to the same object. In other words, they are not just equivalent; they are identical.

Although immutable objects have some advantages, mutable objects have other advantages. Sometimes it is more efficient to modify an existing object, rather than create a new one. And some computations can be expressed more naturally using mutation.

Neither design is always better, which is why you will see both.

10.11 StringBuilder Objects

Here's an example in which mutable objects are efficient and arguably more natural: building a long string by concatenating lots of small pieces.

Strings are particularly inefficient for this operation. For example, consider the following program, which reads 10 lines from `System.in` and concatenates them into a single `String`:

```
String text = "";
for (int i = 0; i < 10; i++) {
    String line = in.nextLine();        // new string
    text = text + line + '\n';    // two more strings
}
System.out.print("You entered:\n" + text);
```

Inside the `for` loop, `in.nextLine()` returns a new string each time it is invoked. The next line of code concatenates `text` and `line`, which creates another string, and then appends the newline character, which creates yet another string.

As a result, this loop creates 30 `String` objects! At the end, `text` refers to the most recent `String`. Garbage collection deletes the rest, but that's a lot of garbage for a seemingly simple program.

The Java library provides the `StringBuilder` class for just this reason. It's part of the `java.lang` package, so you don't need to import it. Because `StringBuilder` objects are mutable, they can implement concatenation more efficiently.

Here's a version of the program that uses `StringBuilder`:

```
StringBuilder text = new StringBuilder();
for (int i = 0; i < 10; i++) {
    String line = in.nextLine();
    text.append(line);
    text.append('\n');
}
System.out.print("You entered:\n" + text);
```

The `append` method takes a `String` as a parameter and appends it to the end of the `StringBuilder`. Each time it is invoked, it modifies the `StringBuilder`; it doesn't create any new objects.

If needed, you can return the `StringBuilder`'s contents as a string by calling the `toString` method:

```
String result = text.toString();
```

The `StringBuilder` class also provides methods for inserting and deleting parts of strings efficiently. Programs that manipulate large amounts of text run much faster if you use `StringBuilder` instead of `String`.

10.12 Vocabulary

attribute: One of the named data items that make up an object.

dot notation: Use of the dot operator (`.`) to access an object's attributes or methods.

UML: Unified Modeling Language, a standard way to draw diagrams for software engineering.

class diagram: An illustration of the attributes and methods for a class.

garbage collection: The process of finding objects that have no references and reclaiming their storage space.

mutable: An object that can be modified at any time. Points and rectangles are mutable by design.

10.13 Exercises

The code for this chapter is in the *ch10* directory of *ThinkJavaCode2*. See page xviii for instructions on how to download the repository. Before you start the exercises, we recommend that you compile and run the examples.

At this point, you know enough to read Appendix C, which is about simple 2D graphics and animations. During the next few chapters, you should take a detour to read this appendix and work through the exercises.

Exercise 10.1 The point of this exercise is to make sure you understand the mechanism for passing objects as parameters.

1. For the following program, draw a stack diagram showing the local variables and parameters of `main` and `riddle` just before `riddle` returns. Use arrows to show which objects each variable references.

2. What is the output of the program?

3. Is the `blank` object mutable or immutable? How can you tell?

```
public static int riddle(int x, Point p) {
    x = x + 7;
    return x + p.x + p.y;
}
```

```
public static void main(String[] args) {
    int x = 5;
    Point blank = new Point(1, 2);

    System.out.println(riddle(x, blank));
    System.out.println(x);
    System.out.println(blank.x);
    System.out.println(blank.y);
}
```

Exercise 10.2 The point of this exercise is to make sure you understand the mechanism for returning new objects from methods. The following code uses `findCenter` and `distance` as defined in this chapter.

1. Draw a stack diagram showing the state of the program just before `findCenter` returns. Include all variables and parameters, and show the objects those variables refer to.

2. Draw a stack diagram showing the state of the program just before `distance` returns. Show all variables, parameters, and objects.

3. What is the output of this program? (Can you tell without running it?)

```
public static void main(String[] args) {
    Point blank = new Point(5, 8);

    Rectangle rect = new Rectangle(0, 2, 4, 4);
    Point center = findCenter(rect);

    double dist = distance(center, blank);
    System.out.println(dist);
}
```

Exercise 10.3 This exercise is about aliasing. Recall that aliases are two variables that refer to the same object. The following code uses `findCenter` and `printPoint` as defined in this chapter.

1. Draw a diagram that shows the state of the program just before the end of `main`. Include all local variables and the objects they refer to.
2. What is the output of the program?
3. At the end of `main`, are `p1` and `p2` aliased? Why or why not?

```
public static void main(String[] args) {
    Rectangle box1 = new Rectangle(2, 4, 7, 9);
    Point p1 = findCenter(box1);
    printPoint(p1);

    box1.grow(1, 1);
    Point p2 = findCenter(box1);
    printPoint(p2);
}
```