GLOBAL EDITION

Introduction to Java™ Programming and Data Structures

Comprehensive Version

ELEVENTH EDITION

Y. Daniel Liang

Pearson

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INTRODUCTION TO JAVA™ PROGRAMMING AND DATA STRUCTURES

COMPREHENSIVE VERSION

Eleventh Edition

Global Edition

Y. Daniel Liang

Armstrong State University

Pearson

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PREFACE

Dear Reader,

Many of you have provided feedback on earlier editions of this book, and your comments and suggestions have greatly improved the book. This edition has been substantially enhanced in presentation, organization, examples, exercises, and supplements.

fundamentals-first

The book is fundamentals first by introducing basic programming concepts and techniques before designing custom classes. The fundamental concepts and techniques of selection statements, loops, methods, and arrays are the foundation for programming. Building this strong foundation prepares students to learn object-oriented programming and advanced Java programming.

problem-driven

This book teaches programming in a problem-driven way that focuses on problem solving rather than syntax. We make introductory programming interesting by using thought-provoking problems in a broad context. The central thread of early chapters is on problem solving. Appropriate syntax and library are introduced to enable readers to write programs for solving the problems. To support the teaching of programming in a problem-driven way, the book provides a wide variety of problems at various levels of difficulty to motivate students. To appeal to students in all majors, the problems cover many application areas, including math, science, business, financial, gaming, animation, and multimedia.

data structures

The book seamlessly integrates programming, data structures, and algorithms into one text. It employs a practical approach to teach data structures. We first introduce how to use various data structures to develop efficient algorithms, and then show how to implement these data structures. Through implementation, students gain a deep understanding on the efficiency of data structures and on how and when to use certain data structures. Finally, we design and implement custom data structures for trees and graphs.

comprehensive version

brief version

The book is widely used in the introductory programming, data structures, and algorithms courses in the universities around the world. This *comprehensive version* covers fundamentals of programming, object-oriented programming, GUI programming, data structures, algorithms, concurrency, networking, database, and Web programming. It is designed to prepare students to become proficient Java programmers. A *brief version* (*Introduction to Java Programming*, Brief Version, Eleventh Edition, Global Edition) is available for a first course on programming, commonly known as CS1. The brief version contains the first 18 chapters of the comprehensive version.

The best way to teach programming is *by example*, and the only way to learn programming is *by doing*. Basic concepts are explained by example and a large number of exercises with various levels of difficulty are provided for students to practice. For our programming courses, we assign programming exercises after each lecture.

Our goal is to produce a text that teaches problem solving and programming in a broad context using a wide variety of interesting examples. If you have any comments on and suggestions for improving the book, please email me.

Sincerely,

Y. Daniel Liang
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ACM/IEEE Curricular 2013 and ABET Course Assessment

The new ACM/IEEE Computer Science Curricular 2013 defines the Body of Knowledge organized into 18 Knowledge Areas. To help instructors design the courses based on this book, we provide sample syllabi to identify the Knowledge Areas and Knowledge Units. The sample syllabi are for a three semester course sequence and serve as an example for institutional customization. The sample syllabi are accessible from the Instructor Resource Center.

Many of our users are from the ABET-accredited programs. A key component of the ABET accreditation is to identify the weakness through continuous course assessment against the course outcomes. We provide sample course outcomes for the courses and sample exams for measuring course outcomes on the Instructor Resource Center.

What's New in This Edition?

This edition is completely revised in every detail to enhance clarity, presentation, content, examples, and exercises. The major improvements are as follows:

- The book's title is changed to Introduction to Java Programming and Data Structures with new enhancements on data structures. The book uses a practical approach to introduce design, implement, and use data structures and covers all topics in a typical data structures course. Additionally, it provides bonus chapters that cover advanced data structures such as 2-4 trees, B-trees, and red-black trees.
- Updated to the latest Java technology. Examples and exercises are improved and simplified by using the new features in Java 8.
- The default and static methods are introduced for interfaces in Chapter 13.
- The GUI chapters are updated to JavaFX 8. The examples are revised. The user interfaces in the examples and exercises are now resizable and displayed in the center of the window.
- Inner classes, anonymous inner classes, and lambda expressions are covered using practical examples in Chapter 15.
- More examples and exercises in the data structures chapters use lambda expressions to simplify coding. Method references are introduced along with the `Comparator` interface in Section 20.6.
- The `forEach` method is introduced in Chapter 20 as a simple alternative to the foreach loop for applying an action to each element in a collection.
- Use the default methods for interfaces in Java 8 to redesign and simplify `MyList`, `MyArrayList`, `MyLinkedList`, `Tree`, `BST`, `AVLTree`, `MyMap`, `MyHashMap`, `MySet`, `MyHashSet`, `Graph`, `UnweightedGraph`, and `WeightedGraph` in Chapters 24–29.
- Chapter 30 is brand new to introduce aggregate operations for collection streams.
- FXML and the Scene Builder visual tool are introduced in Chapter 31.
- The Companion Website has been redesigned with new interactive quiz, CheckPoint questions, animations, and live coding.
- More than 200 additional programming exercises with solutions are provided to the instructor on the Instructor Resource Center. These exercises are not printed in the text.

Pedagogical Features

The book uses the following elements to help students get the most from the material:

- The **Objectives** at the beginning of each chapter list what students should learn from the chapter. This will help them determine whether they have met the objectives after completing the chapter.
- The **Introduction** opens the discussion with a thought-provoking question to motivate the reader to delve into the chapter.
- **Key Points** highlight the important concepts covered in each section.
- **Check Points** provide review questions to help students track their progress as they read through the chapter and evaluate their learning.
- **Problems and Case Studies**, carefully chosen and presented in an easy-to-follow style, teach problem solving and programming concepts. The book uses many small, simple, and stimulating examples to demonstrate important ideas.
- The **Chapter Summary** reviews the important subjects that students should understand and remember. It helps them reinforce the key concepts they have learned in the chapter.
- **Quizzes** are accessible online, grouped by sections, for students to do self-test on programming concepts and techniques.
- **Programming Exercises** are grouped by sections to provide students with opportunities to apply the new skills they have learned on their own. The level of difficulty is rated as easy (no asterisk), moderate (*), hard (**), or challenging (***). The trick of learning programming is practice, practice, and practice. To that end, the book provides a great many exercises. Additionally, more than 200 programming exercises with solutions are provided to the instructors on the Instructor Resource Center. These exercises are not printed in the text.
- **Notes**, **Tips**, **Cautions**, and **Design Guides** are inserted throughout the text to offer valuable advice and insight on important aspects of program development.

Note
Provides additional information on the subject and reinforces important concepts.

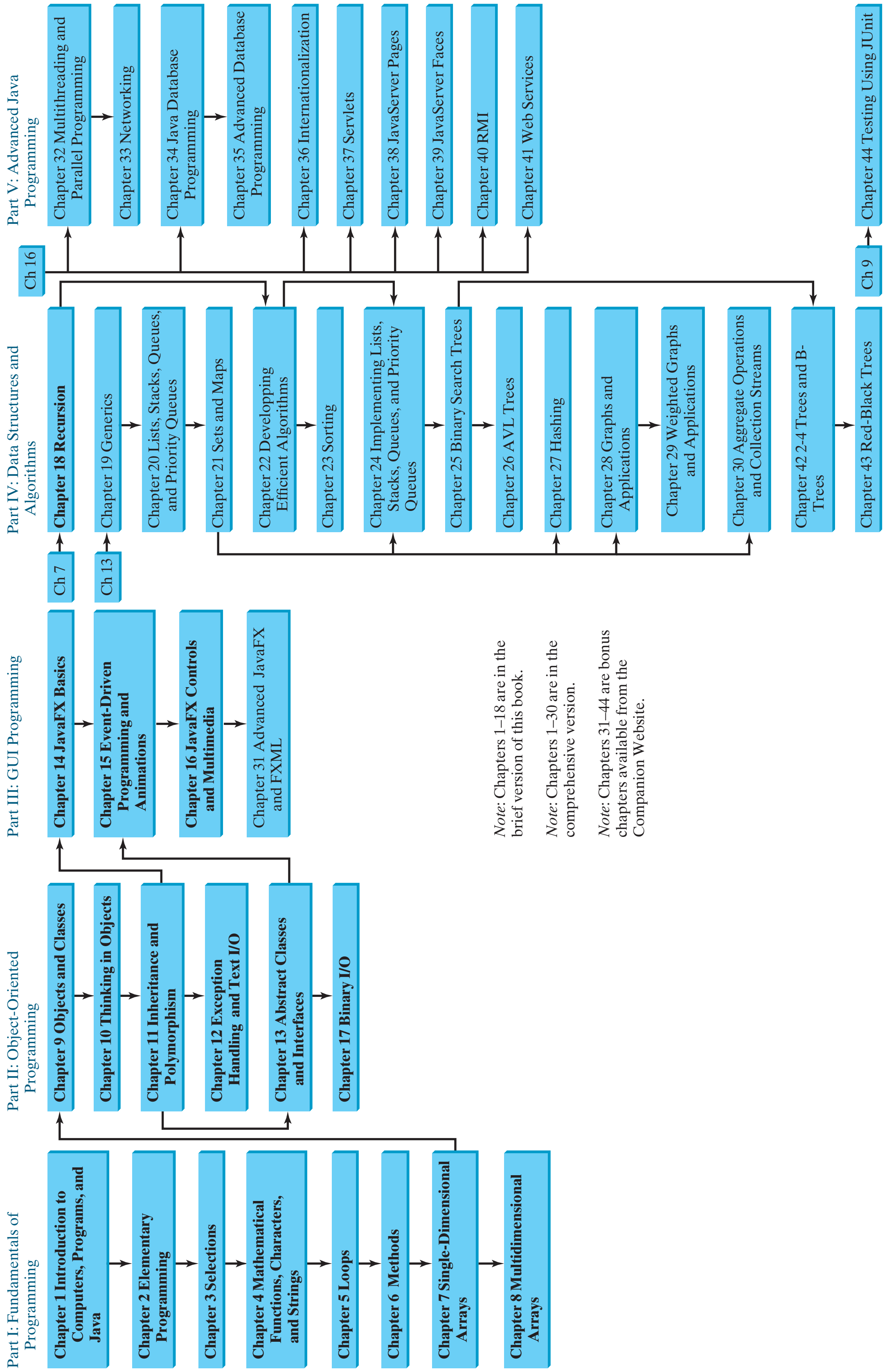
Tip
Teaches good programming style and practice.

Caution
Helps students steer away from the pitfalls of programming errors.

Design Guide
Provides guidelines for designing programs.

Flexible Chapter Orderings

The book is designed to provide flexible chapter orderings to enable GUI, exception handling, recursion, generics, and the Java Collections Framework to be covered earlier or later. The diagram on the next page shows the chapter dependencies.


Part I: Fundamentals of Programming
Chapter 1 Introduction to Computers, Programs, and Java
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Chapter 4 Mathematical Functions, Characters, and Strings
Chapter 5 Loops
Chapter 6 Methods
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Chapter 43 Red-Black Trees
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Chapter 33 Networking
Chapter 34 Java Database Programming
Chapter 35 Advanced Database Programming
Chapter 36 Internationalization
Chapter 37 Servlets
Chapter 38 JavaServer Pages
Chapter 39 JavaServer Faces
Chapter 40 RMI
Chapter 41 Web Services
Chapter 44 Testing Using JUnit

Note: Chapters 1–18 are in the brief version of this book.

Note: Chapters 1–30 are in the comprehensive version.

Note: Chapters 31–44 are bonus chapters available from the Companion Website.

Organization of the Book

The chapters can be grouped into five parts that, taken together, form a comprehensive introduction to Java programming, data structures and algorithms, and database and Web programming. Because knowledge is cumulative, the early chapters provide the conceptual basis for understanding programming and guide students through simple examples and exercises; subsequent chapters progressively present Java programming in detail, culminating with the development of comprehensive Java applications. The appendixes contain a mixed bag of topics, including an introduction to number systems, bitwise operations, regular expressions, and enumerated types.

Part I: Fundamentals of Programming (Chapters 1–8)

The first part of the book is a stepping stone, preparing you to embark on the journey of learning Java. You will begin to learn about Java (Chapter 1) and fundamental programming techniques with primitive data types, variables, constants, assignments, expressions, and operators (Chapter 2), selection statements (Chapter 3), mathematical functions, characters, and strings (Chapter 4), loops (Chapter 5), methods (Chapter 6), and arrays (Chapters 7–8). After Chapter 7, you can jump to Chapter 18 to learn how to write recursive methods for solving inherently recursive problems.

Part II: Object-Oriented Programming (Chapters 9–13, and 17)

This part introduces object-oriented programming. Java is an object-oriented programming language that uses abstraction, encapsulation, inheritance, and polymorphism to provide great flexibility, modularity, and reusability in developing software. You will learn programming with objects and classes (Chapters 9–10), class inheritance (Chapter 11), polymorphism (Chapter 11), exception handling (Chapter 12), abstract classes (Chapter 13), and interfaces (Chapter 13). Text I/O is introduced in Chapter 12 and binary I/O is discussed in Chapter 17.

Part III: GUI Programming (Chapters 14–16 and Bonus Chapter 31)

JavaFX is a new framework for developing Java GUI programs. It is not only useful for developing GUI programs, but also an excellent pedagogical tool for learning object-oriented programming. This part introduces Java GUI programming using JavaFX in Chapters 14–16. Major topics include GUI basics (Chapter 14), container panes (Chapter 14), drawing shapes (Chapter 14), event-driven programming (Chapter 15), animations (Chapter 15), and GUI controls (Chapter 16), and playing audio and video (Chapter 16). You will learn the architecture of JavaFX GUI programming and use the controls, shapes, panes, image, and video to develop useful applications. Chapter 31 covers advanced features in JavaFX.

Part IV: Data Structures and Algorithms (Chapters 18–30 and Bonus Chapters 42–43)

This part covers the main subjects in a typical data structures and algorithms course. Chapter 18 introduces recursion to write methods for solving inherently recursive problems. Chapter 19 presents how generics can improve software reliability. Chapters 20 and 21 introduce the Java Collection Framework, which defines a set of useful API for data structures. Chapter 22 discusses measuring algorithm efficiency in order to choose an appropriate algorithm for applications. Chapter 23 describes classic sorting algorithms. You will learn how to implement several classic data structures lists, queues, and priority queues in Chapter 24. Chapters 25 and 26 introduce binary search trees and AVL trees. Chapter 27 presents hashing and implementing maps and sets using hashing. Chapters 28 and 29 introduce graph applications. Chapter 30 introduces aggregate operations for collection streams. The 2-4 trees, B-trees, and red-black trees are covered in Bonus Chapters 42–43.

Part V: Advanced Java Programming (Chapters 32-41, 44)

This part of the book is devoted to advanced Java programming. Chapter 32 treats the use of multithreading to make programs more responsive and interactive and introduces parallel programming. Chapter 33 discusses how to write programs that talk with each other from different hosts over the Internet. Chapter 34 introduces the use of Java to develop database projects. Chapter 35 delves into advanced Java database programming. Chapter 36 covers the use of internationalization support to develop projects for international audiences. Chapters 37 and 38 introduce how to use Java servlets and JavaServer Pages to generate dynamic content from Web servers. Chapter 39 introduces modern Web application development using JavaServer Faces. Chapter 40 introduces remote method invocation and Chapter 41 discusses Web services. Chapter 44 introduces testing Java programs using JUnit.

Appendixes

This part of the book covers a mixed bag of topics. Appendix A lists Java keywords. Appendix B gives tables of ASCII characters and their associated codes in decimal and in hex. Appendix C shows the operator precedence. Appendix D summarizes Java modifiers and their usage. Appendix E discusses special floating-point values. Appendix F introduces number systems and conversions among binary, decimal, and hex numbers. Finally, Appendix G introduces bitwise operations. Appendix H introduces regular expressions. Appendix I covers enumerated types.

Java Development Tools

You can use a text editor, such as the Windows Notepad or WordPad, to create Java programs and to compile and run the programs from the command window. You can also use a Java development tool, such as NetBeans or Eclipse. These tools support an integrated development environment (IDE) for developing Java programs quickly. Editing, compiling, building, executing, and debugging programs are integrated in one graphical user interface. Using these tools effectively can greatly increase your programming productivity. NetBeans and Eclipse are easy to use if you follow the tutorials. Tutorials on NetBeans and Eclipse can be found in the supplements on the Companion Website www.pearsonglobaleditions.com/Liang.

IDE tutorials

Student Resources

The Companion Website (www.pearsonglobaleditions.com/Liang) contains the following resources:

- Answers to CheckPoint questions
- Solutions to majority of even-numbered programming exercises
- Source code for the examples in the book
- Interactive quiz (organized by sections for each chapter)
- Supplements
- Debugging tips
- Video notes
- Algorithm animations

Supplements

The text covers the essential subjects. The supplements extend the text to introduce additional topics that might be of interest to readers. The supplements are available from the Companion Website.

Instructor Resources

The Companion Website, accessible from www.pearsonglobaleditions.com/Liang, contains the following resources:

- Microsoft PowerPoint slides with interactive buttons to view full-color, syntax-highlighted source code and to run programs without leaving the slides.
- Solutions to a majority of odd-numbered programming exercises.
- More than 200 additional programming exercises and 300 quizzes organized by chapters. These exercises and quizzes are available only to the instructors. Solutions to these exercises and quizzes are provided.
- Web-based quiz generator. (Instructors can choose chapters to generate quizzes from a large database of more than two thousand questions.)
- Sample exams. Most exams have four parts:
    - Multiple-choice questions or short-answer questions
    - Correct programming errors
    - Trace programs
    - Write programs
- Sample exams with ABET course assessment.
- Projects. In general, each project gives a description and asks students to analyze, design, and implement the project.

Some readers have requested the materials from the Instructor Resource Center. Please understand that these are for instructors only. Such requests will not be answered.

Online Practice and Assessment with MyProgrammingLab

MyProgrammingLab™

MyProgrammingLab helps students fully grasp the logic, semantics, and syntax of programming. Through practice exercises and immediate, personalized feedback, MyProgrammingLab improves the programming competence of beginning students who often struggle with the basic concepts and paradigms of popular high-level programming languages.

A self-study and homework tool, a MyProgrammingLab course consists of hundreds of small practice problems organized around the structure of this textbook. For students, the system automatically detects errors in the logic and syntax of their code submissions and offers targeted hints that enable students to figure out what went wrong—and why. For instructors, a comprehensive gradebook tracks correct and incorrect answers and stores the code inputted by students for review.

MyProgrammingLab is offered to users of this book in partnership with Turing's Craft, the makers of the CodeLab interactive programming exercise system. For a full demonstration, to see feedback from instructors and students, or to get started using MyProgrammingLab in your course, visit www.myprogramminglab.com.

Video Notes

VideoNote

We are excited about the new Video Notes feature that is found in this new edition. These videos provide additional help by presenting examples of key topics and showing how to solve problems completely from design through coding. Video Notes are available from www.pearsonglobaleditions.com/Liang.

Animation

Algorithm Animations

We have provided numerous animations for algorithms. These are valuable pedagogical tools to demonstrate how algorithms work. Algorithm animations can be accessed from the Companion Website.

Acknowledgments

I would like to thank Armstrong State University for enabling me to teach what I write and for supporting me in writing what I teach. Teaching is the source of inspiration for continuing to improve the book. I am grateful to the instructors and students who have offered comments, suggestions, corrections, and praise. My special thanks go to Stefan Andrei of Lamar University and William Bahn of University of Colorado Colorado Springs for their help to improve the data structures part of this book.

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CONTENTS

Chapter 31–44 are available from the Companion Website at www.pearsonglobaleditions.com/Liang

VideoNotes

Locations of VideoNotes

www.pearsonglobaleditions.com/Liang

VideoNote

Animations

CHAPTER

1

Introduction to Computers, Programs, and Java™

Objectives

- To understand computer basics, programs, and operating systems (§§1.2–1.4).
- To describe the relationship between Java and the World Wide Web (§1.5).
- To understand the meaning of Java language specification, API, JDK™, JRE™, and IDE (§1.6).
- To write a simple Java program (§1.7).
- To display output on the console (§1.7).
- To explain the basic syntax of a Java program (§1.7).
- To create, compile, and run Java programs (§1.8).
- To use sound Java programming style and document programs properly (§1.9).
- To explain the differences between syntax errors, runtime errors, and logic errors (§1.10).
- To develop Java programs using NetBeans™ (§1.11).
- To develop Java programs using Eclipse™ (§1.12).

1.1 Introduction

Key Point

The central theme of this book is to learn how to solve problems by writing a program.

what is programming?
programming
program

This book is about programming. So, what is programming? The term *programming* means to create (or develop) software, which is also called a *program.* In basic terms, software contains instructions that tell a computer—or a computerized device—what to do.

Software is all around you, even in devices you might not think would need it. Of course, you expect to find and use software on a personal computer, but software also plays a role in running airplanes, cars, cell phones, and even toasters. On a personal computer, you use word processors to write documents, web browsers to explore the Internet, and e-mail programs to send and receive messages. These programs are all examples of software. Software developers create software with the help of powerful tools called *programming languages.*

This book teaches you how to create programs by using the Java programming language. There are many programming languages, some of which are decades old. Each language was invented for a specific purpose—to build on the strengths of a previous language, for example, or to give the programmer a new and unique set of tools. Knowing there are so many programming languages available, it would be natural for you to wonder which one is best. However, in truth, there is no "best" language. Each one has its own strengths and weaknesses. Experienced programmers know one language might work well in some situations, whereas a different language may be more appropriate in other situations. For this reason, seasoned programmers try to master as many different programming languages as they can, giving them access to a vast arsenal of software-development tools.

If you learn to program using one language, you should find it easy to pick up other languages. The key is to learn how to solve problems using a programming approach. That is the main theme of this book.

You are about to begin an exciting journey: learning how to program. At the outset, it is helpful to review computer basics, programs, and operating systems (OSs). If you are already familiar with such terms as central processing unit (CPU), memory, disks, operating systems, and programming languages, you may skip Sections 1.2–1.4.

1.2 What Is a Computer?

Key Point

A computer is an electronic device that stores and processes data.

hardware
software

A computer includes both *hardware* and *software.* In general, hardware comprises the visible, physical elements of the computer, and software provides the invisible instructions that control the hardware and make it perform specific tasks. Knowing computer hardware isn't essential to learning a programming language, but it can help you better understand the effects that a program's instructions have on the computer and its components. This section introduces computer hardware components and their functions.

A computer consists of the following major hardware components (see Figure 1.1):

- A central processing unit (CPU)
- Memory (main memory)
- Storage devices (such as disks and CDs)
- Input devices (such as the mouse and the keyboard)
- Output devices (such as monitors and printers)
- Communication devices (such as modems and network interface cards (NIC))

bus

A computer's components are interconnected by a subsystem called a *bus.* You can think of a bus as a sort of system of roads running among the computer's components; data and power travel along the bus from one part of the computer to another. In personal computers,

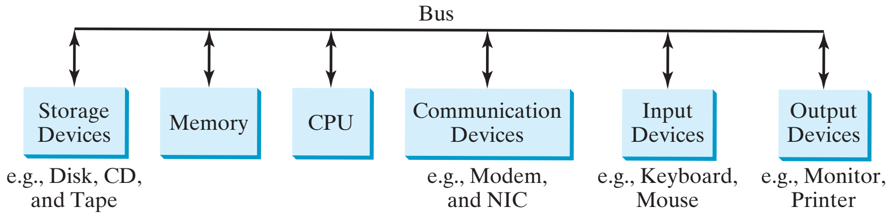

FIGURE 1.1 A computer consists of a CPU, memory, storage devices, input devices, output devices, and communication devices.

the bus is built into the computer's *motherboard*, which is a circuit case that connects all of the parts of a computer together. motherboard

1.2.1 Central Processing Unit

The *central processing unit (CPU)* is the computer's brain. It retrieves instructions from the memory and executes them. The CPU usually has two components: a *control unit* and an *arithmetic/logic unit.* The control unit controls and coordinates the actions of the other components. The arithmetic/logic unit performs numeric operations (addition, subtraction, multiplication, and division) and logical operations (comparisons). CPU

Today's CPUs are built on small silicon semiconductor chips that contain millions of tiny electric switches, called *transistors*, for processing information.

Every computer has an internal clock that emits electronic pulses at a constant rate. These pulses are used to control and synchronize the pace of operations. A higher clock *speed* enables more instructions to be executed in a given period of time. The unit of measurement of clock speed is the *hertz* (*Hz*), with 1 Hz equaling 1 pulse per second. In the 1990s, computers measured clock speed in *megahertz* (*MHz*), but CPU speed has been improving continuously; the clock speed of a computer is now usually stated in *gigahertz (GHz)*. Intel's newest processors run at about 3 GHz. speed hertz megahertz gigahertz

CPUs were originally developed with only one core. The *core* is the part of the processor that performs the reading and executing of instructions. In order to increase the CPU processing power, chip manufacturers are now producing CPUs that contain multiple cores. A multicore CPU is a single component with two or more independent cores. Today's consumer computers typically have two, three, and even four separate cores. Soon, CPUs with dozens or even hundreds of cores will be affordable. core

1.2.2 Bits and Bytes

Before we discuss memory, let's look at how information (data and programs) are stored in a computer.

A computer is really nothing more than a series of switches. Each switch exists in two states: on or off. Storing information in a computer is simply a matter of setting a sequence of switches on or off. If the switch is on, its value is 1. If the switch is off, its value is 0. These 0s and 1s are interpreted as digits in the binary number system and are called *bits* (binary digits). bits

The minimum storage unit in a computer is a *byte.* A byte is composed of eight bits. A small number such as **3** can be stored as a single byte. To store a number that cannot fit into a single byte, the computer uses several bytes. byte

Data of various kinds, such as numbers and characters, are encoded as a series of bytes. As a programmer, you don't need to worry about the encoding and decoding of data, which the computer system performs automatically, based on the encoding scheme. An *encoding scheme* is a set of rules that govern how a computer translates characters and numbers into data with which the computer can actually work. Most schemes translate each character into a encoding scheme