

Prelude *to* Programming

Concepts and Design

Sixth Edition

Stewart Venit | Elizabeth Drake



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Brief Contents

Preface xv

0	Introduction	1
1	An Introduction to Programming	25
2	Data Representation	67
3	Developing a Program	113
4	Selection Structures: Making Decisions	179
5	Repetition Structures: Looping	255
6	More about Loops and Decisions	329
7	Arrays: Lists and Tables	407
8	Searching and Sorting Arrays	465
9	Program Modules, Subprograms, and Functions	527
10	Sequential Data Files	599
11	Object-Oriented and Event-Driven Programming	655

Appendix A: Study Skills 727

Appendix B: The ASCII Character Set: Printable Characters 735

Appendix C: Answers to Self Checks 739

Index 779

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Contents

Preface xv

0 Introduction 1

In the Everyday World: You Are Already a Programmer! 2

0.1 A Brief History of Computers 2

What Is a Computer? 2

Personal Computers 4

The Internet 7

0.2 Computer Basics 8

The Central Processing Unit 9

Internal Memory 9

Mass Storage Devices 10

Input Devices 12

Output Devices 12

0.3 Software and Programming Languages 14

Types of Software 14

Types of Programming and Scripting Languages 15

Chapter Review and Exercises 19

1 An Introduction to Programming 25

In the Everyday World: You Are Already a Programmer! 26

1.1 What Is Programming? 26

A General Problem-Solving Strategy 27

Creating Computer Programs: The Program Development Cycle 28

1.2 Basic Programming Concepts 29

A Simple Program 29

Data Input 32

Program Variables and Constants 34

1.3 Data Processing and Output 37

Processing Data 37

Data Output 41

1.4 Data Types 45

The Declare Statement 45

	Character and String Data	45
1.5	Integer Data	48
	Operations on Integers	49
1.6	Floating Point Data	50
	The Decl <code>are</code> Statement Revisited	51
	Types of Floating Point Numbers	53
1.7	Running With RAPTOR (Optional)	58
	Introducing RAPTOR	58
	<i>Chapter Review and Exercises</i>	60

2 Data Representation 67

In the Everyday World: It Isn't Magic—It's Just Computer Code 68

2.1	Decimal and Binary Representation	68
	Bases and Exponents	68
	The Binary System	70
2.2	The Hexadecimal System	73
	Hexadecimal Digits	73
	Using Hexadecimal Notation	77
2.3	Integer Representation	80
	Unsigned Integer Format	80
	Sign-and-Magnitude Format	81
	One's Complement Format	84
	Two's Complement Format	86
2.4	Floating Point Representation	91
	Floating Point Numbers: the Integer Part	91
	Floating Point Numbers: the Fractional Part	91
	Converting a Decimal Fraction to Binary	93
	Putting the Two Parts Together	96
2.5	Putting it All Together	97
	Scientific Notation	97
	Exponential Notation	98
	Base 10 Normalization	99
	Normalizing Binary Floating Point Numbers	100
	The Excess ₁₂₇ System	100
	Base 2 Normalization	101
	Single- and Double-Precision Floating Point Numbers	101
	Hexadecimal Representation	104

Chapter Review and Exercises 106

3 Developing a Program 113

In the Everyday World: Planning to Program? You Need a Plan 114

3.1	The Program Development Cycle	115
	The Process of Developing a Program	115
	Additional Steps in the Cycle	118
3.2	Program Design	122
	Modular Programming	122

3.3 Coding, Documenting, and Testing a Program 131

Coding and Documenting a Program 131

Testing a Program 133

Types of Errors 134

3.4 Commercial Programs: Testing and Documenting 135

The Testing Phase Revisited 136

External Documentation 136

3.5 Structured Programming 138

Flowcharts 138

Control Structures 143

Programming Style 146

3.6 Running With RAPTOR (Optional) 147

Getting Started 148

Introduction to RAPTOR Symbols 149

Variables 151

RAPTOR Symbols 155

Run It: The Sign-In Program 164

Developing the Program 165

Creating the Program in RAPTOR: Input 165

Creating the Program in RAPTOR: Processing 168

Creating the Program in RAPTOR: Output 169

Check It Out 170

*Chapter Review and Exercises 172***4 Selection Structures: Making Decisions 179****In the Everyday World: Decisions, Decisions, Decisions . . . 180****4.1 An Introduction to Selection Structures 181**

Types of Selection Structures 181

Single- and Dual-Alternative Structures 182

4.2 Relational and Logical Operators 188

Relational Operators 188

Logical Operators 191

Hierarchy of Operations 196

4.3 ASCII Code and Comparing Strings 199

Representing Characters With Numbers 199

4.4 Selecting from Several Alternatives 203

Using If Structures 203

Using Case-Like Statements 206

4.5 Applications of Selection Structures 210

Defensive Programming 210

Menu-Driven Programs 214

4.6 Focus on Problem Solving: A New Car Price Calculator 216

Problem Statement 216

Problem Analysis 217

Program Design 217

Program Code 220

Program Test 220

4.7 Running With RAPTOR (Optional) 221

- The Selection Symbol 221
- The Call Symbol and Subcharts 224
- An Example 226
- Run It: The New Car Price Calculator 232
- Developing the Program 232
- Check It Out 242

Chapter Review and Exercises 243

5 Repetition Structures: Looping 255**In the Everyday World: Doing the Same Thing Over and Over and Knowing When to Stop 256****5.1 An Introduction to Repetition Structures: Computers Never Get Bored! 257**

- Loop Basics 257
- Relational and Logical Operators 261

5.2 Types of Loops 263

- Pre-Test and Post-Test Loops 263
- Counter-Controlled Loops 268

5.3 The For Loop 274

- The For Statement 275
- The For Loop in Action 278
- The Careful Bean Counter 281

5.4 Applications of Repetition Structures 286

- Using Sentinel-Controlled Loops to Input Data 286
- Data Validation 290
- The Floor() and Ceiling() Functions 294
- Computing Sums and Averages 297

5.5 Focus on Problem Solving: A Cost, Revenue, and Profit Problem 302

- Problem Statement 302
- Problem Analysis 302
- Program Design 304
- Program Code 307
- Program Test 307

5.6 Running With RAPTOR (Optional) 308

- Repetition: The Loop Symbol 308
- A Short Example 310
- Run It: Encryption: The Secret Message Encoder 312
- What is Encryption? 313
- Problem Statement 313
- Developing the Program 313
- Developing the Encrypting Algorithms 314
- Check It Out 320

Chapter Review and Exercises 321

6 More about Loops and Decisions 329

In the Everyday World: Loops Within Loops 330

6.1 Combining Loops with If-Then Statements 330

Exiting a Loop 331

6.2 Combining Loops and Decisions in Longer Programs 341

The Length_Of() Function 346

The Print Statement and the New Line Indicator 347

6.3 Random Numbers 351

The Random() Function 351

Not Really Random: The Pseudorandom Number 356

6.4 Nested Loops 357

Nested For Loops 357

Nesting Other Kinds of Loops 362

A Mental Workout: Mind Games 367

6.5 Focus on Problem Solving: A Guessing Game 374

Problem Statement 375

Problem Analysis 375

Program Design 376

Program Code 381

Program Test 381

6.6 Running With RAPTOR (Optional) 383

Two Short Examples 383

Run It: Validating a Password 387

Problem Statement 387

Developing the Program 387

Check the length of the password (4–8 characters) 389

Check the first character of the password (cannot be a number, 0–9) 391

Check that the password contains one of the special characters (#, *, or \$) 392

Chapter Review and Exercises 399

7 Arrays: Lists and Tables 407

In the Everyday World: Organize It with Lists and Tables 408

7.1 One-Dimensional Arrays 409

Array Basics 409

7.2 Parallel Arrays 416

Some Advantages of Using Arrays 420

A Word About Databases 423

7.3 Strings as Arrays of Characters 424

Concatenation Revisited 424

String Length versus Array Size 426

7.4 Two-Dimensional Arrays 429

An Introduction to Two-Dimensional Arrays 430

Using Two-Dimensional Arrays 431

7.5	Focus on Problem Solving: The Magic Square	436
	Problem Statement	436
	Problem Analysis	437
	Program Design	438
	Program Code	444
	Program Test	444
7.6	Running With RAPTOR (Optional)	445
	A Short Example	448
	Run It: Self-Grading Math Test	450
	Problem Statement	450
	Developing and Creating the Program	450
	Check It Out	456
	<i>Chapter Review and Exercises</i>	<i>459</i>
8	Searching and Sorting Arrays	465
	In the Everyday World: Searching and Sorting	466
8.1	Introduction to Searching and Sorting	466
	The Serial Search Technique	466
	Basic Steps in a Serial Search	467
	Pseudocode for a Serial Search	468
8.2	The Bubble Sort Technique	471
	Swapping Values	472
	Using the Bubble Sort Algorithm	474
8.3	The Binary Search	480
	Use the Binary Search for Large Arrays	481
8.4	The Selection Sort	486
	General Selection Sort Technique	486
	Applying the Selection Sort Technique	488
8.5	Focus on Problem Solving: A Grade Management Program	491
	Problem Statement	491
	Problem Analysis	491
	Program Design	493
	Program Code	499
	Program Test	500
8.6	Running With RAPTOR (Optional)	500
	The Serial Search	500
	The Bubble Sort	503
	The Binary Search	505
	The Selection Sort	507
	Run It: Soccer Camp	509
	Problem Statement	509
	Developing and Creating the Program	509
	Check It Out	515
	Revise and Improve	516
	Check It Out	517
	<i>Chapter Review and Exercises</i>	<i>519</i>

9 Program Modules, Subprograms, and Functions 527

In the Everyday World: Living and Programming in Manageable Pieces: Subprograms 528

9.1 Data Flow Diagrams, Arguments, and Parameters 529

A Big Sale: The Sale Price Computation Program 529

Data Flow Diagrams 530

An Introduction to Arguments and Parameters 531

9.2 More about Subprograms 537

Value and Reference Parameters 537

How to Tell the Difference between Value and Reference Parameters 539

Two Helpful Functions: ToUpper() and ToLower() 542

The Scope of a Variable 545

9.3 Functions 550

Built-in Functions 550

User-Defined Functions 553

9.4 Recursion 558

The Recursive Process 558

9.5 Focus on Problem Solving: A Fitness Plan 563

Problem Statement 563

Problem Analysis 563

Program Design 564

Program Code 570

Program Test 570

9.6 Running With RAPTOR (Optional) 573

RAPTOR Built-In Functions (Procedures) 573

Creating a New Procedure 576

Run It: The Fitness Plan 581

Problem Statement 581

Developing and Creating the Program 582

Check It Out 590

Chapter Review and Exercises 592

10 Sequential Data Files 599

In the Everyday World: Keeping it On File 600

10.1 An Introduction to Data Files 601

File Basics 601

Creating and Reading Sequential Files 603

10.2 Modifying a Sequential File 608

Deleting Records 609

Modifying Records 612

Inserting Records 613

Using Arrays in File Maintenance 615

10.3 Merging Sequential Files 617

- 10.4 Focus on Problem Solving: Control Break Processing 620**
 - Problem Statement 620
 - Problem Analysis 621
 - Program Design 622
 - Coding and Testing the Program 625
- 10.5 Focus on Problem Solving: The Invoice Preparation Program 625**
 - Problem Statement 626
 - Problem Analysis 626
 - Program Design 627
 - Program Code 631
 - Program Test 631
- 10.6 Running With RAPTOR (Optional) 632**
 - Creating Data Files with the Redirect_Output() Procedure 632
 - Displaying Data Files with the Redirect_Input() Procedure 633
 - The Limitations 636
 - Run It: Professor Weisheit's Semester Grades 637
 - Check It Out 645
- Chapter Review and Exercises 647*

11 Object-Oriented and Event-Driven Programming 655

- In the Everyday World: Objects are Everywhere 656**
- 11.1 Classes and Objects 656**
 - Classes 656
 - Defining Classes and Creating Objects 659
 - Creating Objects 661
 - The Constructor 663
- 11.2 More Features of Object-Oriented Programming 664**
 - Benefits of Object-Oriented Languages 664
 - Inheritance and Polymorphism 665
- 11.3 Object-Oriented Program Design and Modeling 675**
 - Modeling Languages 678
 - Unified Modeling Language (UML) 678
- 11.4 Graphical User Interfaces and Event-Driven Programming 681**
 - Window Components 681
 - Creating GUI Objects in a Program 682
 - Event-Driven Programming 684
 - Handling Events 684
 - Event-Driven Program Design 687
- 11.5 Focus on Problem Solving: Another Grade Management Program 689**
 - Problem Statement 689
 - Problem Analysis 689
 - Program Design 690
 - Program Code 695
 - Program Test 696

11.6 Running With RAPTOR (Optional) 697

- Object-Oriented Mode 697
- Creating a Class 697
- The main Program 704
- Inheritance and Polymorphism 704
- Run It: Monster Evasion 705
- Problem Statement 705
- Developing and Creating the Program 705
- The main program 709
- Using the Classes 713
- Check It Out 716

Chapter Review and Exercises 718

Appendix A:**Study Skills 727**

- A.1 Achieving Success in the Course 727**
- A.2 Using the Textbook 728**
- A.3 Doing the Homework 729**
- A.4 Writing Programs 730**
- A.5 Preparing for Tests 731**
- A.6 More about Preparing for Tests 732**
- A.7 Taking Tests 733**
- A.8 Overcoming Test Anxiety 734**

Appendix B:**The ASCII Character Set: Printable Characters 735****Appendix C:****Answers to Self Checks 739**

Index 779

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Preface

Prelude to Programming: Concepts & Design provides a language-independent introduction to programming concepts that helps students learn the following:

- General programming topics, such as data types, control structures, arrays, files, functions, and subprograms
- Structured programming principles, such as modular design, proper program documentation and style, and event-driven and object-oriented program design
- Basic tools and algorithms, such as data validation, defensive programming, sums and averages computation, and searching and sorting algorithms
- Real programming experience through the optional use of RAPTOR, a free flowchart-based programming environment
- Data representation of integer and floating point numbers

No prior computer or programming experience is necessary.

Changes to the Sixth Edition

There are significant and exciting changes in this edition. The text continues to strive to enhance learning programming concepts and to provide students with an enriched experience. Throughout the text, concepts build from clear and simple introductory explanations to complex and challenging Examples and Review Exercises. Major improvements include the following:

- Rather than relegating the material on data representation to Appendices, an entire chapter is devoted to these concepts. This chapter is completely independent of the rest of the content and can be skipped with no loss of continuity. However, instructors who want to include the material now have more examples and end-of-chapter Review Exercises.
- Chapter 0 has been revised with up-to-date content relating to new technologies.
- Chapter 1 has been revised and now includes information on the Boolean data type.
- The material on arrays, searching, and sorting has been divided into two chapters. Chapter 7 focuses on creating and using both one- and

two-dimensional arrays. Chapter 8 presents algorithms with extensive examples for searching and sorting.

- The text uses RAPTOR, a free flowcharting software application that allows students to create and run programs without focusing on syntax. Each chapter, from Chapter 3 on, includes an optional section devoted to learning RAPTOR and using RAPTOR to develop interesting, executable programs.
- Throughout the text Examples, Self Checks, and Review Exercises have been redesigned when necessary to ensure that they can be worked with or without RAPTOR.
- The Review Exercises in each chapter contain Multiple Choice, True/False, Short Answer, and a Programming Challenges section. All Challenge problems are suitable for RAPTOR.
- When real code is given throughout the text, JavaScript code has been added.
- More built-in functions and properties are introduced including `Length_Of()`, `To_ASCII()`, `To_Character()`, `Indexing[]`, and more.
- The content in Chapter 11 on object-oriented programming has been thoroughly revised and simplified.
- New material on event-driven programming has been added to Chapter 11.

Organization of the Text

The text is written and organized to allow flexibility in covering topics. Material is presented in such a way that it can be used in any introductory programming course at any level. Each concept is presented in a clear, easily understood manner and the level of difficulty builds slowly. The **What & Why** sidebars give students the opportunity to think above and beyond the material in the Examples and encourage discussion and student interaction. The **Making it Work** sidebars demonstrate how concepts are applied in the real world. **Examples**, **Self Checks**, and **Review Exercises** increase in difficulty from most basic to very challenging. The **Programming Challenges** sections at the end of each chapter give students a chance to create longer, comprehensive programs from scratch and, if RAPTOR is used, they can run the programs and see the results.

The text has been designed so that instructors can use it for students at various levels. The core of the text consists of Chapter 1 and Chapters 3–7. Chapters 0 and 2 are optional; Chapter 2 in particular covers material that is relatively complex and may be skipped without consequence. Chapters 8–11 are independent of one another except that some material in Chapter 9 is required to understand Chapter 11. Thus, the text lends itself to a custom book adoption.

Chapter Summaries

- Chapter 0 provides an overview of general computer concepts.
- Chapter 1 discusses basic problem solving strategy and the essential components of a computer program (input, processing, and output). A section on data types introduces students to numeric, string, and Boolean types.

- Chapter 2 is dedicated to data representation. Students learn to convert decimal numbers to binary and hexadecimal. The various ways to represent integers (unsigned, signed, two's complement) as well as floating point numbers are covered. IEEE standards are used to represent floating point numbers in single- and double-precision. The material in this chapter is completely independent from the rest of the book.
- Chapter 3 introduces the program development process, the principles of modular design, pseudocode, and flowcharts. Documentation, testing, syntax and logic errors, and an overview of the basic control structures are covered.
- Chapter 4 covers decision (selection) structures including single-, dual- and multiple-alternative structures, relational and logical operators, the ASCII coding scheme, defensive programming, and menu-driven programs.
- Chapters 5 and 6 present a complete coverage of repetition structures (loops). Chapter 5 focuses on the basic loop structures: pre- and post-test loops, sentinel-controlled loops, counter-controlled loops, and loops for data input, data validation, and computing sums and averages. Chapter 6 builds on the basics from the previous chapters to create programs that use repetition structures in combination with decision structures, nested loops, and random numbers.
- Chapter 7 covers one-dimensional, two-dimensional, and parallel arrays. Representation of character strings as arrays is also discussed. The material in this chapter has been expanded from the previous edition, including more examples to assist students in understanding this difficult material.
- Chapter 8 covers searching and sorting. Two search techniques (serial and binary searches) and two sort techniques (bubble and selection sorts) are included with expanded coverage.
- Chapter 9 covers functions and modules, including the use of arguments and parameters, value and reference parameters, passing by reference versus passing by value, and the scope of a variable. Built-in and user-defined functions are covered. Recursion—an advanced topic—is discussed in some depth but can be skipped if desired.
- Chapter 10 is about sequential data files. The discussion covers records and fields and how to create, write, and read from sequential files. Topics also include how to delete, modify, and insert records, and how to merge files. Arrays are used in conjunction with data files for file maintenance. The control break processing technique is demonstrated in a longer program.
- Chapter 11 is an introduction to the concepts of object-oriented programming and event-driven programming. The object-oriented material in this chapter has been revised for better understandability. The material on event-driven programming is new to this edition. A short introduction to modeling languages, including UML is given. Object-oriented design topics include classes (parent and child), objects, inheritance, polymorphism, public versus private attributes and methods, and the use of constructors. The material on event-driven programming includes the graphical user interface and window components. Properties and methods for various window controls are also covered.

Many sections throughout the text are devoted to more advanced applications and are optional. In particular, the Focus on Problem Solving sections develop relatively complex program designs, which some instructors may find useful to illustrate the chapter material and others may elect to skip to save time. RAPTOR can be used as a tool to illustrate concepts by creating examples throughout the text in RAPTOR but can also be used to create longer and more challenging, creative programs.



Running With RAPTOR: A Flowcharting Environment

In this edition, each chapter from Chapter 3 onward contains an optional section entitled **Running With RAPTOR**. The section describes how to use RAPTOR for that chapter's material with screenshots and step-by-step instructions. Short examples demonstrate how RAPTOR is used to work with the chapter's content and a longer program is developed. In many chapters the RAPTOR program is an implementation of the long program developed in the Focus on Problem Solving section. The Running With RAPTOR sections can be skipped with no loss of continuity. However, if used, the longer RAPTOR programs give students a real-life experience by creating interesting, running programs including games, encryption, and more.

Features of the Text

In the Everyday World

Beginning with Chapter 1, each chapter starts with a discussion of how the material in that chapter relates to familiar things (for example, “Arrays in the Everyday World”) This material provides an introduction to the programming logic used in that chapter through an ordinary and easily understood topic, and establishes a foundation upon which programming concepts are presented.



Making It Work

The **Making It Work** sidebars provide information about how to implement concepts in an actual high-level language, such as C++, Java, JavaScript, or Visual Basic. These boxed sidebars appear throughout the text and are self-contained and optional.



What & Why

Often we conclude an Example with a short discussion about what would happen if the program were run, or what would happen if something in the program were changed. These **What & Why** sidebars help students deepen their understanding of how programs run. They are useful in initiating classroom discussion.

Pointers and Style Pointers

The concepts of programming style and documentation are introduced in Chapter 3 and emphasized throughout. Other **Pointers** appear periodically throughout the text. These short notes provide insight into the subject or specialized knowledge about the topic at hand.



Examples

There are more than 200 numbered worked Examples in the text. The pseudocode in the Examples includes line numbers for easy reference. Detailed line-by-line discussions follow the code with sections entitled **What Happened?**

Focus on Problem Solving

Each chapter from Chapter 4 to the end includes a **Focus on Problem Solving** section which presents a real-life programming problem, analyzes it, designs a program to solve it, discusses appropriate coding considerations, and indicates how the program can be tested. In the process, students not only see a review of the chapter material, but also work through a programming problem of significant difficulty. These sections are particularly useful to prepare students for a language-specific programming course. For selected programs there are real code implementations in C++, Java, Visual Basic, and Python available on the Pearson website which can be used to demonstrate how the concepts learned in the text apply to real-life programs. The program code illustrates the congruence between the pseudocode taught in this book and the code in a specific programming language. Executable files are also included so the actual programs can be run, even if the code is not used pedagogically.

Exercises

Many new exercises have been added to this edition to correspond with new material. Many exercises have been revised to permit them to be implemented with RAPTOR. The text contains the following diverse selection:

- **Self Checks** at the end of each section include items that test students' understanding of the material covered in that section (answers to Self Checks are in Appendix C)
- **Review Questions** at the end of each chapter include questions of various types that provide further review of the chapter material (Answers to the odd-numbered questions are available on the student support website; answers to the even-numbered questions are on the instructor support web site).
- **Programming Challenges** at the end of each chapter require students to design programs using the material learned in that chapter and earlier chapters. All Programming Challenges can be implemented with RAPTOR. Solutions to all Programming Challenges in RAPTOR are available on the instructor support web site.

Supplements

Student Support Web Site

A variety of resources are available with this book. Students may access them at www.pearsonhighered.com/venit-drake.

Instructor's Supplements

Supplemental materials are available to qualified instructors at www.pearsonhighered.com/irc, including the following:

- PowerPoint Presentations for all Chapters
- Solutions to all Self Checks including RAPTOR implementations of select problems
- Solutions to all Review Exercises including corresponding RAPTOR programs
- RAPTOR programs corresponding to all Programming Challenges
- Testbank

For further information about obtaining instructor supplements, contact your campus Pearson Education sales representative.

Acknowledgments

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—*Elizabeth Drake
and Stewart Venit*

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—*Elizabeth Drake*

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—*Stewart Venit*

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Introduction

O

In this introduction, we will discuss the history of computers and computer **hardware** and **software**—the devices and programs that make a computer work.

After reading this introduction, you will be able to do the following:

- Understand the evolution of computing devices from ancient Babylonia to the twenty-first century
- Understand the components that make up a typical computer system: the central processing unit, internal memory, mass storage, and input and output devices
- Know the types of internal memory—RAM and ROM—and understand their functions
- Know the types of mass storage: magnetic, optical, solid state, and online storage
- Know the types of software used by a modern computer: application software and system software
- Know the levels of programming languages: machine language, assembly language, and high-level language
- Know the types of programming and scripting languages used to create software
- Understand the distinction between programming and scripting languages

In the Everyday World

Computers Everywhere

A century ago, a child would listen in wonder as his parents described what life was like before cars, electricity, and telephones. Today, a child listens in wonder as his parents describe what life was like without video games, smart phones, GPS systems, and computers. Seventy years ago, electronic computers didn't exist. Now, we use computers daily. Computers are in homes, schools, and offices; in supermarkets and fast food restaurants; on airplanes and submarines. Computers are in our phones, kitchen appliances, and cars. We carry them in our backpacks, pockets, and purses. They are used by the young and old, filmmakers and farmers, bankers and baseball managers. By taking advantage of a wealth of diverse and sophisticated software (programs and apps), we are able to use computers almost limitlessly for education, communication, entertainment, money management, product design and manufacture, and business and institutional processes.

0.1 A Brief History of Computers

Calculators, devices used to increase the speed and accuracy of numerical computations, have been around for a long time. For example, the abacus, which uses rows of sliding beads to perform arithmetic operations, has roots that date back more than 5,000 years to ancient Babylonia. More modern mechanical calculators, using gears and rods, have been in use for almost 400 years. In fact, by the late nineteenth century, calculators of one sort or another were relatively commonplace. However, these machines were by no means *computers* as we use the word today.

What Is a Computer?

A **computer** is a mechanical or an electronic device that can efficiently store, retrieve, and manipulate large amounts of information at high speed and with great accuracy. Moreover, it can execute tasks and act upon intermediate results without human intervention by carrying out a list of instructions called a **program**.

Although we tend to think of the computer as a recent development, Charles Babbage, an Englishman, designed and partially built a true computer in the mid-1800s. Babbage's machine, which he called an *Analytical Engine*, contained hundreds of axles and gears and could store and process 40-digit numbers. Babbage was assisted in his work by Ada Augusta Byron, the daughter of the poet Lord Byron. Ada Byron grasped the importance of the invention and helped to publicize the project. A major programming language (Ada) was named after her. Unfortunately, Babbage never finished his Analytical Engine. His ideas were too advanced for the existing technology, and he could not obtain enough financial backing to complete the project.

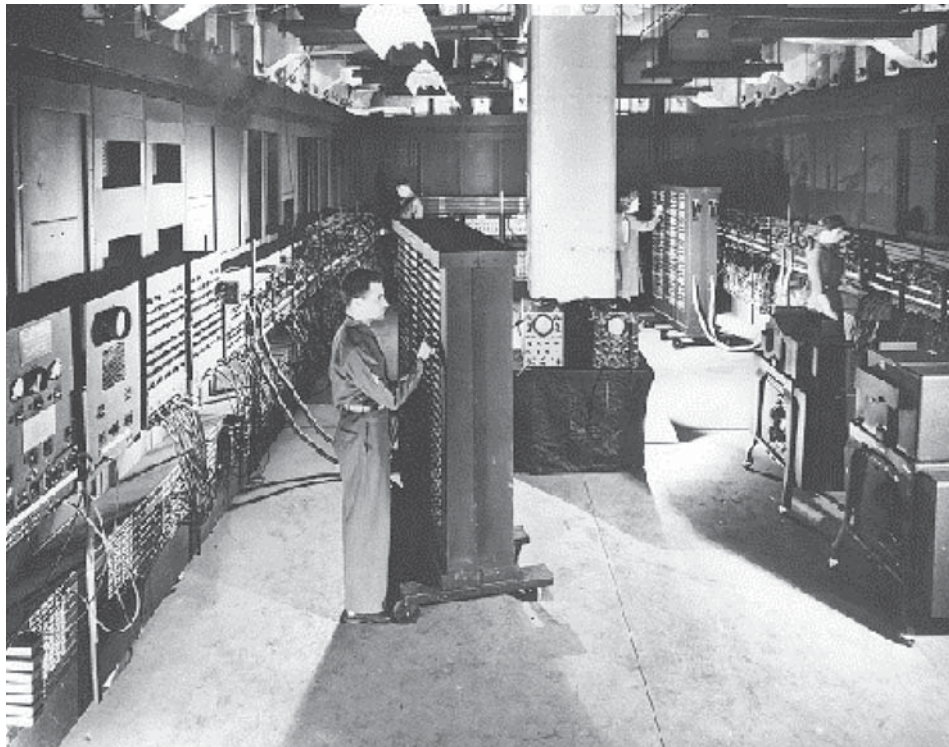
Serious attempts to build a computer were not renewed until nearly 70 years after Babbage's death. Around 1940, Howard Aiken at Harvard University, John Atanasoff, and Clifford Berry at Iowa State University built machines that came close to being true computers. However, Aiken's Mark I could not act independently on

its intermediate results, and the Atanasoff-Berry computer required the frequent intervention of an operator during its computations.

Just a few years later in 1945, a team at the University of Pennsylvania, led by John Mauchly and J. Presper Eckert, completed work on the world's first fully operable electronic computer. Mauchly and Eckert named it ENIAC, an acronym for Electronic Numerical Integrator and Computer. ENIAC (see Figure 0.1) was a huge machine. It was 80 feet long, 8 feet high, weighed 33 tons, contained over 17,000 vacuum tubes in its electronic circuits, and consumed 175,000 watts of electricity. For its time, ENIAC was a truly amazing machine because it could accurately perform up to 5,000 additions per second. However, by current standards, it was exceedingly slow. A modern run-of-the-mill personal computer can exceed 100 million operations per second!

For the next decade or so, all electronic computers used **vacuum tubes** (see Figure 0.2) to do the internal switching necessary to perform computations. These machines, which we now refer to as first-generation computers, were large by modern standards, although not as large as ENIAC. They required a climate-controlled environment and a lot of tender love and care to keep them operating. By 1955, about 300 computers—built mostly by IBM and Remington Rand—were being used, primarily by large businesses, universities, and government agencies.

Figure 0.1 The ENIAC computer



Source: U.S. Army

Figure 0.2 A vacuum tube

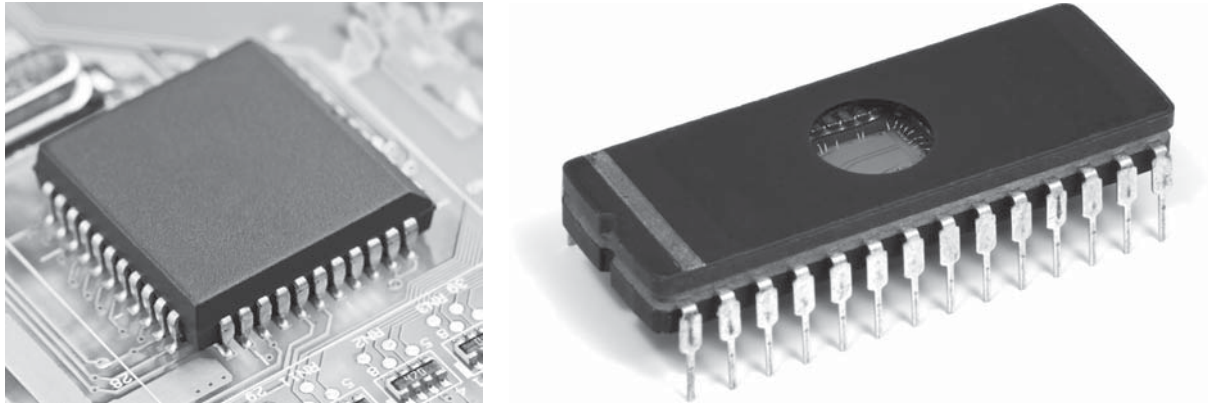
By the late 1950s, computers had become much faster and more reliable. The most significant change at this time was that the large, heat-producing vacuum tubes were replaced by relatively small transistors. The **transistor** (see Figure 0.3) is one of the most important inventions of the twentieth century. It was developed at Bell Labs in the late 1940s by William Shockley, John Bardeen, and Walter Brattain, who later shared a Nobel Prize for their achievement. Transistors are small and require very little energy, especially compared to vacuum tubes. Therefore, many transistors can be packed close together in a compact enclosure.

In the early 1960s, Digital Equipment Corporation (DEC) took advantage of small, efficient packages of transistors called **integrated circuits** to create the **minicomputer**, a machine roughly the size of a four-drawer filing cabinet. Because these computers not only were smaller but also less expensive than their predecessors, they were an immediate success. Nevertheless, sales of larger computers, now called **mainframes**, also rapidly increased. The computer age had clearly arrived and the industry leader was the IBM innovative System 360.

Personal Computers

Despite the increasing popularity of computers, it was not until the late 1970s that the computer became a household appliance. This development was made possible by the invention of the **microchip** (see Figure 0.4) in the 1960s. A microchip is a piece of silicon about the size of a postage stamp, packed with thousands of electronic components. The microchip and its more advanced cousin, the **microprocessor**, led to the creation of the world's first **personal computer (PC)** in 1974. The PC

Figure 0.3 An early transistor

Figure 0.4 The microchip

was relatively inexpensive compared to its predecessors and was small enough to fit on a desktop. This landmark computer, the Altair 8800 microcomputer, was unveiled in 1975. Although it was a primitive and not a very useful machine, the Altair inspired thousands of people, both hobbyists and professionals to become interested in PCs. Among these pioneers were Bill Gates and Paul Allen, who later founded Microsoft Corporation, now one of the world's largest companies.

Apple Computers and the IBM PC

The Altair also captured the imagination of two young Californians, Stephen Wozniak and Steven Jobs. They were determined to build a better, more useful computer. They founded Apple Computer, Inc., and in 1977 they introduced the Apple II, which was an immediate hit. With the overwhelming success of this machine and Tandy Corporation's TRS-80, companies that were manufacturing larger minicomputers and mainframes began to notice. In 1981, IBM introduced the popular IBM PC (see Figure 0.5), and the future of the PC was assured.

Figure 0.5 The IBM PC, introduced in 1981, is an antique now!

Many companies hoping to benefit from the success of the IBM PC, introduced computers that could run the same programs as the IBM, and these “IBM compatibles” soon dominated the market. Even the introduction of Apple’s innovative and easy-to-use Macintosh in 1984 could not stem the tide of the IBM compatibles. These computers, virtually all of which make use of Microsoft’s Windows operating system, have also spawned a huge array of software (computer programs) never dreamed of by the manufacturers of the original mainframes. This software includes word processors, photo editing programs, Web browsers, spreadsheet programs, database systems, presentation graphics programs, and a seemingly infinite variety of computer games. However, while in 2000 the Windows operating system commanded more than 95% of the market share, today’s mobile devices, such as smart phones and tablets, have reduced Microsoft’s domination drastically with Google’s Android operating system and the Apple operating system providing strong competition.

Today’s Computers

Today the computer market comprises a vast array of machines. Personal computers are everywhere and range in price from a few hundred to a few thousand dollars. For the most part, their manufacturers are billion dollar companies like IBM, Dell, Hewlett-Packard, and Apple. Although PCs are small and inexpensive, they produce a remarkable amount of computing power. Today’s tablets, which can weigh less than a pound and fit into a handbag, are far more powerful than the most advanced mainframes of the mid-1970s (see Figure 0.6).

Minicomputers have also found their niche. Unlike PCs, these machines can be used by a number of people (typically 16 or more) working simultaneously at separate and remote **terminals**. Each terminal consists of a keyboard and a display screen. Minicomputers have become the mainstay of many small businesses and universities, but mainframe computers are by no means dinosaurs. These relatively large and costly machines supply users with tremendous power to manipulate information. **Supercomputers** (see Figure 0.7) are even more powerful than mainframes and can process well over 1 billion instructions per second. For a special effects company like Industrial Light and Magic or a government agency like the Internal Revenue Service, there is no substitute for a large mainframe or supercomputer.

Figure 0.6 Today’s laptop and tablet computers

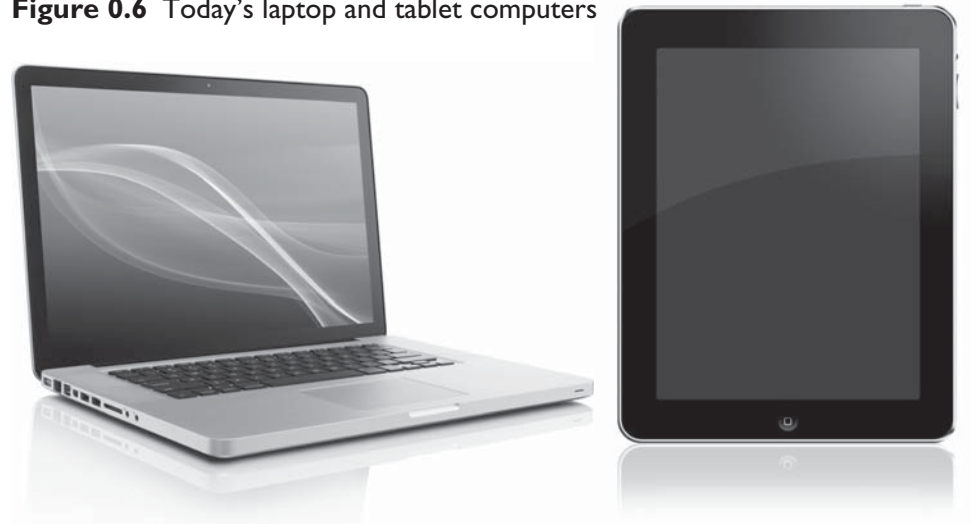


Figure 0.7 The Jaguar/Cray XT5—a modern supercomputer



The Internet

Despite the recent advances in computer technology, arguably the most significant development in the last 15 years has been the phenomenal rise in popularity of the **Internet**—a worldwide collection of *networks*. A **network** consists of two or more linked computers that are able to share resources and data wirelessly or via cable or phone lines. The Internet has roots that date back to a relatively small U.S. Defense Department project in the late 1960s. Since then, the Internet has grown from a small collection of mainframe computers used by universities and the military to more than 2.5 billion users worldwide who range in age from preschoolers to centenarians. Before the advent of smart phones, the two main attractions of the Internet were email and the World Wide Web. **Email**, which is short for *electronic mail*, allows anyone with access to the Internet to use his or her computer to exchange messages with another Internet user anywhere in the world almost instantaneously and at little or no cost. The **World Wide Web** (more simply called the **Web**) originated in 1989. It is a vast collection of linked documents (web pages) created by Internet users and stored on thousands of Internet-connected computers.

Today social networking sites have rivaled the popularity of email. These sites are part of Web2.0, the next generation of the World Wide Web. **Web2.0** consists of web applications that facilitate information sharing, user-centered design, and collaboration. While the term suggests a new version of the Web, it is not an update or change in technical specifications, but rather a change in the way people use the Web. Web2.0 generally refers to Web-based communities (such as Second Life), wikis (such as the online encyclopedia, Wikipedia), social-networking sites (such as Facebook), video-sharing sites (like YouTube), and more.

Self Check for Section 0.1

- 0.1 What characteristics of a computer distinguish it from the following?
 - a. A simple (non-programmable) calculator
 - b. A programmable calculator

- 0.2 Complete each of the following statements:
- A _____ is a list of instructions to be carried out by the computer.
 - The first fully operative electronic computer was called _____.
 - The fastest computers in use today are called _____.
 - The _____ is a worldwide collection of interlinked networks.
- 0.3 True or false? The first personal computers were produced in the 1970s.
- 0.4 True or false? Transistors, which eventually replaced the vacuum tubes of early computers, were invented in the 1940s.
- 0.5 True or false? Minicomputers and mainframe computers have become obsolete; they are no longer in use.
- 0.6 True or false? Web2.0 is a new version of the World Wide Web, including updated technical specifications.
- 0.7 Match the people listed in the first column with the corresponding computer from the second column.
- | | | |
|---------------------------------------|-----|----------------------|
| 1. Charles Babbage and Ada Byron | ___ | a. ENIAC |
| 2. J. Presper Eckert and John Mauchly | ___ | b. Apple II |
| 3. Steven Jobs and Stephen Wozniak | ___ | c. Analytical Engine |

0.2 Computer Basics

In Section 0.1 we defined a computer as a mechanical or an electronic device that can efficiently store, retrieve, and manipulate large amounts of information at high speed and with great accuracy. Regardless of the type of computer—from the original desktop machine with a separate tower, monitor, keyboard, and mouse to the smallest, thinnest smart phone to the elaborate digital display on a car’s dashboard—a computer consists of the same basic components. As the definition implies, a computer must have the ability to input, store, manipulate, and output data. These functions are carried out by the following five main components of a computer system:

1. The central processing unit (CPU)
2. Internal memory (consisting of RAM and ROM)
3. Mass storage devices (magnetic, optical, and solid state) and the Cloud
4. Input devices (primarily the keyboard and mouse)
5. Output devices (primarily the monitor and printer)

In this section, we will describe these components as they are implemented on a modern personal computer.

In a desktop PC, the CPU, internal memory, and most mass storage devices are located in the **system unit**. The input and output devices are housed in their own enclosures and are connected to the system unit by cables, or more recently, by wireless transmitters. Components like these, which are used by a computer but located outside the system unit, are sometimes referred to as **peripherals**. Laptop and tablet computers house the CPU, internal memory, mass storage devices, a monitor, and a keyboard, all in one relatively small package. The physical equipment that makes up the computer system is known as hardware.

The Central Processing Unit

The **central processing unit** (also called the **processor** or **CPU**) is the brain of the computer. It receives the program instructions, performs the arithmetic and logical operations necessary to execute them, and controls the other computer components. In a PC, the processor consists of millions of transistors that reside on a single microchip about the size of a postage stamp and plug into the computer's main circuit board, the **motherboard**.

More than any other component, the CPU distinguishes one computer from another. A primary factor in determining the power of a processor is its speed, measured in *gigahertz* (GHz). For example, the Pentium IV microprocessor, produced by Intel Corporation for use in PCs, is a chip that is produced in several variations that run at speeds up to 4 GHz. However, due to various factors, some processors are more powerful than others running at the same speed.

Internal Memory

A computer uses its **internal memory** to store instructions and data to be processed by the CPU. In a PC, memory resides on a series of chips either plugged directly into the motherboard or into one or more smaller circuit boards connected to the motherboard. There are two types of internal memory: **read-only memory (ROM)** and **random-access memory (RAM)**.

ROM contains an unalterable set of instructions that the computer uses during its start-up process and for certain other basic operations. RAM on the other hand, can be read from and written to. It's used by the computer to hold program instructions and data. You can think of ROM as a reference sheet, and RAM as a scratchpad, albeit a very large scratchpad. ROM is an integrated circuit programmed with specific data when it is manufactured. This information cannot be altered by the user; therefore, ROM is a permanent form of memory storage while RAM is the memory used by the computer to hold the data you are working on at any given time. For example, if you are writing an English essay with a word processor, as you write the essay you see it on your monitor, but it is also being held in RAM. When you close the word processing program or turn off the computer, all the information stored in RAM is lost. That's why it's important to save your work to some permanent storage medium—as most of us have learned at one time or another, to our dismay!

The smallest unit of memory is the **bit**. A bit can store only two different values—a zero or a one. It takes eight bits—one byte—to store a single character in memory. (Loosely speaking, a *character* is any symbol you can type, such as a letter, digit, or a punctuation mark.) Storing an instruction usually takes sixteen or more bits.

It would be impractical to talk about the size of a file in bits when just a single line of text might use hundreds of bits. Instead, the basic unit of memory is a **byte**. Memory is measured in **kilobytes (KB)**, **megabytes (MB)**, or **gigabytes (GB)**. One kilobyte is 1,024 ($1,024 = 2^{10}$) bytes and one megabyte is 1,024 kilobytes. A gigabyte is 1,073,741,824 ($1,024^3$ or 2^{30}) bytes. For example, 128 MB of RAM can store 134,217,728 characters of information at one time because, mathematically, the number of characters equals the number of bytes as follows:

$$128 \text{ MB} \times \frac{1,024 \text{ KB}}{\text{MB}} \times \frac{1,024 \text{ bytes}}{\text{KB}} = 134,217,728 \text{ bytes}$$