

A Beginner's Guide  
That Makes You Feel **SMART**

# C++ WITHOUT FEAR

## SECOND EDITION



```
void main() {  
    cout << "Hi!";  
}
```

- **Learn** programming basics fast
- **Write** your first C++ programs

### NEW FEATURES

- **Even more** figures, examples, and exercises
- **Even more** puzzles and games
- **An expanded** 75-page language reference
- **Instructions** for downloading free C++ software

**BRIAN OVERLAND**

Updated  
for  
C++0x!

FREE SAMPLE CHAPTER

SHARE WITH OTHERS



# *C++ Without Fear*

## *Second Edition*

---

*This page intentionally left blank*

# *C++ Without Fear*

## *Second Edition*

---

**A Beginner's Guide That  
Makes You Feel Smart**

Brian Overland



PRENTICE  
HALL

Upper Saddle River, NJ • Boston • Indianapolis • San Francisco  
New York • Toronto • Montreal • London • Munich • Paris • Madrid  
Capetown • Sydney • Tokyo • Singapore • Mexico City

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed with initial capital letters or in all capitals.

The author and publisher have taken care in the preparation of this book, but make no expressed or implied warranty of any kind and assume no responsibility for errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of the use of the information or programs contained herein.

The publisher offers excellent discounts on this book when ordered in quantity for bulk purchases or special sales, which may include electronic versions and/or custom covers and content particular to your business, training goals, marketing focus, and branding interests. For more information, please contact:

U.S. Corporate and Government Sales  
(800) 382-3419  
corpsales@pearsontechgroup.com

For sales outside the United States please contact:

International Sales  
international@pearson.com

Visit us on the Web: [informit.com/ph](http://informit.com/ph)

*Library of Congress Cataloging-in-Publication Data*

Overland, Brian R.

C++ without fear : a beginner's guide that makes you feel smart /  
Brian Overland.—2nd ed.

p. cm.

Includes index.

ISBN 978-0-13-267326-6 (pbk. : alk. paper)

1. C++ (Computer program language) I. Title.

QA76.73.C153O838 2011

005.13'3—dc22

2011004218

Copyright © 2011 Pearson Education, Inc.

All rights reserved. Printed in the United States of America. This publication is protected by copyright, and permission must be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. For information regarding permissions, write to:

Pearson Education, Inc.  
Rights and Contracts Department  
501 Boylston Street, Suite 900  
Boston, MA 02116  
Fax: (617) 671-3447

ISBN-13: 978-0-13-267326-6

ISBN-10: 0-13-267326-6

Text printed in the United States on recycled paper at Edwards Brothers in Ann Arbor, Michigan.

Third printing, August 2012

*For Colin*

*This page intentionally left blank*

# Contents

---

<i>Preface</i>	xxiii
About This Book: How It's Different	xxiii
Onward to the Second Edition	xxiv
“Where Do I Begin?”	xxv
Icons, Icons, Who's Got the Icons?	xxv
What Is Not Covered?	xxvi
Getting Started with C++: A Free Compiler	xxvii
A Final Note: Have Fun!	xxvii
<i>Acknowledgments</i>	xxix
<i>About the Author</i>	xxxi
<b>Chapter 1</b>	
<i>Your First C++ Programs</i>	1
Thinking Like a Programmer	1
Computers Do Only What You Tell Them	1
Determine What the Program Will Do	1
Write the Equivalent C++ Statements	2
<i>Interlude</i> How “Smart” Are Computers, Really?	4
Some Nerdy Definitions—A Review	4
What's Different About C++?	7
Building a C++ Program	8
Enter the Program Statements	8
Build the Program (Compile and Link)	8

Test the Program	9
Revise as Needed	9
Installing Your Own C++ Compiler	10
Example 1.1. Print a Message	11
If You're Using the Dev-C++ Environment	12
If You're Using Microsoft Visual Studio	12
How It Works	13
Exercises	15
<i>Interlude</i> What about the #include and using?	15
Advancing to the Next Print Line	16
Example 1.2. Print Multiple Lines	16
How It Works	17
Exercises	18
<i>Interlude</i> What Is a String?	18
Storing Data: C++ Variables	19
Introduction to Data Types	20
<i>Interlude</i> Why Double Precision, Not Single?	22
Example 1.3. Convert Temperatures	22
How It Works	24
Optimizing the Program	26
Exercises	28
A Word about Variable Names and Keywords	28
Exercise	29
Chapter 1 Summary	30
<b>Chapter 2</b> <i>Decisions, Decisions</i>	33
But First, a Few Words about Data Types	33
Decision Making in Programs	34
<i>Interlude</i> What about Artificial Intelligence (AI)?	35
if and if-else	35
<i>Interlude</i> Why Two Operators (= and ==)?	38
Example 2.1. Odd or Even?	39
How It Works	40
Optimizing the Code	42
Exercise	42
Introducing Loops	43
<i>Interlude</i> Infinite Loopiness	46
Example 2.2. Print 1 to N	46

How It Works	47
Optimizing the Program	49
Exercises	49
True and False in C++	50
<i>Interlude</i> The bool Data Type	51
The Increment Operator (++)	51
Statements vs. Expressions	52
Introducing Boolean (Short-Circuit) Logic	53
<i>Interlude</i> What Is “true”?	55
Example 2.3. Testing a Person’s Age	55
How It Works	56
Exercise	56
Introducing the Math Library	57
Example 2.4. Prime-Number Test	57
How It Works	59
Optimizing the Program	60
Exercise	60
Example 2.5. The Subtraction Game (NIM)	60
How It Works	63
Exercises	63
Chapter 2 Summary	64
<b>Chapter 3</b> <i>The Handy, All-Purpose “for” Statement</i>	67
Loops Used for Counting	67
Introducing the “for” Loop	68
A Wealth of Examples	70
<i>Interlude</i> Does “for” Always Behave Like “while”?	71
Example 3.1. Printing 1 to N with “for”	72
How It Works	73
Exercises	73
Compound Statements (Blocks) with “for”	74
Declaring Loop Variables on the Fly	74
Example 3.2. Prime-Number Test with “for”	75
How It Works	77
Exercise	79
Comparative Languages 101: The Basic “For” Statement	79
Chapter 3 Summary	80

<b>Chapter 4</b>	<i>Functions: Many Are Called</i>	83
	The Concept of Function	83
	The Basics of Using Functions	85
	Step 1: Declare (Prototype) the Function	85
	Step 2: Define the Function	85
	Step 3: Call the Function	86
	Example 4.1. The avg() Function	87
	How It Works	88
	Function Call a Function!	89
	Exercises	90
	Example 4.2. Prime-Number Function	90
	How It Works	92
	Exercises	93
	Local and Global Variables	93
	<i>Interlude</i> Why Global Variables at All?	95
	Recursive Functions	95
	Example 4.3. Prime Factorization	96
	How It Works	98
	<i>Interlude</i> Interlude for Math Junkies	100
	Exercises	101
	Example 4.4. Euclid's Algorithm for GCF	101
	How It Works	103
	<i>Interlude</i> Who Was Euclid?	104
	Exercises	105
	<i>Interlude</i> Interlude for Math Junkies: Rest of the Proof	105
	Example 4.5. Beautiful Recursion: Tower of Hanoi	106
	How It Works	109
	Exercises	110
	Example 4.6. Random-Number Generator	110
	How It Works	111
	Exercises	113
	Games and More Games	113
	Chapter 4 Summary	115
<b>Chapter 5</b>	<i>Arrays: All in a Row...</i>	117
	A First Look at C++ Arrays	117
	Initializing Arrays	119

Zero-Based Indexing	119
<i>Interlude</i> Why Use Zero-Based Indexes?	120
Example 5.1. Print Out Elements	121
How It Works	121
Exercises	122
Example 5.2. How Random Is Random?	123
How It Works	125
Exercises	127
Strings and Arrays of Strings	128
Example 5.3. Card Dealer #1	129
How It Works	131
Exercise	132
Example 5.4. Card Dealer #2	132
How It Works	134
Exercise	135
Example 5.5. Card Dealer #3	136
How It Works	138
Optimizing the Program	140
Exercise	141
A Word to the Wise	141
2-D Arrays: Into the Matrix	142
Chapter 5 Summary	143
<b>Chapter 6</b> <i>Pointers: Getting a Handle on Data</i>	145
What the Heck Is a Pointer, Anyway?	145
The Concept of Pointer	146
<i>Interlude</i> What Do Addresses Look Like?	147
Declaring and Using Pointers	148
Example 6.1. Print Out Addresses	151
Example 6.2. The double_it Function	152
How It Works	153
Exercises	154
Swap: Another Function Using Pointers	155
Example 6.2. Array Sorter	156
How It Works	160
Exercises	161
Pointer Arithmetic	161

Pointers and Array Processing	163
Example 6.3. Zero Out an Array	165
How It Works	166
Writing More Compact Code	166
Exercises	167
Chapter 6 Summary	168
<b>Chapter 7</b> <i>Strings: Analyzing the Text</i>	169
Text Storage on the Computer	169
<i>Interlude</i> How Does the Computer Translate Programs?	170
It Don't Mean a Thing If It Ain't Got That String	171
String-Manipulation Functions	172
Example 7.1. Building Strings	174
How It Works	175
Exercises	176
<i>Interlude</i> What about Escape Sequences?	177
Reading String Input	178
Example 7.2. Get a Number	180
How It Works	181
Exercise	183
Example 7.3. Convert to Uppercase	183
How It Works	184
Exercises	185
Individual Characters vs. Strings	185
Example 7.4. Breaking Up Input with Strtok	186
How It Works	188
Exercises	188
The New C++ String Type	189
Include String-Class Support	189
Declare and Initialize Variables of Type string	189
Working with Variables of Type string	190
Input and Output	191
Example 7.5. Building Strings with the string Type	191
How It Works	192
Exercises	193
Other Operations on the string Type	193
Chapter 7 Summary	194

<b>Chapter 8</b>	<i>Files: Electronic Storage</i>	197
	Introducing File-Stream Objects	197
	How to Refer to Disk Files	199
	Example 8.1. Write Text to a File	200
	How It Works	201
	Exercises	203
	Example 8.2. Display a Text File	203
	How It Works	204
	Exercises	205
	Text Files vs. “Binary” Files	206
	<i>Interlude</i> Are “Binary Files” Really More Binary?	208
	Introducing Binary Operations	208
	Example 8.3. Random-Access Write	211
	How It Works	213
	Exercises	214
	Example 8.4. Random-Access Read	214
	How It Works	216
	Exercises	217
	Chapter 8 Summary	217
<b>Chapter 9</b>	<i>Some Advanced Programming Techniques</i>	221
	Command-Line Arguments	221
	Example 9.1. Display File from Command Line	223
	How It Works	224
	Improving the Program	225
	<i>Interlude</i> The Virtue of Predefined Constants	226
	Exercises	226
	Function Overloading	227
	<i>Interlude</i> Overloading and Object Orientation	228
	Example 9.2. Printing Different Types of Arrays	228
	How It Works	230
	Exercise	230
	The do-while Loop	230
	The switch-case Statement	232
	Multiple Modules	234
	Exception Handling: I Take Exception to That!	237
	Say Hello to Exceptions	237

	Handling Exceptions: A First Attempt	238
	Introducing try-catch Exception Handling	238
	Chapter 9 Summary	240
<b>Chapter 10</b>	<i>New Features of C++0x</i>	243
	Overview of C++0x Features	243
	The long long Type (not long long long)	244
	<i>Interlude</i> Why a “Natural” Integer?	246
	Working with 64-Bit Literals (Constants)	246
	Accepting long long Input	247
	Formatting long long Numbers	248
	Example 10.1. Fibonacci: A 64-Bit Example	250
	How It Works	253
	Exercises	254
	Localizing Numbers	254
	<i>Interlude</i> Who Was Fibonacci?	255
	Range-Based “for” (For Each)	256
	Example 10.2. Setting an Array with Range-Based “for”	258
	How It Works	260
	Exercises	260
	The auto and decltype Keywords	261
	The nullptr Keyword	262
	Strongly Typed Enumerations	263
	enum Classes in C++0x	265
	Extended enum Syntax: Controlling Storage	266
	Example 10.3. Rock, Paper, Scissors Game	267
	How It Works	269
	A More Interesting Game	271
	Exercises	272
	Raw String Literals	273
	Chapter 10 Summary	273
<b>Chapter 11</b>	<i>Introducing Classes: The Fraction Class</i>	277
	Object Orientation: Quasi-Intelligent Data Types	277
	<i>Interlude</i> OOP...Is It Worth It?	278
	Point: A Simple Class	279
	<i>Interlude</i> Interlude for C Programmers: Structures and Classes	281

Private: Members Only (Protecting the Data)	281
Exmple 11.1. Testing the Point Class	284
How It Works	286
Exercises	286
Introducing the Fraction Class	286
Inline Functions	289
Find the Greatest Common Factor	291
Find the Lowest Common Denominator	292
Example 11.2. Fraction Support Functions	293
How It Works	294
Exercises	296
Example 11.3. Testing the Fraction Class	296
How It Works	299
<i>Interlude</i> A New Kind of #include?	299
Exercise	300
Example 11.4. Fraction Arithmetic: add and mult	300
How It Works	304
Exercises	305
Chapter 11 Summary	305
<b>Chapter 12</b> <i>Constructors: If You Build It...</i>	307
Introducing Constructors	307
Multiple Constructors (Overloading)	309
C++0x Only: Initializing Members within a Class	309
The Default Constructor—and a Warning	310
<i>Interlude</i> Is C++ Out to Trick You with the Default Constructor?	312
C++0x Only: Delegating Constructors	313
C++0x Only: Consistent Initialization	314
Example 12.1. Point Class Constructors	315
How It Works	316
Exercises	317
Example 12.2. Fraction Class Constructors	317
How It Works	320
Exercises	320
Reference Variables and Arguments (&)	321
The Copy Constructor	323
<i>Interlude</i> The Copy Constructor and References	325

	Example 12.3. Fraction Class Copy Constructor	325
	How It Works	328
	Exercises	329
	A Constructor from String to Fract	329
	Chapter 12 Summary	331
<b>Chapter 13</b>	<i>Operator Functions: Doing It with Class</i>	333
	Introducing Class Operator Functions	333
	Operator Functions as Global Functions	336
	Improve Efficiency with References	338
	Example 13.1. Point Class Operators	340
	How It Works	342
	Exercises	343
	Example 13.2. Fraction Class Operators	343
	How It Works	346
	Optimizing the Code	347
	Exercises	348
	Working with Other Types	348
	The Class Assignment Function (=)	349
	The Test-for-Equality Function (==)	350
	A Class “Print” Function	351
	Example 13.3. The Completed Fraction Class	352
	How It Works	355
	Exercises	356
	C++0x Only: User-Defined Literals	357
	Defining a Raw-String Literal	358
	Defining a Cooked Literal	359
	Chapter 13 Summary	360
<b>Chapter 14</b>	<i>Dynamic Memory and the String Class</i>	363
	Dynamic Memory: The “new” Keyword	363
	Objects and “new”	365
	Allocating Multiple Data	366
	<i>Interlude</i> Dealing with Problems in Memory Allocation	368
	Example 14.1. Dynamic Memory in Action	368

How It Works	369
Exercise	370
Introducing Class Destructors	370
Example 14.2. A Simple String Class	371
How It Works	373
Exercises	376
“Deep” Copying and the Copy Constructor	376
The “this” Keyword	378
Revisiting the Assignment Operator	379
Writing a Concatenation Function	380
Example 14.3. The Complete String Class	382
How It Works	385
Exercises	386
Chapter 14 Summary	387
<b>Chapter 15</b> <i>Two Complete OOP Examples</i>	389
Introducing Linked Lists	389
Node Design	390
Implementing a Simple Linked List	391
An Alphabetical List	393
Example 15.1. Names in Alpha Order	395
How It Works	397
Dealing with Memory Leaks	399
C++ Only: Using Smart Pointers to Clean Up	400
<i>Interlude</i> Recursion vs. Iteration Compared	401
Exercises	402
Tower of Hanoi, Animated	402
Mystack Class Design	403
Using the Mystack Class	404
Example 15.2. Animated Tower	405
How It Works	408
Exercises	410
Chapter 15 Summary	411
<b>Chapter 16</b> <i>Easy Programming with STL</i>	413
Introducing the List Template	413
<i>Interlude</i> Writing Templates in C++	414

Creating and Using a List Class	415
Creating and Using Iterators	416
C++0x Only: For Each	418
<i>Interlude</i> Pointers vs. Iterators	418
Example 16.1. STL Ordered List	419
How It Works	420
A Continually Sorted List	421
Exercises	422
Designing an RPN Calculator	422
<i>Interlude</i> A Brief History of Polish Notation	424
Using a Stack for RPN	424
Introducing the Generalized STL Stack Class	427
Example 16.2. Reverse Polish Calculator	428
How It Works	429
Exercises	431
Correct Interpretation of Angle Brackets	432
Chapter 16 Summary	432
<b>Chapter 17</b> <i>Inheritance: What a Legacy</i>	435
How to Subclass	435
<i>Interlude</i> Why “public” Base Classes?	437
Example 17.1. The FloatFraction Class	438
How It Works	439
Exercises	440
Problems with the FloatFraction Class	440
C++ Only: Inheriting Base-Class Constructors	441
Example 17.2. The Completed FloatFraction Class	442
How It Works	444
Exercises	445
Protected Members	445
Object Containment	447
Safe Inheritance Through Class Hierarchies	448
Chapter 17 Summary	451
<b>Chapter 18</b> <i>Polymorphism: Object Independence</i>	453
A Different Approach to the FloatFraction Class	453
Virtual Functions to the Rescue!	454

<i>Interlude</i> What Is the Virtual Penalty?	455
Example 18.1. The Revised FloatFraction Class	456
How It Works	459
Exercise	460
C++ Only: Requiring Explicit Overrides	460
“Pure Virtual” and Other Abstract Matters	461
Abstract Classes and Interfaces	462
Object Orientation and I/O	464
cout Is Endlessly Extensible	464
But cout Is Not Polymorphic	465
Example 18.2. True Polymorphism: The Printable Class	466
How It Works	468
Exercise	470
A Final Word (or Two)	470
A Final, Final Word	472
Chapter 18 Summary	472
<b>Appendix A</b> <i>Operators</i>	475
The Scope (::) Operator	478
The sizeof Operator	478
Old and New Style Type Casts	479
Integer vs. Floating-Point Division	480
Bitwise Operators (&,  , ^, ~, <<, and >>)	480
Conditional Operator	481
Assignment Operators	482
Join (,) Operator	482
<b>Appendix B</b> <i>Data Types</i>	483
Precision of Data Types	484
Data Types of Numeric Literals	485
String Literals and Escape Sequences	486
Two’s Complement Format for Signed Integers	487

---

<b>Appendix C</b>	<b><i>Syntax Summary</i></b>	491
	Basic Expression Syntax	491
	Basic Statement Syntax	492
	Control Structures and Branch Statements	493
	The if-else Statement	493
	The while Statement	493
	The do-while Statement	494
	The for Statement	494
	The switch-case Statement	495
	The break Statement	496
	The continue Statement	496
	The goto Statement	497
	The return Statement	497
	The throw Statement	497
	Variable Declarations	498
	Function Declarations	500
	Class Declarations	502
	Enum Declarations	503
<b>Appendix D</b>	<b><i>Preprocessor Directives</i></b>	505
	The #define Directive	505
	The ## Operator (Concatenation)	507
	The defined Function	507
	The #elif Directive	507
	The #endif Directive	508
	The #error Directive	508
	The #if Directive	508
	The #ifdef Directive	509
	The #ifndef Directive	510
	The #include Directive	510
	The #line Directive	511
	The #undef Directive	511
	Predefined Constants	511

<b>Appendix E</b>	<i>ASCII Codes</i>	513
<b>Appendix F</b>	<i>Standard Library Functions</i>	517
	String (C-String) Functions	517
	Data-Conversion Functions	517
	Single-Character Functions	517
	Math Functions	520
	Randomization Functions	521
	Time Functions	521
	Formats for the strftime Function	523
<b>Appendix G</b>	<i>I/O Stream Objects and Classes</i>	525
	Console Stream Objects	525
	I/O Stream Manipulators	526
	Input Stream Functions	528
	Output Stream Functions	528
	File I/O Functions	529
<b>Appendix H</b>	<i>STL Classes and Objects</i>	531
	The STL String Class	531
	The <list> Template	533
	The <stack> Template	535
<b>Appendix I</b>	<i>Glossary of Terms</i>	537
	<i>Index</i>	553

*This page intentionally left blank*

# Preface

---

Many years ago, when I had to learn C overnight to make a living as a programmer (this was before C++), I would have given half my salary to find a mentor, a person would say, “Here are the potholes in the road...errors that you are sure to make in learning C. And here’s how to steer around them.” Instead, I had to sweat and groan through every error a person could make.

I’m not just talking about programmers who can write or writers who can program. Each of those is rare enough. Much rarer still is the person who is programmer, writer, and *teacher*—someone who will steer you around the elementary gotchas and enthusiastically communicate the “whys” of the language, including why this stuff is not just useful but, in its own way, kind of cool.

It’s hard to find such a person. But way back then, I swore this is the person I’d become.

Later, at Microsoft, I started in tech support and testing and worked my way into management. But my most important job (I felt) was explaining new technology. I was sometimes the second or third person in the world to see a new feature of a programming language, and my job was to turn a cryptic spec into readable prose for the rest of the universe to understand. I took the goal of “make this simple” as not just a job but a mission.

## *About This Book: How It's Different*

---

What’s different about this book is that I’m an advocate for you, the reader. I’m on your side, not that of some committee. I’m aware of all the ways you are “supposed” to program and why they are supposed to be better (and I do discuss those issues), but I’m mostly concerned about telling you what *works*.

This book assumes you know nothing at all about programming—that you basically know how to turn on a computer and use a mouse. For those of you more knowledgeable, you’ll want to breeze through the first few chapters.

The creators of C and C++—Dennis Ritchie and Bjarne Stroustrup, respectively—are geniuses, and I’m in awe of what they accomplished. But although C and C++ are great languages, there are some features that beginners (and even relatively advanced programmers) never find uses for, at least not for the first few years. I’m not afraid to tell you that information up front: what language features you can and should ignore. At the same time, I’m also eager to tell you about the elegant features of C++ that can save you time and energy.

This is a book about practical examples. It’s also a book about having fun! The great majority of examples in this book either are useful and practical or—by using puzzles and games—are intrinsically entertaining.

So, have no fear! I won’t bludgeon you to death with overly used (and highly *abused*) terms like *data abstraction*, which professors love but which forever remain fuzzy to the rest of us. At the same time, there are some terms—*object orientation* and *polymorphism*—that you will want to know, and I provide concrete, practical contexts for understanding and using them.

## *Onward to the Second Edition*

---

The first edition has sold increasingly well over the years. I believe that’s a testament to the variety of learning paths it supplied: complete examples, exercises, and generous use of conceptual art. The second edition builds on these strengths in many ways:

- ◆ **Coverage of new features in C++0x:** This is the new specification for C++ that will be standard by the time you have this book in your hands. Compiler vendors either have brought their versions of C++ up to this standard or are in the process of doing so. This book covers well over a dozen new features from this specification in depth.
- ◆ **Examples galore, featuring puzzles and games:** By the end of Chapter 2, you’ll learn how to enter a program, barely a page long, that not only is a complete game but even has an optimal strategy for the computer. Just see whether you can beat it! But this is only the beginning. This edition features puzzles and games, much more so than the first edition.
- ◆ **Generous use of conceptual art:** The use of clarifying illustrations to address abstract points was one of the biggest strengths of the first edition. This edition has substantially more of these.
- ◆ **Even more exercises:** These encourage the reader to learn in the best way...by taking apart an example that works, analyzing it, and figuring out how to modify it to make it do your own thing.

- ◆ **No-nonsense syntax diagrams:** Programming and playing games is fun, but sometimes you need straightforward information. The syntax diagrams in this book, accompanied by loads of examples, clarify exactly how the language works, statement by statement and keyword by keyword.
- ◆ **Introduction to Standard Template Library (STL):** Although I lacked the space to do a complete STL manual, this edition (unlike the first) introduces you to the wonders of this exciting feature of C++, showing how it can save you time and energy and enable you to write powerful applications in a remarkably small space.
- ◆ **Expanded reference:** The appendixes in the back are intended as a mini desk reference to use in writing C++ programs. This edition has significantly expanded these appendixes.
- ◆ **Essays, or “interludes” for the philosophically inclined:** Throughout the book, I detour into areas related to C++ but that impact the larger world, such as computer science, history of programming, mathematics, philosophy, and artificial intelligence. But these essays are set aside as sidebars so as not to interfere with the flow of the subject. You can read them at your leisure.

---

## *“Where Do I Begin?”*

---

As I mentioned, this book assumes you know nothing about programming. If you can turn on a computer and use a menu system, keyboard, and mouse, you can begin on page 1. If you already have some familiarity with programming, you’ll want to go through the first two or three chapters quickly.

If you already know a lot about C or C++ and are mainly interested in the new features of C++0x, you may want to go straight to Chapter 10, “New Features of C++0x.”

And if you know C and are now starting to learn about object orientation with the C++ language, you may want to start with Chapter 11, “Introducing Classes: The Fraction Class.”

---

## *Icons, Icons, Who’s Got the Icons?*

---

Building on the helpful icons used in the first edition, this edition provides even more—as signposts on the pages to help you find what you need. Be sure to look for these symbols.



These sections take apart program examples and explain, line by line, how and why the examples work. You don't have to wade through long programming examples. I do that for you! (Or rather, we go through the examples together.)



After each full programming example, I provide at least one exercise, and usually several, that builds on the example in some way. These encourage you to alter and extend the programming code you've just seen. This is the best way to learn. The answers can be found on the book's Web site ([www.informit.com/title/9780132673266](http://www.informit.com/title/9780132673266)).



These sections develop an example by showing how it can be improved, made shorter, or made more efficient.



As with "Optimizing," these sections take the example in new directions, helping you learn by showing how the example can be varied or modified to do other things.



This icon indicates a place where a keyword of the language is introduced and its usage clearly defined.

**C++0x** ► This icon is used to indicate sections that apply only to versions of C++ compliant with the new C++0x specification. Depending on the version of C++ you have, either these sections will apply to you or they won't. If your version is not C++0x-compliant, you'll generally want to skip these sections.

## *What Is Not Covered?*

---

Relatively little, as it turns out. The two features not covered at all are bit fields and unions. Although these features are useful for some people, their application tends to be highly specialized—limited to a few special situations—and not particularly useful to people first learning the language. Of course, I encourage you to learn about them on your own later.

Another area in which I defer to other books is the topic of writing your own template classes, which I touch on just briefly in Chapter 16. Without a doubt, the ability to write new template classes is one of the most amazing features of state-of-the-art C++, but it is a very advanced and complex topic. For me to cover it adequately and exhaustively could easily have taken another 400 or 500 pages!

Fortunately, although templates and the Standard Template Library (STL) are advanced subjects, there are some good books on the subject—for example, *C++ Templates: The Complete Guide*, by David Vandevor and Nicolai M. Josuttis; *STL Tutorial and Reference Guide: C++ Programming with the Standard Template Library, Second Edition*, by David R. Musser, Gillmer J. Derge, and Atul Saini; and *Effective STL: 50 Specific Ways to Improve Your Use of the Standard Template Library*, by Scott Meyers.

And remember that Chapter 16 does introduce you to using STL, which provides extremely useful, existing templates for you to take advantage of.

---

## *Getting Started with C++: A Free Compiler*

---

Although this edition doesn't come with a CD with a free compiler on it, that is no longer necessary. You can download some excellent shareware (that is, free) versions of C++ from the Internet that not only have a free compiler (that's the application that translates your programs into machine-readable form) but also a very good development environment. And they install easily.

To download this free software, start by going to the book's Web site: [www.informit.com/title/9780132673266](http://www.informit.com/title/9780132673266).

As mentioned earlier, you will also find downloadable copies of all the full program examples in the book, as well as answers to exercises.

---

## *A Final Note: Have Fun!*

---

Once again, there is nothing to fear about C++. Yes, there are those nasty pot-holes I started out discussing, but remember, I'm going to steer you around them. Admittedly, C++ is not a language for the weak of heart; it assumes you know exactly what you're doing. But it doesn't have to be intimidating. I hope you use the practical examples and find the puzzles and games entertaining. This is a book about learning and about taking a road to new knowledge, but more than that, it's a book about enjoying the ride.

*This page intentionally left blank*

# *Acknowledgments*

---

I am likely to leave many deserving people out this time, but a few names cry out for special mention. The book's editor, Peter Gordon, not only took the initiative in arranging for the new edition but did a lovely job of nursing the book through all its stages along with the author's ego. His long-suffering right hand, Kim Boedigheimer, was a better person than we all deserved, coming to the rescue again and again and kindly aiding the author. I'd also like to extend a special thanks to Kim Wimpsett and Anna Popick, who unexpectedly have been an absolute delight to work with in getting the book through its final tense stages.

Closer to home in the Seattle area: I also want to make special mention to veteran Microsoft programmers John R. Bennett and Matt Greig, who provided superb insights about the latest directions of C++. Some of the more interesting new sections in the book came about directly as a result of extended conversations with these experts.

*This page intentionally left blank*

# About the Author

---



**Brian Overland** published his first article in a professional math journal at age 14.

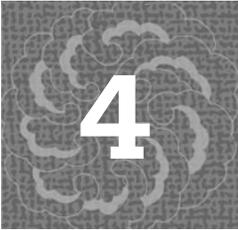
After graduating from Yale, he began working on large commercial projects in C and Basic, including an irrigation-control system used all over the world. He also tutored students in math, computer programming, and writing, as well as lecturing to classes at Microsoft and at the community-college level. On the side, he found an outlet for his lifelong love of writing by publishing film and drama reviews in local newspapers. His qualifications as an author of technical books are

nearly unique because they involve so much real programming and teaching experience, as well as writing.

In his 10 years at Microsoft, he was a tester, author, programmer, and manager. As a technical writer, he became an expert on advanced utilities, such as the linker and assembler, and was the “go-to” guy for writing about new technology. His biggest achievement was probably organizing the entire documentation set for Visual Basic 1.0 and having a leading role in teaching the “object-based” way of programming that was so new at the time. He was also a member of the Visual C++ 1.0 team.

Since then, he has been involved with the formation of new start-up companies (sometimes as CEO). He is currently working on a novel.

*This page intentionally left blank*

4

# Functions: Many Are Called

---



The most fundamental building block in the programming toolkit is the function—often known as *procedure* or *subroutine* in other languages. A function is a group of related statements that accomplish a specific task. Once you define a function, you can execute it whenever you need to do so.

Understanding functions is a crucial step to programming in C++: Without functions, it would be a practical impossibility to engage in serious programming projects. Imagine how difficult it would be to write a word processor, for example, without some means of dividing the labor. Functions make this possible.

## *The Concept of Function*

---

If you've followed the book up until this point, you've already seen use of a function—the `sqrt` function, which takes a single number as input and returns a result.

```
double sqrt_of_n = sqrt(n);
```

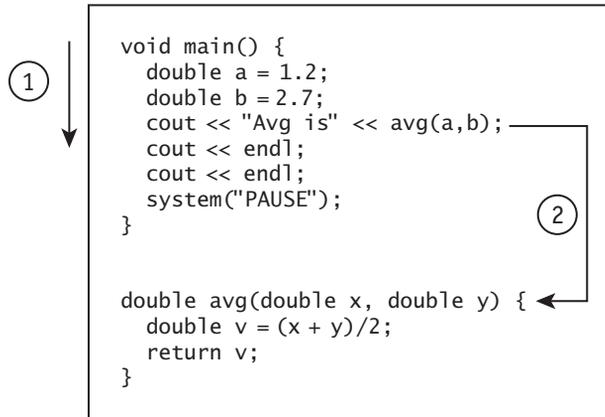
This is not far removed from the mathematical concept of function. A function takes zero or more inputs—called *arguments*—and returns an output, called a *return value*. Here's another example. This function takes two inputs and returns their average:

```
cout << avg(1.0, 4.0);
```

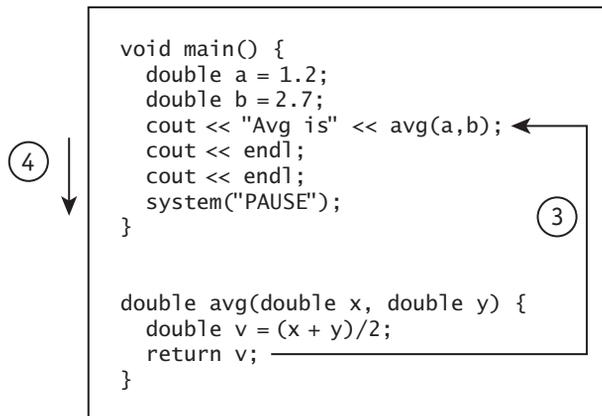
Once a function is written, you can call it any number of times. By *calling* a function, you transfer execution of the program to the function-definition code, which runs until it is finished or until it encounters a **return** statement; execution then is transferred back to the caller.

This may sound like a foreign language if you're not used to it. It's easy to see in a conceptual diagram. In the following example, the program 1) runs normally

until it calls the function `avg`, passing the arguments `a` and `b`, and 2) as a result, the program transfers execution to `avg`. (The values of `a` and `b` are passed to `x` and `y`, respectively.)



The function runs until it encounters `return`, at which point: 3) execution returns to the caller of the function, which in this case prints the value that was returned. Then, 4) execution resumes normally inside `main`, and the program continues until it ends.



Note that only `main` is guaranteed to be executed. Other functions run only as called. But there are many ways a function can be called. For example, `main` can call a function `A`, which in turn calls `B` and `C`, which in turn calls `D`.

## *The Basics of Using Functions*

I recommend the following approach for creating and calling user-defined functions:

- 1 At the beginning of your program, *declare* the function.
- 2 Somewhere in your program, *define* the function.
- 3 Other functions can then call the function.

### *Step 1: Declare (Prototype) the Function*

A function declaration (or *prototype*) provides type information only. It has this syntax:

```
return_type    function_name (argument_list);
```

The *return\_type* is a data type indicating what kind of value the function returns (what it passes back). If the function does not return a value, use **void**.

The *argument\_list* is a list of zero or more argument names—separated by commas if there are more than one—each preceded by the corresponding type. (Technically, you don't need the argument names in a prototype, but it is a good programming practice.) For example, the following statement declares a function named `avg`, which takes two arguments of type **double** and returns a **double** value.

```
double avg(double x, double y);
```

The *argument\_list* may be empty, which indicates that it takes no arguments.

### *Step 2: Define the Function*

The function definition tells what the function does. It uses this syntax:

```
return_type    function_name (argument_list) {  
    statements  
}
```

Most of this looks like a declaration. The only thing that's different is that the semicolon is replaced by zero or more statements between two braces (`{}`). The braces are required no matter how few statements you have. For example:

```
double avg(double x, double y) {  
    return (x + y) / 2;  
}
```

The **return** statement causes immediate exit, and it specifies that the function returns the amount  $(x + y) / 2$ . Functions with no return value can still use the **return** statement but only to exit early.

```
return;
```

### *Step 3: Call the Function*

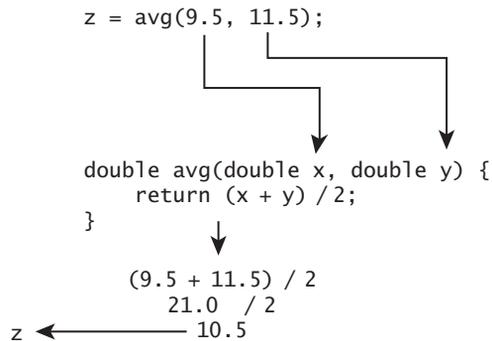
Once a function is declared and defined, it can be used—or rather, *called*—any number of times, from any function. For example:

```
n = avg(9.5, 11.5);  
n = avg(5, 25);  
n = avg(27, 154.3);
```

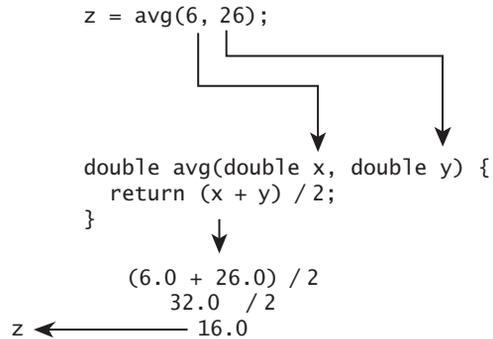
A function call is an expression: As long as it returns a value other than **void**, it can be used inside a larger expression. For example:

```
z = x + y + avg(a, b) + 25.3;
```

When the function is called, the values specified in the function call are passed to the function arguments. Here's how a call to the `avg` function works, with sample values 9.5 and 11.5 as input. These are *passed* to the function, as arguments. When the function returns, the value in this case is assigned to `z`.



Another call to the function might pass different values—in this case, 6 and 26. (Because these are integer values, they are implicitly converted, or *promoted*, to type **double**.)



### Example 4.1. *The avg() Function*

This section shows a simple function call in the context of a complete program. It demonstrates all three steps: declare a function, define it, and call it.

#### avg.cpp

```
#include <iostream>  
using namespace std;  
  
// Function must be declared before being used.  
  
double avg(double x, double y);  
  
int main() {  
    double a = 0.0;  
    double b = 0.0;  
  
    cout << "Enter first number and press ENTER: ";  
    cin >> a;  
    cout << "Enter second number and press ENTER: ";  
    cin >> b;  
  
    // Call the function avg().  
    cout << "Average is: " << avg(a, b) << endl;
```

▼ continued on next page

avg.cpp, cont.

```
        system("PAUSE");
        return 0;
    }

    // Average-number function definition
    //
    double avg(double x, double y) {
        return (x + y)/2;
    }
```



## How It Works

This code is a very simple program, but it demonstrates the three steps I outlined earlier:

- 1 *Declare* (that is, prototype) the function at the beginning of the program.
- 2 *Define* the function somewhere in the program.
- 3 *Call* the function from within another function (in this case, **main**).

Although function declarations (prototypes) can be placed anywhere in a program, you should almost always place them at the beginning. The general rule is that functions must be declared before being called. (They do not, however, have to be defined before being called, which makes it possible for two functions to call each other.)

```
double avg(double x, double y);
```

The function definition for the `avg` function is extremely simple, containing only one statement. In general, though, function definitions can contain as many statements as you want.

```
double avg(double x, double y) {
    return (x + y)/2;
}
```

The **main** function calls `avg` as part of a larger expression. The computed value (in this case, the average of the two inputs, `a` and `b`) is returned to this statement in **main**, which then prints the result.

```
cout << "Average is: " << avg(a, b) << endl;
```



## Function Call a Function!

A program can have any number of functions. For example, you could have two functions in addition to **main**, as in the following version of the program. Lines that are new or changed are in bold.

### avg2.cpp

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

// Functions must be declared before being used.

void print_results(double a, double b);
double avg(double x, double y);

int main() {
    double a = 0.0;
    double b = 0.0;

    cout << "Enter first number and press ENTER: ";
    cin >> a;
    cout << "Enter second number and press ENTER: ";
    cin >> b;

    // Call the function pr_results().
print_results(a, b);

    system("PAUSE");
    return 0;
}

// print_results function definition
//
void print_results(double a, double b) {
    cout << "Average is: " << avg(a, b) << endl;
}
```

▼ *continued on next page*

avg2.cpp, cont.

```
// Average-number function definition
//
double avg(double x, double y) {
    return (x + y)/2;
}
```

This version is a little less efficient, but it illustrates an important principle: You are not limited to only one or two functions. The program creates a flow of control as follows:

main() → print\_results() → avg()



## EXERCISES

**Exercise 4.1.1.** Write a program that defines and tests a factorial function. The factorial of a number is the product of all whole numbers from 1 to N. For example, the factorial of 5 is  $1 * 2 * 3 * 4 * 5 = 120$ . (Hint: Use a for loop as described in Chapter 3.)

**Exercise 4.1.2.** Write a function named print\_out that prints all the whole numbers from 1 to N. Test the function by placing it in a program that passes a number n to print\_out, where this number is entered from the keyboard. The print\_out function should have type void; it does not return a value. The function can be called with a simple statement:

```
print_out(n);
```

Example 4.2.

## *Prime-Number Function*

Chapter 2 included an example that was actually useful: determining whether a specified number was a prime number. We can also write the prime-number test as a function and call it repeatedly.

The following program uses the prime-number example from Chapters 2 and 3 but places the relevant C++ statements into their own function, is\_prime.

prime2.cpp

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

prime2.cpp, cont.

```
// Function must be declared before being used.
bool prime(int n);

int main() {
    int i;

    // Set up an infinite loop; break if user enters 0.
    // Otherwise, evaluate n from prime-ness.

    while (true) {
        cout << "Enter num (0 = exit) and press ENTER: ";
        cin >> i;
        if (i == 0)                // If user entered 0, EXIT
            break;
        if (prime(i))              // Call prime(i)
            cout << i << " is prime" << endl;
        else
            cout << i << " is not prime" << endl;
    }
    system("PAUSE");
    return 0;
}

// Prime-number function. Test divisors from
// 2 to sqrt of n. Return false if a divisor
// found; otherwise, return true.

bool prime(int n) {
    int i;

    for (i = 2; i <= sqrt(n); i++) {
        if (n % i == 0)            // If i divides n evenly,
            return false;        // n is not prime.
    }
    return true;                 // If no divisor found, n is prime.
}
```



## How It Works

As always, the program adheres to the pattern of 1) declaring function type information at the beginning of the program (*prototyping* the function), 2) defining the function somewhere in the program, and 3) calling the function.

The prototype says that the prime function takes an integer argument and returns a `bool` value, which will be either `true` or `false`. (Note: If you have a really old compiler, you may have to use the `int` type instead of `bool`.)

```
bool prime(int n);
```

The function definition is a variation on the prime-number code from Chapter 3, which used a `for` loop. If you compare the code here to Example 3.2 on page 75, you'll see only a few differences.

```
bool prime(int n) {
    int i;

    for (i = 2; i <= sqrt(n); i++) {
        if (n % i == 0) // If i divides n evenly,
            return false; // n is not prime.
    }
    return true; // If no divisor found, return
true.
}
```

Another difference is that instead of setting a Boolean variable, `is_prime`, this version returns a Boolean result. The logic here is as follows:

```
For all whole numbers from 2 to the square root of n,
  If n is evenly divisible by the loop variable (i),
    Return the value false immediately.
```

Remember that the modulus operator (`%`) carries out division and returns the remainder. If this remainder is 0, that means the second number divides the second evenly—in other words, it is a *divisor* or *factor* of the second number.

The action of the `return` statement here is key. This statement returns immediately—causing program execution to exit from the function and passing control back to `main`. There's no need to use `break` to get out of the loop.

The loop in the main function calls the prime function. The use of a `break` statement here provides an exit mechanism, so the loop isn't really infinite. As soon as the user enters 0, the loop terminates and the program ends. Here I've put the exit lines in bold.

```

while (true) {
    cout << "Enter num (0 = exit) and press ENTER:
";
    cin >> i;
    if (i == 0)                // If user entered 0, EXIT
        break;
    if (prime(i))              // Call prime(i)
        cout << i << " is prime" << endl;
    else
        cout << i << " is not prime" << endl;
}

```

The rest of the loop calls the `prime` function and prints the result of the prime-number test. Note that the `prime` function, in this case, returns a `true/false` value, and so the call to `prime(i)` can be used as an `if/else` condition.



## EXERCISES

- Exercise 4.2.1.** Optimize the prime-number function by calculating the square root of `n` only once during each function call. Declare a local variable `sqrt_of_n` of type `double`. (Hint: A variable is local if it is declared inside the function.) Then use this variable in the loop condition.
- Exercise 4.2.2.** Rewrite `main` so that it tests all the numbers from 2 to 20 and prints out the results, each on a separate line. (Hint: Use a `for` loop, with `i` running from 2 to 20.)
- Exercise 4.2.3.** Write a program that finds the first prime number greater than 1 billion (1,000,000,000).
- Exercise 4.2.4.** Write a program that lets the user enter any number `n` and then finds the first prime number larger than `n`.

## Local and Global Variables

Nearly every programming language has a concept of local variable. As long as two functions mind their own data, as it were, they won't interfere with each other.

That's definitely a factor in the previous example (Example 4.2). Both `main` and `prime` have a local variable named `i`. If `i` were not local—that is, if it was shared between functions—then consider what could happen.

First, the `main` function executes `prime` as part of evaluating the `if` condition. Let's say that `i` has the value 24.

```
if (prime(i))
    cout << i << " is prime" << endl;
else
    cout << i << " is not prime" << endl;
```

The value 24 is passed to the `prime` function.

```
// Assume i is not declared here, but is global.
```

```
int prime(int n) {
    for (i = 2; i <= sqrt((double) n); i++)
        if (n % i == 0)
            return false;

    return true; // If no divisor found, n is
prime.
}
```

Look what this function does. It sets `i` to 2 and then tests it for divisibility against the number passed, 24. This test passes—because 2 does divide into 24 evenly—and the function returns. But `i` is now equal to 2 instead of 24.

Upon returning, the program executes

```
cout << i << " is not prime" << endl;
```

which prints the following:

```
2 is not prime
```

This is not what was wanted, since we were testing the number 24!

So, to avoid this problem, declare variables local unless there is a good reason not to do so. If you look back at Example 2.3, you'll see that `i` is local; `main` and `prime` each declare their own version of `i`.

Is there ever a good reason to not make a variable local? Yes, although if you have a choice, it's better to go local, because you want functions interfering with each other as little as possible.

You can declare global—that is, nonlocal—variables by declaring them outside of any function definition. It's usually best to put all global declarations near the beginning of the program, before the first function. A variable is recognized only from the point it is declared, to the end of the file.

For example, you could declare a global variation named `status`:

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

int status = 0;

void main () {
    //
}
```

Now, the variable named `status` may be accessed by any function. Because this variable is global, there is only one copy of it; if one function changes the value of `status`, this reflects the value of `status` that other functions see.

## Interlude

### Why Global Variables at All?

For reasons shown in the previous section, global variables can be dangerous. Habitual use of global variables can cause shocks to a program, because changes performed by one function cause unexpected effects in another.

But if they are so dangerous, why use them at all?

Well, they are often necessary, or nearly so. Global variables are often the best way to communicate information *between* functions; otherwise, you might need a long series of argument lists that transfer all the program information back and forth.

Beginning with Chapter 11, we'll work with classes, which provide an alternative, and generally superior, way for closely related functions to share data with each other: Functions of the same class have access to private data that no one else does.

## Recursive Functions

So far, I've only shown the use of `main` calling other functions defined in the program, but in fact, any function can call any function. But can a function call itself?

Yes. And as you'll see, it's less crazy than it sounds. The technique of a function calling itself is called *recursion*. The obvious problem is the same one for infinite loops: If a function calls itself, when does it ever stop? The problem is easily solved, however, by putting in some mechanism for stopping.

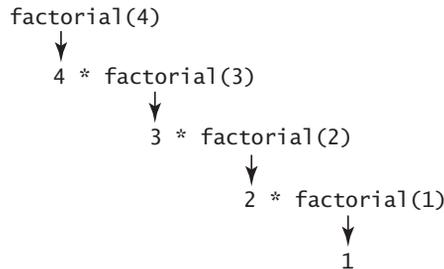
Remember the factorial function from Exercise 4.1.1 (page 90)? We can rewrite this as a recursive function:

```
int factorial(int n) {
    if (n <= 1)
        return 1;
    else
        return n * factorial(n - 1); // RECURSION!
}
```

For any number greater than 1, the factorial function issues a call to itself but with a lower number. Eventually, the function `factorial(1)` is called, and the cycle stops.

There is a literal *stack* of calls made to the function, each with a different argument for `n`, and now they start returning. The *stack* is a special area of memory maintained by the computer: It is a last-in-first-out (LIFO) mechanism that keeps track of information for all pending function calls. This includes arguments and local variables, if any.

You can picture how to call a `factorial(4)` this way.



Many functions that use a `for` statement can be rewritten so they use recursion instead. But does it always make sense to use that approach?

No. The example here is not an ideal one, because it causes the program to store all the values 1 through `n` on the stack, rather than totaling them up directly in a loop. This approach is not efficient. The next section makes a better use of recursion.

### Example 4.3. *Prime Factorization*

The prime-number examples we've looked at so far are fine, but they have a limitation. They tell you, for example, that a number such as 12,001 is not prime,

but they don't tell anything more. Wouldn't it be more useful to know what numbers divide into 12,001?

It'd be more useful to generate the *prime factorization* for any requested number. This would show us exactly what prime numbers divide into that number. For example, if the number 36 was input, we'd get this:

2, 2, 3, 3

If 99 was input, we'd get this:

3, 3, 11

And if a prime number was input, the result would be the number itself. For example, if 17 was input, the output would be 17.

We have almost all the programming code to do this already. Only a few changes need to be made to the prime-number code. To get prime-factorization, first get the lowest divisor, and then factor the remaining quotient. To get all the divisors for a number  $n$ , do this:

For all whole numbers from 2 to the square root of  $n$ ,

If  $n$  is evenly divisible by the loop variable ( $i$ ),

Print  $i$  followed by a comma, and

Rerun the function on  $n / i$ , and

Exit the current function

If no divisors found, print  $n$  itself

This logic is a recursive solution, which we can implement in C++ by having the function `get_divisors` call itself.

#### prime3.cpp

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

void get_divisors(int n);

int main() {
    int n = 0;

    cout << "Enter a number and press ENTER: ";
    cin >> n;
```

▼ continued on next page

prime3.cpp, cont.

```
    get_divisors(n);
    cout << endl;
    system("PAUSE");
    return 0;
}

// Get divisors function
// This function prints all the divisors of n,
// by finding the lowest divisor, i, and then
// rerunning itself on n/i, the remaining quotient.

void get_divisors(int n) {
    int i;
    double sqrt_of_n = sqrt(n);

    for (i = 2; i <= sqrt_of_n; i++)
        if (n % i == 0) { // If i divides n evenly,
            cout << i << ", "; // Print i,
            get_divisors(n / i); // Factor n/i,
            return; // and exit.
        }

    // If no divisor is found, then n is prime;
    // Print n and make no further calls.

    cout << n;
}
```



## How It Works

As always, the program begins by declaring functions—in this case, there is one function other than **main**. The new function is `get_divisors`.

Also, the beginning of the program includes `iostream` and `cmath`, because the program uses `cout`, `cin`, and `sqrt`. You don't need to declare `sqrt` directly, by the way, because this is done for you in `cmath`.

```
#include <iostream>
#include <cmath>

void get_divisors(int n);
```

The `main` function just gets a number from the user and calls `get_divisors`.

```
int main() {
    int n = 0;

    cout << "Enter a number and press ENTER: ";
    cin >> n;

    cout << endl;
    system("PAUSE");
    return 0;
}
```

The `get_divisors` function is the interesting part of this program. It has a `void` return value, meaning that it doesn't pass back a value. But it still uses the `return` statement to exit early.

```
void get_divisors(int n) {
    int i;
    double sqrt_of_n = sqrt(n);

    for (i = 2; i <= sqrt_of_n; i++)
        if (n % i == 0) { // If i divides n evenly,
            cout << i << ", "; // Print i,
            get_divisors(n / i); // Factor n/i,
            return; // and exit.
        }

    // If no divisor is found, then n is prime;
    // Print n and make no further calls.

    cout << n;
}
```

The heart of this function is a loop that tests numbers from 2 to the square root of `n` (which has been calculated and placed in the variable `sqrt_of_n`).

```
for (i = 2; i <= sqrt_of_n; i++)
    if (n % i == 0) { // If i divides n evenly,
        cout << i << ", "; // Print i,
        get_divisors(n / i); // Factor n/i,
        return; // and exit.
    }
```

If the expression  $n \% i == 0$  is true, that means the loop variable  $i$  divides evenly into  $n$ . In that case, the function does several things: It prints out the loop variable, which is a divisor; calls itself recursively; and exits.

The function calls itself with the value  $n/i$ . Because the factor  $i$  is already accounted for, the function needs to get the prime-number divisors for *the remaining factors* of  $n$ , and these are contained in  $n/i$ .

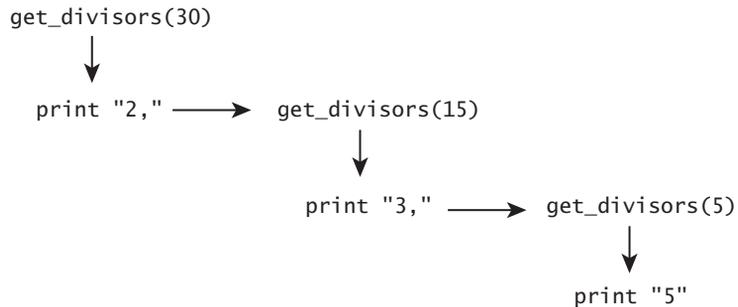
If no divisors are found, that means the number being tested is prime. The correct response is to print this number and stop.

```
cout << n;
```

For example, suppose that 30 is input. The function tests to see what the lowest divisor of 30 is. The function prints the number 2 and then reruns itself on the remaining quotient, 15 (because 30 divided by 2 is 15).

During the next call, the function finds the lowest divisor of 15. This is 3, so it prints 3 and then reruns itself on the remaining quotient, 5 (because 15 divided by 3 is 5).

Here's a visual summary. Each call to `get_divisors` gets the lowest divisor and then makes another call unless the number being tested is prime.



## Interlude

### Interlude for Math Junkies

A little reflection shows why the lowest divisor is always a prime number. Suppose we test a positive whole number and that  $A$  is the lowest divisor *but is not a prime*. Since  $A$  is not prime, it must have at least one divisor of its own,  $B$ , that is not equal to either 1 or  $A$ .

But if  $B$  divides evenly into  $A$  and  $A$  is a divisor of the target number, then  $B$  must also be a divisor of the target number. Furthermore,  $B$  is less than  $A$ . Therefore, the hypothesis that the lowest divisor is not prime results in a contradiction.



## Interlude

▼ *continued*

This is easy to see by example. Any number divisible by 4 (a nonprime) is also divisible by 2 (a prime). The prime factors will always be found first, as long as you keep looking for the lowest divisor.



### EXERCISES

**Exercise 4.3.1.** Rewrite the `main` function for Example 4.3 so that it prints the prompt message “Enter a number (0 = exit) and press ENTER.” The program should call `get_divisors` to show the prime factorization and then prompt the user again, until he or she enters 0. (Hint: If you need to, look at the code for Example 4.2, on page 90.)

**Exercise 4.3.2.** Write a program that calculates triangle numbers by using a recursive function. A triangle number is the sum of all whole numbers from 1 to  $N$ , in which  $N$  is the number specified. For example,  $\text{triangle}(5) = 5 + 4 + 3 + 2 + 1$ .

**Exercise 4.3.3.** Modify Example 4.3 so that it uses a *nonrecursive* solution. You will end up having to write more code. (Hint: To make the job easier, write two functions: `get_all_divisors` and `get_lowest_divisor`. The `main` function should call `get_all_divisors`, which in turn has a loop: `get_all_divisors` calls `get_lowest_divisor` repeatedly, each time replacing  $n$  with  $n/i$ , where  $i$  is the divisor that was found. If  $n$  itself is returned, then the number is prime, and the loop should stop.)

### Example 4.4.

## *Euclid's Algorithm for GCF*

In the early grades of school, we're asked to figure out greatest common factors (GCFs). For example, the greatest common factor of 15 and 25 is 5. Your teacher probably lectured you about GCF until you didn't want to hear about it anymore.

Wouldn't it be nice to have a computer figure this out for you? We'll focus just on GCF, because as I'll show in Chapter 11, if you can figure out the CGF of two numbers, you can easily compute the lowest common multiple (LCM).

The technique was worked out almost 2,500 years ago by a Greek mathematician named Euclid, and it's one of the most famous in mathematics.

To get CGF: For whole two numbers  $A$  and  $B$ :

If  $B$  equals 0,

The answer is  $A$ .

Else

The answer is  $\text{GCF}(B, A\%B)$

You may remember remainder division (%) from earlier chapters.  $A\%B$  means this:

Divide  $A$  by  $B$  and produce the remainder.

For example,  $5\%2$  equals 1, and  $4\%2$  equals 0. A result of 0 means that  $B$  divides  $A$  evenly.

If  $B$  does not equal 0, the algorithm replaces the arguments  $A, B$  with the arguments  $B, A\%B$  and calls itself recursively. This solution works for two reasons:

- The terminal case ( $B$  equals 0) is valid. The answer is  $A$ .
- The general case is valid:  $\text{GCF}(A, B)$  equals  $\text{GCF}(B, A\%B)$ , so the function calls itself with new arguments  $B$  and  $A\%B$ .

The terminal case, in which  $B$  equals 0, is valid assuming  $A$  is nonzero. You can see that  $A$  divides evenly into both itself and 0, but nothing larger can divide into  $A$ . (Note that 0 can be divided evenly by any whole number except itself.) For example, 997 is the greatest common factor for the pair (997, 0). Nothing larger divides evenly into both.

The general case is valid if the following is true:

The greatest common factor of the pair ( $B, A\%B$ ) is also the greatest common factor of the pair ( $A, B$ ).

It turns out this *is* true, and because it is, the GCF problem is passed along from the pair ( $A, B$ ) to the pair ( $B, A\%B$ ). This is the general idea of recursion: Pass the problem along to a simpler case involving smaller numbers.

It can be shown that the pair ( $B, A\%B$ ) involves numbers less than or equal to the pair ( $A, B$ ). Therefore, during each recursive call, the algorithm uses successively smaller numbers until  $B$  is zero.

I save the rest of the proof for an interlude at the end of this section. Here is a complete program for computing greatest common factors:

**gcf.cpp**

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

gcf.cpp, cont.

```
int gcf(int a, int b);

int main()
{
    int a = 0, b = 0; // Inputs to GCF.

    cout << "Enter a: ";
    cin >> a;
    cout << "Enter b: ";
    cin >> b;
    cout << "GCF = " << gcf(a, b) << endl;

    system("PAUSE");
    return 0;
}

int gcf(int a, int b) {
    if (b == 0)
        return a;
    else
        return gcf(b, a%b);
}
```

4



## How It Works

All that `main` does in this case is to prompt for two input variables `a` and `b`, call the greatest-common-factor function (`gcf`), and print results:

```
cout << "GCF = " << gcf(a, b) << endl;
```

As for the `gcf` function, it implements the algorithm discussed earlier:

```
int gcf(int a, int b) {
    if (b == 0)
        return a;
    else
        return gcf(b, a%b);
}
```

The algorithm keeps assigning the old value of `B` to `A` and the value `A%B` to `B`. The new arguments are equal or less to the old. They get smaller until `B` equals 0.

For example, if we start with  $A = 300$  and  $B = 500$ , the first recursive call switches their order. (This always happens if  $B$  is larger.) From that point onward, each call to `gcf` involves smaller arguments until the terminal case is reached:

VALUE OF A	VALUE OF B	VALUE OF A%B (DIVIDE AND GET REMAINDER)
300	500	300
500	300	200
300	200	100
200	100	0
100	0	Terminal case: answer is 100

When  $B$  is 0, the `gcf` function no longer computes  $A\%B$  but instead produces the answer.

If the initial value of  $A$  is larger than  $B$ , the algorithm produces an answer even sooner. For example, suppose  $A = 35$  and  $B = 25$ .

VALUE OF A	VALUE OF B	VALUE OF A%B (DIVIDE AND GET REMAINDER)
35	25	10
25	10	5
10	5	0
5	0	Terminal case: answer is 5

## Interlude

### Who Was Euclid?

Who was this Euclid guy? Wasn't he the Greek who wrote about geometry? (Something like "The shortest distance between two points is a straight line"?)

Indeed he was. Euclid's *Elements* is one of the most famous books in Western civilization. For almost 2,500 years it was used as a standard textbook in schools. In this work he demonstrated for the first time a *tour de force* of deductive logic, proving all that was then known about geometry. In fact, he invented the whole *idea* of proof. It is a great work that has had profound influence on mathematicians and philosophers ever since.



## Interlude

▼ *continued*

It was Euclid who (according to legend) said to King Ptolemy of Alexandria, “Sire, there is no royal road to geometry.” In other words, you gotta work for it.

Although its focus is on geometry, Euclid’s book has results in number theory as well. The algorithm here is the most famous of these results. Euclid expressed the problem geometrically, finding the biggest length commensurable with two sides of a rectangle. He conceived the problem in terms of rectangles, but we can use any two integers.



## EXERCISES

**Exercise 4.4.1.** Revise the program so that it prints out all the steps involved in the algorithm. Here is a sample output:

```
GCF(500, 300) =>
GCF(300, 200) =>
GCF(200, 100) =>
GCF(100, 0) =>
100
```

**Exercise 4.4.2.** For experts: Revise the `gcf` function so that it uses an iterative (loop-based) approach. Each cycle through the loop should stop if `B` is zero; otherwise, it should set new values for `A` and `B` and then continue. You’ll need a temporary variable—`temp`—to hold the old value of `B` for a couple of lines: `temp=b`, `b=a%b`, and `a=temp`.



## Interlude

### Interlude for Math Junkies: Rest of the Proof

Earlier, I worked out some of a proof of Euclid’s algorithm. What remains is to show that the greatest common factor of the pair  $(B, A\%B)$  is also the greatest common factor of the pair  $(A, B)$ . This is true if we can show the following:

- ▶ If a number is a factor of both  $A$  and  $B$ , it is also a factor of  $A\%B$ .
- ▶ If a number is a factor of both  $B$  and  $A\%B$ , it is also a factor of  $A$ .

▼ *continued on next page*


**Interlude**
▼ *continued*

If these are true, then all the common factors of one pair are common factors of the other pair. In other words, the set of Common Factors (A, B) is identical to the set of common factors (B, A%B). Since the two sets are identical, they have the *greatest member*—therefore, they share the greatest common factor.

Consider the remainder-division operator (%). It implies the following, where  $m$  is a whole number:

$$A = mB + A\%B$$

$A\%B$  is equal or less than  $A$ , so the general tendency of the algorithm is to get progressively smaller numbers. Assume that  $n$ , a whole number, is a factor of both  $A$  and  $B$  (meaning it divides both evenly). In that case:

$$A = cn$$

$$B = dn$$

where  $c$  and  $d$  are whole numbers. Therefore:

$$cn = m(dn) + A\%B$$

$$A\%B = cn - mdn = n(c - md)$$

This demonstrates that if  $n$  is a factor of both  $A$  and  $B$ , it is also a factor of  $A\%B$ . By similar reasoning, we can show that if  $n$  is a factor of both  $B$  and  $A\%B$ , it is also a factor of  $A$ .

Because the common factors for the pair (A, B) are identical to the common factors for the pair (B, A%B), it follows that they share the greatest common factor. Therefore,  $GCF(A, B)$  equals  $GCF(B, A\%B)$ . QED.

**Example 4.5.***Beautiful Recursion: Tower of Hanoi*

Strictly speaking, the earlier examples don't require recursion. With some effort, they can be revised as iterative (loop-based) functions. But there is a problem that illustrates recursion beautifully, solving a problem that would be very difficult to solve otherwise.

This is the Tower of Hanoi puzzle: You have three stacks of rings. Each ring is smaller than the one it sits on. The challenge is to move all the rings from the first stack to the third, subject to these constraints:

- You can move only one ring at a time.
- You can place a ring only on top of a larger ring, never a smaller.

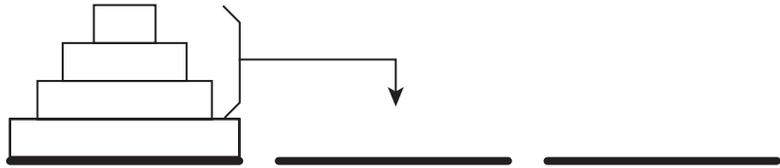
It sounds easy, until you try it! Consider a stack four rings high: You start by moving the top ring from the first stack, but where do you move it, and what do you do after that?

To solve the problem, assume we already know how to move a group of  $N-1$  rings. Then, to move  $N$  rings from a source stack to a destination stack, do the following:

- 1 Move  $N-1$  rings from the source stack to the (currently) unused, or “other,” stack.
- 2 Move a single ring from the source stack to the destination stack.
- 3 Move  $N-1$  rings from the “other” stack to the destination stack.

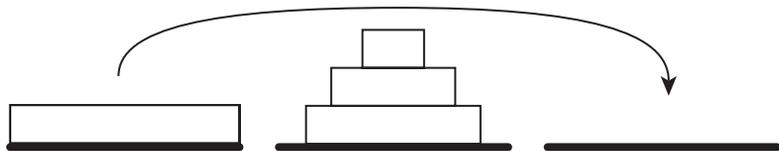
This is easier to envision graphically. First, the algorithm moves  $N-1$  rings from the source stack to the “other” stack (“other” being the stack that is neither source nor destination for the current move). In this case,  $N$  is 4 and  $N-1$  is 3, but these numbers will vary.

1. Move  $N-1$  rings from source to “other.”



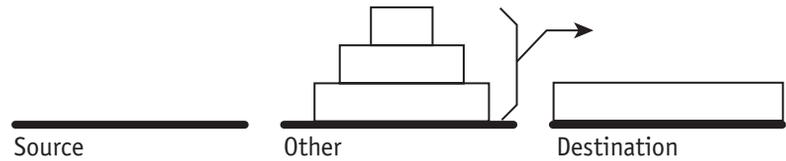
After this recursive move, at least one ring is left at the top of the source stack. This top ring is then moved: This is a simple action, moving one ring from source to destination.

2. Move one ring from source to destination, directly.



Finally, we perform another recursive move, moving  $N-1$  rings from “other” (the stack that is currently neither source nor destination) to the destination.

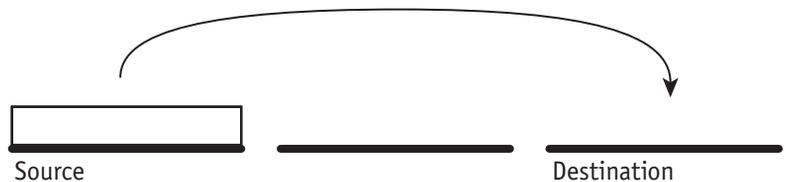
3. Move  $N-1$  rings from "other" to destination.



What permits us to move  $N-1$  rings in steps 1 and 3, when the constraints tell us that we can move only one?

Remember the basic idea of recursion. Assume the problem *has already been solved* for the case  $N-1$ , although this may require many steps. All we have to do is tell the program how to solve the  $N$ th case in terms of the  $N-1$  case. The program magically does the rest.

It's important, also, to solve the terminal case,  $N = 1$ . But that's trivial. Where one ring is involved, we simply move the ring as desired.



The following program shows the C++ code that implements this algorithm:

#### **tower.cpp**

```
#include <cstdlib>
#include <iostream>

using namespace std;
void move_rings(int n, int src, int dest, int other);

int main()
{
    int n = 3; // Stack is 3 rings high

    move_rings(n, 1, 3, 2); // Move stack 1 to stack 3
    system("PAUSE");
}
```

tower.cpp, cont.

```
    return 0;
}

void move_rings(int n, int src, int dest, int other) {
    if (n == 1) {
        cout << "Move from " << src << " to " << dest
            << endl;
    } else {
        move_rings(n - 1, src, other, dest);
        cout << "Move from " << src << " to " << dest
            << endl;
        move_rings(n - 1, other, dest, src);
    }
}
```

4



## How It Works

The program is brief considering what it does. In this example, I've set the stack size to just three rings, although it can be any positive integer:

```
int n = 3; // Stack is 3 rings high
```

The call to the `move_rings` function says that three rings should be moved from stack 1 to stack 3; these are determined by the second and third arguments, respectively. The “other” stack, stack 2, will be used in intermediate steps.

```
move_rings(n, 1, 3, 2); // Move stack 1 to stack
3
```

This small example—moving only three rings—produces the following output. You can verify the correctness of this solution by using three different coins, all of different sizes.

```
Move from 1 to 3
Move from 1 to 2
Move from 3 to 2
Move from 1 to 3
Move from 2 to 1
Move from 2 to 3
Move from 1 to 3
```

Try setting `n` to 4, and you'll get a list of moves more than twice as long.

The core of the `move_ring` function is the following code, which implements the general solution described earlier. Remember, this recursive approach assumes the  $N-1$  case has already been solved. The function therefore passes along most of the problem to the  $N-1$  case.

```

move_rings(n - 1, src, other, dest);
cout << "Move from " << src << " to " << dest
      << endl;
move_rings(n - 1, other, dest, src);

```

Notice how the functional role of the three stacks is continually switched between *source* (where to move a group of rings from), *destination* (where the group is going), and *other* (the intermediate stack, which is not used now but will be at the next level).



## EXERCISES

**Exercise 4.5.1.** Revise the program so that the user can enter any positive integer value for  $n$ . Ideally, you should test the input to see whether it is greater than 0.

**Exercise 4.5.2.** Instead of printing the “Move” message directly on the screen, have the `move_ring` function call yet another function, which you give the name `exec_move`. The `exec_move` function should take a source and destination stack number as its two arguments. Because this is a separate function, you can use as many lines of code as you need to print a message. You can print a more informative message:

Move the top ring from stack 1 to stack 3.

## Example 4.6. *Random-Number Generator*

OK, we’ve had enough fun with recursion. It’s time to move on to another, highly practical example. This one generates random numbers—a function at the heart of many game programs.

The test program here simulates any number of dice rolls. It does this by calling a function, `rand_0toN1`, which takes an argument,  $n$ , and randomly returns a number from 0 to  $n - 1$ . For example, if the user inputs the number 6, this program simulates dice rolls:

3 4 6 2 5 3 1 1 6

Here is the program code:

**dice.cpp**

```
#include <iostream>
#include <cmath>
#include <cstdlib>
#include <ctime>
using namespace std;

int rand_0toN1(int n);

int main() {
    int n, i;
    int r;

    srand(time(NULL)); // Set seed for random numbers.

    cout << "Enter number of dice to roll: ";
    cin >> n;

    for (i = 1; i <= n; i++) {
        r = rand_0toN1(6) + 1; // Get a number 1 to 6
        cout << r << " ";    // Print it
    }
    system("PAUSE");
    return 0;
}

// Random 0-to-N1 Function.
// Generate a random integer from 0 to N-1, with each
// integer an equal probability.
//
int rand_0toN1(int n) {
    return rand() % n;
}
```

4



## How It Works

The beginning of the program has to include a number of files to support the functions needed for random-number generation:

```
#include <iostream>
#include <cmath>
#include <cstdlib>
#include <ctime>
using namespace std;
```

Make sure you include the last three here—`cmath`, `cstdlib`, and `ctime`—whenever you use random-number generation.

Random-number generation is a difficult problem in computing, because computers follow deterministic rules—which, by definition, are nonrandom. The solution is to generate what's called a *pseudorandom* sequence by taking a number and performing a series of complex transformations on it.

To do this, the program needs a number as random as possible to start off the sequence. So, we're back where we started, aren't we?

Well, fortunately no. You can take the system time and use it as a *seed*: That is the first number in the sequence.

```
srand(time(NULL));
```

`NULL` is a predefined value that means a data address set to nothing. You don't need to worry about it for now. The effect in this case is simply to get the current time.

**C++0x** ► The C++0x specification provides the `nullptr` keyword, which should be used in preference to `NULL` if you have a C++0x-compliant compiler.

A program that uses random numbers should call `srand` first. System time changes too quickly for a human to guess its exact value, and even a tiny difference in this number causes big changes in the resulting sequence. This is a practical application of what chaos theorists call the Butterfly Effect.

The rest of `main` prompts for a number and then prints the quantity of random numbers requested. A `for` loop makes repeated calls to `rand_0toN1`, a function that returns a random number from 0 to  $n - 1$ :

```
for (i = 1; i <= n; i++) {
    r = rand_0toN1(6) + 1; // Get num from 1 to 6
    cout << r << " "; // Print it out
}
```

Here is the function definition for the `rand_0toN1` function:

```
int rand_0toN1(int n) {
    return rand() % n;
}
```

This is one of the simplest functions we've seen yet! Calling `rand` produces a number anywhere in the range of the `int` type, which, on 32-bit systems, can be anywhere in the range of roughly plus or minus two billion. But we want much smaller numbers.

The solution is to use your old friend, the remainder-division operator (`%`), to divide by `n` and return the remainder. No matter how large the amount being divided, the result must be a number from 0 to `n-1`, which is exactly what the function is being asked to provide.

In this case, the function is called with the argument 6, so it returns a value from 0 to 5. Adding 1 to the number gives a random value in the range 1 to 6, which is what we want.



## EXERCISES

**Exercise 4.4.1.** Write a random-number generator that returns a number from 1 to `N` (rather than 0 to `N-1`), where `N` is the integer argument passed to it.

**Exercise 4.4.2.** Write a random-number generator that returns a random floating-point number between 0.0 and 1.0. (Hint: Call `rand`, cast the result `r` to type `double` by using `static_cast<double>(r)`, and then divide by the highest value in the `int` range, `RAND_MAX`.) Make sure you declare the function with the `double` return type.

## Games and More Games

Now that we know how to write functions and generate random numbers, it's possible to enhance some game programs.

The Subtraction Game example at the end of Chapter 2 can be improved. Right now, when the user plays optimal strategy, the computer responds by choosing 1. We can make this more interesting by randomizing the computer's response in these situations. The following program makes the necessary changes, putting altered lines in bold:

**nim2.cpp**

```
#include <iostream>
#include <cmath>
#include <ctime>
#include <cstdlib>
```

▼ *continued on next page*

nim2.cpp, cont.

```
using namespace std;

int rand_0toN1(int n);

int main() {
    int total, n;

    srand(time(NULL)); // Set seed for random numbers.

    cout << "Welcome to NIM. Pick a starting total: ";
    cin >> total;
    while (true) {

        // Pick best response and print results.

        if ((total % 3) == 2) {
            total = total - 2;
            cout << "I am subtracting 2." << endl;
        } else if ((total % 3) == 1) {
            total--;
            cout << "I am subtracting 1." << endl;
        } else {
            n = 1 + rand_0toN1(2); // n = 1 or 2.
            total = total - n;
            cout << "I am subtracting ";
            cout << n << "." << endl;
        }
        cout << "New total is " << total << endl;
        if (total == 0) {
            cout << "I win!" << endl;
            break;
        }
    }
    // Get user's response; must be 1 or 2.

    cout << "Enter num to subtract (1 or 2): ";
    cin >> n;
    while (n < 1 || n > 2) {
        cout << "Input must be 1 or 2." << endl;
        cout << "Re-enter: ";
        cin >> n;
    }
}
```

nim2.cpp, cont.

```
        total = total - n;
        cout << "New total is " << total << endl;
        if (total == 0) {
            cout << "You win!" << endl;
            break;
        }
    }
    system("PAUSE");
    return 0;
}

int rand_0toN1(int n) {
    return rand() % n;
}
```

Chapter 2 presented an exercise: Alter this program so that it permits any number from 1 to N to be subtracted each time, where N is set at the beginning. That problem is left as an exercise for this version as well. (You can even prompt the end user for this value before the game starts. As always, the computer should win whenever the user does not play perfect strategy.)

The last full example in Chapter 10 presents a game of Rock, Paper, Scissors that can be programmed even with C++ compilers that are not fully C++0x compliant. To use the example in Chapter 10 (Example 10.3) with weak, rather than strong, enumerations, replace this line in Chapter 10:

```
enum class Choice { rock, paper, scissors };
```

with this:

```
enum Choice { rock, paper, scissors };
```

Also, remove the `using` statement:

```
using namespace Choice;
```

## Chapter 4 *Summary*

Here are the main points of Chapter 4:

- In C++, you can use functions to define a specific task, just as you might use a subroutine or procedure in another language. C++ uses the name function for all such routines, whether they return a value or not.

- You need to declare all your functions (other than **main**) at the beginning of the program so that C++ has the type information required. Function declarations, also called *prototypes*, use this syntax:

```
type function_name (argument_list);
```

- You also need to define the function somewhere in the program, to tell what the function does. Function definitions use this syntax:

```
type function_name (argument_list) {
    statements
}
```

- A function runs until it ends or until the **return** statement is executed. A **return** statement that passes a value back to the caller has this form:

```
return expression;
```

- A return statement can also be used in a **void** function (function with no return value) just to exit early, in which case it has a simpler form:

```
return;
```

- Local variables are declared inside a function definition; global variables are declared outside all function definitions, preferably before **main**. If a variable is local, it is not shared with other functions; two functions can each have a variable named *i* (for example) without interfering with each other.
- Global variables enable functions to share common data, but such sharing provides the possibility of one function interfering with another. It's a good policy not to make a variable global unless there's a clear need to do so.
- The addition-assignment operator (**+=**) provides a concise way to add a value to a variable. For example:

```
n += 50; // n = n + 50
```

- C++ functions can use recursion—meaning they call themselves. (A variation on this is when two or more functions call each other.) This technique is valid as long as there is a case that terminates the calls. For example:

```
int factorial(int n) {
    if (n <= 1)
        return 1;
    else
        return n * factorial(n - 1); // RECURSION!
```

# Index

---

## Symbols

- > (access class member) operator, 391, 476
- += (add and assign) operator, 477
- (change sign of) operator, 333, 476
- (decrement) operator
  - associativity, precedence, and syntax of, 476
  - safe use of, 55
  - using with loops, 52, 70
- " " (double quotes)
  - distinguishing strings from individual characters, 185
  - in **#include** syntax, 510
- >= (greater than or equal to) operator. See Greater than or equal to (>=) operator
- != (inequality) operator, 47, 477
- , (join) operator
  - associativity, precedence, and syntax of, 477
  - as delimiters in text, 187
  - uses of, 482
- <<= (left shift and assign) operator, 477
- <= (less than or equal to) operator, 47, 477
- \*= (multiply and assign) operator, 477
- .\* (pointer-to-member) operator, 476
- >\* (pointer-to-member) operator, 476
- >>= (right shift and assign) operator, 477
- = (subtract and assign) operator, 477
- (subtraction) operator, 342–343, 476
- . (access class member) operator, 476
- /= (divide and assign) operator, 477
- / (divide) operator, 476
- // (double slashes), in comment syntax, 23–24
- :: (scope) operator, 476, 478
- ;(semicolon)
  - class or data declaration ending with, 280
  - compound statements and, 36
  - termination of function prototypes, 119
  - termination of statements, 52–53
  - use in program syntax, 14
- \ (backslash), 177
- | (bitwise OR) operator, 477, 480
- || (logical OR) operator, 477
- + (addition) operator. See Addition (+) operator
- ++ (increment) operator. See Increment (++) operator
- = (assignment) operator. See Assignment operator (=)
- == (equality) operator. See Equality operator (==)
- & (address) operator, 160, 321, 476
- &= (bitwise AND and assign) operator, 477
- ! (logical negation) operator
  - associativity, precedence, and syntax of, 476
  - swap function and, 161
  - types of Boolean operators, 54

&& (bitwise AND) operator. See AND (&&) operator

## (concatenation) operator, 507

%= (modular divide and assign) operator, 477

% (modulus or remainder) operator  
 associativity, precedence, and syntax of, 476  
 declaring, 335–336  
 prime number function and, 92  
 random number generation and, 113  
 using in Odd-or-Even program, 41–42

() (function call) operator, 476

\* (indirection operator), 149, 166, 476

\* (multiply) operator, 476

?: (conditional) operator, 481, 506

[] (access array element) operator, 476

^= (bitwise XOR and assign) operator, 477

^ (bitwise XOR) operator, 477, 480

{ } (braces). See Braces { }

~ (bitwise negation) operator, 476, 481

< > (angle brackets)  
 correct interpretation of, 432  
 #include syntax, 299–300, 510–511

<< (bitwise left shift or stream op) operator, 476, 481

< (less than) operator. See Less than (<) operator

>> (bitwise right shift or stream op) operator, 476, 481

> (greater than) operator, 47, 477

>> (stream input) operator, 180

## Numbers

16-bit integers (short), 244–245

2-D arrays, 142–143

32-bit  
 addresses, 148  
 integers (long), 244–245

64-bit  
 addresses, 148

Fibonacci numbers as 64-bit example, 250–254

integers (**long long**), 244–245

literals (constants), in C++Ox specification, 246–247

## A

Abstract classes  
 declaring an abstract Printable class, 465  
 defined, 537  
 as a pattern for subclasses, 463  
 specifying and enforcing a set of services (as an interface), 463–464  
 stream classes demonstrating  
 extensibility of OOP, 464–466  
 virtual functions in, 462

Access array element ([]) operator, 476

Access class member (->) operator, 476

Access levels  
 defined, 537  
 public, protected, and private, 446

ACK (acknowledgement signal), 513–514

Add and assign (+=) operator, 477

add function  
 adding arithmetic functions to Fraction class, 300–305  
 refining in Fraction class, 347–348

Addition (+) operator  
 adding to Point class, 342–343  
 associativity, precedence, and syntax of, 476  
 declaring, 334  
 overloading in Fraction class, 348–349  
 using with references, 338–339

Address operator (&), 160, 476

Addresses  
 32-bit and 64-bit, 148  
 arr constant, 161–163  
 comparing address expressions to each other, 163

- CPUs determining location by, 145
  - defined, 537
  - doubling variable whose address is
    - passed via pointer, 152–155
  - pointers and, 146
  - printing, 151–152
- Advanced programming. See Programming, advanced
- Aggregates, for initializing arrays, 119
- AI (Artificial intelligence), 35
- Algorithms, in data evaluation, 4
- Alphabetical lists, 393–395
- American National Standards Institute (ANSI)
  - data types supported by, 483
  - defined, 537
- AND (&&) operator
  - associativity, precedence, and syntax of, 477
  - operating on integers of same width, 480
  - testing a person's age (example of Boolean logic), 55–56
  - types of Boolean operators, 54
- Angle brackets (< >)
  - correct interpretation of, 432
  - #include** syntax, 299–300, 510–511
- ANSI (American National Standards Institute)
  - data types supported by, 483
  - defined, 537
- Applications, defined, 5, 537
- argc**, command-line argument, 222, 224–225
- Arguments
  - catch statements, 239
  - command-line, 221–222
  - compared with pointers, 321
  - declaring functions and, 83, 85, 500
  - defined, 538
  - operators, 335
  - pointers, 172
  - references, 322–323
- argv**, command-line argument, 222
- Arithmetic functions, adding to Fraction class, 300–305
- Arithmetic operators
  - pointers and, 162
  - precedence of, 54
- arr** constant, in addressing, 161–163
- Arrays
  - 2-D, 142–143
  - allocating array of any size, 368–370
  - boundary problems in indexing, 141
  - Card Dealer #1 (example), 129–132
  - Card Dealer #2 (example), 132–136
  - Card Dealer #3 (example), 136–140
  - as container for range-based for, 257
  - distinguishing strings from individual characters, 185–186
  - initializing, 119
  - linked lists compared with, 389
  - overview of, 117
  - pointers used in processing, 163–164
  - `print_array` function (example), 228–230
  - printing out elements (example), 121–123
  - range-based "for" (for each) in setting, 258–261
  - sorting with swap function, 156–161
  - of strings, 128–129
  - strings as arrays based on **char** type, 171
  - summary, 143–144
  - testing randomness with, 123–127
  - uses of, 117–119
  - zero-based indexes and, 119–120
- Artificial intelligence (AI), 35
- ASCII code
  - char** type and, 171–172
  - corresponding to characters, 169
  - defined, 538
  - distinguishing strings from individual characters, 185–186
  - extended codes for DEC, HEX, and CHAR, 515
  - reading string input, 178
  - special meanings of nonprintable characters, 513

- ASCII code (*continued*)
  - standard codes for DEC, HEX, and CHAR, 514
  - strings and, 19
  - text files vs. "binary" files, 206
- Assignment operator (=)
  - copy constructors compared with, 380
  - equality operator (==) compared with, 36, 38–39
  - in expression syntax, 491–492
  - overview of, 349–350
  - precedence of, 166
  - return \*this** statement as last statement in, 379–380
  - in statements, 25–26
- Associativity
  - defined, 538
  - in evaluation of expressions, 166–167
  - of operators, 475–477
- atof** function, 183
- atoi** function, 183, 206
- atoll** function, 247–248
- auto** keyword
  - uses of, 261–262
  - variable modifiers, 499
  - working with exotic types and, 243
- Avg(), 87–88
- B**
- Backslash (\), indicating special meaning, 177
- Backward compatibility
  - with C language, 281
  - defined, 538
  - issues with C, 312–313
- Base 10 numbers. See Decimal notation (base 10)
- Base 16 numbers. See Hexadecimal notation (base 16)
- Base 2 numbers. See Binary notation (base 2)
- Base 8 (Octal notation), 485
- Base classes
  - access levels, 437–438
  - constructors (C++0x only), 441–442
  - defined, 538
  - inheriting from, 435
  - principle of passing something specific (subclass) to something more general (base class), 466
  - subclasses not inheriting constructors from, 440
- base()**, output stream function, 528
- base\_check** keyword, in explicit overrides (C++0x only), 460–461
- Basic language
  - adding OOP extensions to, 279
  - purpose of high-level languages, 7
  - "for" statement in, 79
- Bauer, F. L., 424
- BEL (bell), 513–514
- Binary files
  - operations on, 208–211
  - reading data from, 214–217
  - text files vs., 206–208
  - writing data to, 211–214
- Binary notation (base 2)
  - Fibonacci and, 255
  - floating-point data type and, 33
  - hexadecimal and decimal equivalents, 147
- Bits, 538
- Bitwise left shift or stream op (<<) operator, 476
- Bitwise negation (~) operator, 476, 481
- Bitwise operators
  - associativity, precedence, and syntax of, 476
  - logical operators compared with, 55
  - operating on integers, 480
  - uses of, 481
- Bitwise right shift or stream op (>>) operator, 476, 481

- Bitwise XOR and assign (^=) operator, 477
- Bitwise XOR (^) operator, 477, 480
- Blocks. See Compound statements (blocks)
- Bonacci, Leonardo (Fibonacci), 255
- bool** data type
  - array of bool items, 138–139
  - C++ support for, 51
  - converting logical operators to, 55
  - prime number function and, 92–93
- boolalpha**, 527
- Boolean algebra, 53
- Boolean values (true/false)
  - C++ support for **bool** data type, 50–51
  - defined, 539
  - introducing short-circuit logic, 53–55
  - relational operators returning true or false values, 47
  - testing a person's age (example of Boolean logic), 55–56
- Boundary checking, arrays and, 141
- Braces ({})
  - in **if-else** statements, 37–38
  - in initialization, 314–315
  - in program syntax, 13
- Branch statements. See also Control structures, 493
- break** statements
  - interrupting loops, 46, 60
  - syntax of control structures, 496
  - transferring control out of loop or function, 231
- BS (backspace), 513–514
- Bubble sort algorithm, 156–157
- Bytes
  - defined, 539
  - one byte per character in ASCII code, 170
- C**
- C language
  - .h files, 511
  - backward compatibility with, 281, 312–313
  - C++ built on, 279
  - purpose of high-level languages, 7
- C++, brief history of, 7, 279
- C++ compilers, See Compilers
- C++Ox specification
  - 64-bit literals (constants), 246–247
  - auto** keyword, 261–262
  - base class constructors, 441–442
  - challenges of **long long** type, 247–248
  - consistent initialization, 314–315
  - data types supported by, 483
  - decltype** keyword, 262
  - defined, 539
  - delegating constructors, 313–314
  - enum** classes, 265–266
  - extended enum syntax, 266–267
  - Fibonacci numbers as 64-bit example, 250–254
  - formatting **long long** numbers, 248–249
  - initializing members within a class, 309–310
  - localizing numbers, 254–255
  - new version of **for** loops, 69–70
  - nullptr** keyword, 112, 187, 262–263
  - overview of features in, 243–244
  - range-based "for" (for each), 256–261
  - raw string literals, 273
  - Rock, Paper, Scissors game, 267–272
  - strongly typed enumerations, 263–265
  - summary, 273–275
  - supporting **long long int**, 34, 244–246
  - user-defined literals, 357–359
- C-strings. See Strings (C-strings)
- Callback, 539
- Calling functions
  - arguments in, 227–228
  - avg() example, 87–88
  - as expression, 86–87
  - implementation of, 325

- Calling functions (*continued*)
  - object member functions, 179
  - overview of, 83
  - prototypes and, 235
- Card dealer array examples
  - Card Dealer #1, 129–132
  - Card Dealer #2, 132–136
  - Card Dealer #3, 136–140
- Case
  - case-sensitivity in compiling code, 11
  - Convert to Uppercase program (example), 183–185
  - switch case statements, 232–234
- Casts
  - associativity, precedence, and syntax of cast operator, 476
  - defined, 539
  - new vs. old style for, 479
- catch** keyword, in exception handling, 238–239
- cctype, 185
- Celsius, converting to/from Fahrenheit, 22–26
- Central processing units. See CPUs (central processing units)
- cerr**, 526
- Change sign of (-) operator, 333, 476
- char\***
  - converting to long long integers, 247–248
  - format of string literals, 273, 486
  - for string variables, 128–129
- char** type. See also Strings (C-strings)
  - 8 bit, 245
  - ASCII codes for, 514–515
  - description and range of, 484
  - new string class and, 363
  - strings based on, 171–172
  - syntax of, 186
- Characters
  - accessing individual characters in new string type, 193
  - conversion and testing functions in standard library, 519
  - distinguishing strings from individual characters, 185–186
  - manipulating individual characters in a string, 183–184
- cin**
  - adding values to variables, 19–20
  - description of stream objects, 526
  - file streams as alternative to, 197
  - getline**, 179–180
  - string type and, 191
- class** keyword, 279
- Classes
  - abstract. See Abstract classes
  - arithmetic functions added to, 300–305
  - constructors for, 317–320
  - copy constructors for, 324–329
  - declaring, 279–280, 502–503
  - defined, 540
  - destructors, 370–371
  - encapsulation and, 236
  - enum** class, 265–266
  - exception** class, 240
  - finding GCF of, 291–292
  - finding LCM of, 292
  - Fraction class example. See Fraction class
  - hierarchies for safe inheritance, 448–451
  - inheritance. See Inheritance
  - initializing members within (C++Ox only), 309–310
  - inline functions of, 289–291
  - lists. See List classes
  - naming, 266
  - objects in, 277–278
  - operators for Fraction class, 352–357
  - operators for Point class, 340–348
  - operators for (Print function), 351–352
  - Point class example. See Point class
  - polymorphism. See Polymorphism

- principle of passing something specific (subclass) to something more general (base class), 466
  - private members of, 281–284
  - range-based for contained in, 257
  - relationship with objects and members, 284
  - stack class, 425, 427–428
  - streams. See Streams
  - strings. See String class
  - structures and, 281
  - subclasses. See Subclasses
  - summary, 305–306
  - support functions of, 293–296
  - syntax of class keyword, 279
  - testing, 284–286, 296–300
- clog**, 526
- close()**
  - closing files, 199
  - description of file I/O functions, 529
- cmath library
  - accessing, 57
  - functions in, 520
  - including, 181
- Code
  - defined, 5, 540
  - packaging with data in classes, 277–278
  - as program instructions, 1
- Code reuse
  - inheritance and, 435
  - object containment and, 447–448
- Command-line
  - arguments, 221–222
  - displaying files from, 223–226
- Commas (,). See Join (,) operator
- Comments, use in programs, 23–24
- Compilers
  - as applications, 5
  - building a C++ program, 8–9
  - defined, 5, 540
  - function of, 3
  - ignoring comments, 24
  - installing, 10
  - modules and, 235
  - overloading and, 228
  - translating statements into machine code, 170–171
- Component models, in systems approach to programming, 472
- Compound statements (blocks)
  - defined, 540
  - for executing a series of things, 36
  - if-else** used with, 37–38
  - for** loops used with, 74
  - replacing control structures with, 231
  - syntax of, 492
  - while** loops used with, 43–45
- Computers
  - ability to make judgments, 35
  - doing only what you tell them, 1
  - storing text on, 169–170
- Concatenation
  - defined, 551
  - strcat** and **strncat** functions for, 172–174
  - working with string type and, 193
  - writing function for string class, 380–382
- Conditional (?:) operator, 477
- Conditions
  - in **for** loops, 68–69
  - in **while** loops, 43–45
- Console input, see **cin**
- Console stream objects. See Streams
- const** keyword
  - in declaring copy constructors, 324
  - function modifiers, 501
  - preventing changes to arguments while passing, 340
  - variable modifiers, 499
- Constants
  - 64-bit literals, 246–247
  - advantages of predefined, 225–226
  - all literals are constants, 485

- Constants (*continued*)
- automating assignment of symbolic, 264–265
  - defined, 540
  - end line constant, 16
  - list of predefined, 512
- Constructors
- for base classes (C++Ox only), 441–442
  - cannot be virtual, 455
  - consistent initialization of (C++Ox only), 314–315
  - copy constructors, 323–325
  - copy constructors for Fraction class, 325–329
  - default constructors, 310–313
  - defined, 540
  - delegating (C++Ox only), 313–314, 452
  - for Fraction class, 317–320
  - initializing members within a class (C++Ox only), 309–310
  - initializing objects from strings, 329–331
  - for linked lists, 390–391
  - multiple (overloading), 309
  - overview of, 307–309
  - for Point class, 315–317
  - reference variables and arguments and, 321–323
  - for String class, 374
  - subclasses not inheriting, 440
  - summary, 331–332
- Containers
- range-based for (for each), 257
  - templates creating, 413
- continue** statements, 496
- Control structures
- defined, 540
  - do while**, 231–232
  - else**. See **else**
  - for**. See **for**
  - if**. See **if** statements
  - switch case** statements, 232–234
  - syntax of, 493
  - types of, 230–231
  - while**. See **while**
- Convert to Uppercase program (example), 183–185
- Cooked literals, 359
- Copy constructors
- assignment operator compared with, 380
  - deep copying, 377
  - defined, 541
  - for Fraction class, 325–329
  - member functions automatically supplied by compiler, 349
  - overview of, 323
  - references and, 325
  - shallow copying, 376–377
  - syntax of, 324
- Counting, loops used for, 67–68
- cout**
- console output object, 14
  - description of stream objects, 526
  - file streams as alternative to, 197
  - polymorphism and extensibility of, 464–466
  - print function interacting with, 351–352
  - string type and, 191
  - use of data objects in C++, 7–8
- CPUs (central processing units)
- addresses of locations, 145
  - defined, 541
  - translating statements into machine code prior to execution, 170–171
- CR (carriage return), 513–514
- cstdlib**, 181
- ctemp variable, for holding Celsius values, 19–20, 24–25
- D**
- Data
- arrays, 117

- conversion functions in standard library, 518
  - defined, 5
  - linking data structures using addresses, 146
  - packaging with code in classes, 277–278
  - pointers for sending large amounts of, 146
  - programs and, 1
  - storing via variables, 19–20
  - string data, 19
- Data declaration
- classes, 502–503
  - enumerations, 503–504
  - functions, 500–501
  - semicolon terminating, 280
  - variables, 498–500
- Data members. See Members
- Data types
- classes creating, 277
  - comparing integers with floating point data, 33–34
  - description and range of, 484
  - initializing while declaring, 307
  - introduction to, 20–22
  - of numeric literals, 485–486
  - operations on, 333
  - polymorphism and, 228
  - precision of, 484
- dec**, 527
- Decimal notation (base 10)
- ASCII codes, 514–515
  - Fibonacci and, 255
  - hexadecimal and binary equivalents, 147
  - numeric format of literals, 485
- Decision making
- Boolean values (true/false), 50–51
  - if** and **if-else**, 35–38
  - increment operator (++) and, 51–52
  - loops in, 43–46
  - odd or even, 39–41
  - optimizing Odd-or-Even program, 42
  - overview of, 33
  - print 1 to N loop example, 46–49
  - in programs, 34–35
  - short-circuit logic, 53–55
  - Subtraction Game example (NIM), 60–63
  - summary, 64–65
  - testing a person's age, 55–56
  - testing for prime numbers, 57–60
- Declaration
- of classes, 502–503
  - of classes (Point class example), 279–280
  - defined, 541
  - of enumerations, 503–504
  - of operators, 334–336
  - of pointers, 148–150
- Declaration, of functions
- overview of, 500–501
  - termination of function prototypes, 119
  - user-defined, 85
- Declaration, of variables
- assigning values while initializing, 49
  - avg() example, 87–88
  - on the fly with **for** loops, 74–75
  - local and global variables and, 93–95
  - overview of, 498–500
  - prior to use, 20
  - for string type, 189–190
- decltype** keyword, 243, 262
- Decrement operator (--)
- associativity, precedence, and syntax of, 476
  - safe use of, 55
  - using with loops, 52, 70
- Deep copying, 377
- Default constructors
- defined, 541
  - member functions automatically supplied by compiler, 349
  - supplying constructors vs. accepting default, 310–313

- #define** directive
    - localizing numbers, 254–255
    - overview of, 505–506
    - placing predefined constants with, 225–226
  - defined** function, preprocessor directives, 507
  - Defining functions
    - avg() example, 87–88
    - defined, 541
    - overview of, 85–86
  - DEL (delete), 513–514
  - Delegating constructors (C++0x only), 313–314, 452
  - delete** operator
    - associativity, precedence, and syntax of, 476
    - class destructors and, 370–371
    - pointers to objects and, 365–366
    - releasing allocated memory, 364–365, 367, 370
  - Delimiters, in text, 186
  - Deprecate
    - defined, 541
    - setting null pointers without **nullptr** keyword, 263
  - Dereference, 542
  - Derived classes. See also Subclasses, 279, 541
  - Destructors
    - class destructors, 370–371
    - defined, 542
    - in String class, 374
    - virtual**, 455
  - Dev-C++, 12
  - Dijkstra, E. W., 424
  - Directives. See Preprocessor directives
  - Directories, referencing disk files in, 199–200
  - Displaying text files, 203–206
  - Divisors, lowest divisor as prime number, 100–101
  - do while** statements
    - as loop, 230
    - statement and conditions, 232
    - syntax of, 231, 494
  - Double-precision types. See **double**
  - Double quotes (" ")
    - distinguishing strings from individual characters, 185
    - in **#include** syntax, 510
  - double** type
    - arrays and, 117–118
    - comparing integers with floating point data, 33–34
    - converting strings to, 183
    - "cooked" literals and, 359
    - description and range of, 484
    - as floating-point data type, 21–22
    - precision of, 484
    - range compared with **int**, 127
    - reading binary data, 209–210
    - storing literals in, 485
    - using with **ctemp** and **ftemp** variables, 24–25
  - Double\_it function, doubling variable with, 152–155
  - Dynamic memory allocation
    - allocating memory blocks with, 366–367
    - for array of any size, 368–370
    - new** keyword and, 363–364
    - problems with, 368
- ## E
- #elif** directive, 507–508
  - else** statements
    - as control structure, 231
    - in **if-else** statements, 37–38
    - syntax of, 493
  - Encapsulation
    - defined, 542
    - fout object and, 198
    - private/public distinction and, 236
  - End users. See Users
  - #endif** directive, 508

- endl** stream manipulator
  - description of, 527
  - for end line constant, 16
- ends** stream manipulator, 527
- Enumerations
  - automating assignment of symbolic constants, 264–265
  - enum** classes, 265–266
  - enum** declarations, 503–504
  - extended **enum** syntax, 266–267
  - Rock, Paper, Scissors game, 267–272
  - strongly typed, 244, 263–265
- eof** (end of file) function, file I/O functions, 205, 529
- Equality operator (==)
  - associativity, precedence, and syntax of, 476
  - compared with assignment operator (=), 36, 38–39
  - in Fraction class, 355–356
  - ordered lists and, 419
  - overview of, 350–351
  - precedence of, 166
  - in String class, 374
  - types of relational operators, 47
- #error** directive, 508
- Errors. See also Exception handling
  - syntax errors and program-logic errors, 9–10
  - types of, 237
- Escape sequences, strings, 177–178, 486–487
- Euclid, 101–105
- exception** class, 240
- Exception handling
  - examples of exceptions, 237
  - exceptions as runtime errors, 237
  - exceptions defined, 542
  - in small program, 238
  - throw** statements and, 497
  - try-catch-throw approach to, 238–240
- Expressions
  - evaluating in RPN, 422–423
  - function calls as, 86–87
  - precedence and associativity in evaluating, 166–167
  - single quote vs. double quotes in syntax of, 186
  - statements compared with, 52–53
  - syntax of, 491–492
- Extensibility, of OOP, 464–466
- extern** declaration
  - sharing variables and, 235
  - for variable modifiers, 499–500
- F**
- F** suffix, representing **float** format, 486
- Factorial function
  - overview of, 90
  - rewriting as recursive function, 96
- Factorization, of prime numbers, 96–100
- Fahrenheit, converting to/from Celsius, 22–26
- False/true. See Boolean values (true/false)
- FF (form feed), 513–514
- Fibonacci numbers, 250–254
- File-error exceptions, 240
- File I/O functions, 529–530
- File mode flags, 530
- File stream objects
  - associating with disk files, 198
  - including, 197
- Filenames
  - entering from command-line, 221
  - prompts for, 202, 223
  - referencing disk files, 200
- Files
  - binary operations, 208–211
  - displaying from command line, 223–226
  - displaying text files, 203–206
  - file stream objects, 197–199
  - reading binary data from, 214–217

Files (*continued*)

- referencing disk files, 199–200
- storing data in, 197
- summary, 217–219
- text files vs. "binary" files, 206–208
- writing binary data to, 211–214
- writing text to, 200–203

**fill()** function, output streams, 528

**fixed**, 237–240

**fixed** stream manipulator, 527

## Flags

- file mode flags, 530
- seek direction flags, 530

**float** data type. See also Floating-point data

- description and range of, 484
- F** suffix, 486
- for floating-point data, 21–22
- precision of, 484

## FloatFraction class

- complete version of, 442–445
- implementing and testing, 438–440
- inheriting base-class constructors, 441–442
- problems with, 440–441
- protected members of, 445–446
- as subclass of Fraction class, 436–437
- virtual functions in, 454–455

## Floating-point data

- comparing integers with, 33–34
- converting strings to, 183
- data types for, 20–22
- decimal point in, 485
- defined, 542–543
- division of, 480
- making a value persistent and recalculated as needed, 453, 459–460
- range and precision of, 484
- reading binary data, 209–210

Flow control, in loops. See also Control structures, 37–38, 48

**flush()** function, streams, 528

**flush** stream manipulator, 527

Folders, referencing disk files in, 199–200

For each. See Range-based for (for each)

**for** loops

- comparable statements in other languages, 79–80
- comparing with **while** loops, 71–72
- compound statements and, 74
- counting with, 67–68
- declaring variables on the fly, 74–75
- examples, 70–71
- overview of, 67
- printing numbers from 1 to N with **for** loop, 72–73
- specifying initializer, condition, and increment values, 68–69
- summary, 80–81
- swap function and, 157–161
- testing for prime numbers, 75–79
- testing randomness with arrays, 126–127
- true/false values in, 80
- using with arrays, 121–123

**for** statements

- as control structure, 231
- syntax of, 494–495

Fortran, 120

fout object, output streams and, 198–200

## Fraction class

- arithmetic functions added to, 300–305
- complete version of, 352–357
- constructors for, 317–320
- copy constructor for, 325–329
- finding GCF of, 291–292
- finding LCM of, 292
- initializing objects from strings, 329–331
- inline functions of, 289–291
- operators for, 343–348, 352–357
- overview of, 286–289
- support functions of, 293–296
- testing, 296–300
- this** keyword used with, 378

Friend functions, 337–338

### **fstream**

- for generic file stream, 198
- including, 201

ftemp variable, for holding Fahrenheit values, 19, 24–25

### Functions

- arithmetic functions added to Fraction class, 300–305
- avg(), 87–88
- C-strings, 517–518
- calling, 86–87, 179
- character conversion, 519
- character-testing, 519
- data-conversion, 518
- declaring, 85, 500–501
- defining, 85–86
- Euclid's algorithm for GCFs, 101–106
- friend functions, 337–338
- GCF function added to Fraction class, 291–292
- inline, 289–291
- LCM function added to Fraction class, 292
- local and global variables and, 93–95
- math, 520
- modules for placing in different files, 234–235
- normalize added to Fraction class, 293–296
- operator. See Operators
- overloading, 227–230
- overview of, 83–84
- prime factorization, 96–100
- prime number, 90–93
- in programs, 89–90
- random number generator, 110–113
- randomized, 521
- recursive, 95–96, 106–110
- single-character, 519
- strftime** format, 523–524

- string manipulation, 172–174
- in Subtraction Game, 113–115
- summary, 115–116
- support functions of Fraction class, 296–300
- time functions, 521–523
- virtual. See Virtual functions
- zero\_out\_array, 165–167

## G

- GCFs (greatest common factors)
  - adding GCF function to Fraction class, 291–292
  - defined, 543
  - Euclid's algorithm for, 101–103
  - how it works, 103–106
- Get a Number program, string example, 180–183
- get()** function, stream input, 528
- get\_divisors** function, 99–100
- get\_int** function, 214
- getline()** function
  - description of, 528
  - reading string input, 179–180, 182
  - retrieving line of input with, 176
  - working with string type and, 192
- get\_number** function, 230
- Global functions
  - defining operators as, 334
  - in Fraction class, 355–356
  - operators as, 336–338
- Global variables
  - declaring functions and, 93–95
  - defined, 543
  - initializing to zero, 119
  - necessity of, 95
- go to** statements, 497
- Graphical-user interfaces (GUIs)
  - OOP and, 279
  - safe inheritance and, 448–451
- Greater than (>) operator, 47, 477

- Greater than or equal to ( $\geq$ ) operator
  - associativity, precedence, and syntax of, 477
  - types of relational operators, 47
  - using with **for** loops, 70
- Greatest common factors. See GCFs (greatest common factors)
- GUIs (graphical-user interfaces)
  - OOB and, 279
  - safe inheritance and, 448–451
- H**
- .h files, C language, 511
- Header files
  - cstring and string in, 224
  - defined, 543
  - #include** and, 510
- hex** stream manipulator, 527
- Hexadecimal notation (base 16)
  - ASCII codes, 514–515
  - in C++0x specification, 485
  - decimal and binary equivalents, 147
  - storing numeric variables as, 145
- High-level languages, comparing C++ with other, 7–8
- I**
- I/O (input/output)
  - console stream objects, 525–526
  - file I/O functions, 529–530
  - functions, 528
  - stream classes demonstrating
    - extensibility of OOB, 464–466
  - stream manipulators, 526–527
- IDEs (integrated development environments)
  - defined, 543
  - entering program statements with, 8
- #if** directive, 508–509
- if-else** statements
  - syntax of, 3, 493
  - testing a value against a series of target values, 233
  - use with compound statements, 36–38
- if** statements
  - as control structure, 231
  - syntax of, 35
  - true/false values in, 80
  - use with compound statements, 36–38
- #ifdef** directive, 510
- ifstream**
  - file-input streams, 198
  - including, 201
  - turning off file-error exceptions, 240
- Implementation, defined, 543
- #include** directive
  - cctype, 185
  - cstring, 175
  - for function declarations, 235
  - iostream and fstream, 201
  - list templates, 415
  - overview of, 510–511
  - string type, 189
  - supporting specific parts of standard library, 15
  - syntax options, 299–300
  - using at beginning of Visual Studio programs, 13
- Increment (**++**) operator
  - associativity, precedence, and syntax of, 476
  - precedence of, 166
  - reducing keystrokes with, 67
  - using with loops, 44–45, 51–52, 68–70
- Incrementing
  - in **for** loops, 68–69
  - in **while** loop, 44–45
- Indexes
  - boundary problems in, 141
  - comparing pointer references with, 163
  - data by numbers (arrays), 117–118
  - defined, 543
  - one-based, 120
  - zero-based, 119–120

- Indirection
  - defined, 543
  - indirection-member operator (->), 391
  - indirection operator (\*), 149, 166
- Inequality (!=) operator
  - associativity, precedence, and syntax of, 477
  - types of relational operators, 47
- Infinite loops
  - defined, 544
  - for exiting files, 205
  - overview of, 46
- Infix (Standard) notation, 423
- Inheritance
  - of base class constructors (C++0x only), 441–442
  - defined, 544
  - in FloatFraction class, 442–445
  - hierarchies for safe, 448–451
  - implementing and testing in FloatFraction class, 438–440
  - interfaces implemented via, 462
  - object containment and, 447–448
  - overview of, 435
  - problems in FloatFraction class, 440–441
  - protected members and, 445–446
  - public** keyword for qualifying base classes, 437–438
  - subclassing, 435–437
  - summary, 451–452
  - virtual functions and, 461
- Initialization. See also Constructors
  - of arrays, 119
  - assigning variable values during, 49
  - consistency of, 314–315
  - of Fraction objects from strings, 329–331
  - initializer values in **for** loops, 68–69
  - of types while declaring, 307
- Inline functions
  - addition (+) operator as, 340
  - cannot be virtual, 455
  - constructors as, 308
  - defined, 544
  - of Fraction class, 289–291
  - function modifiers, 501
- Input stream functions. See also I/O (input/output), 528
- insert** function, member functions, 421
- Instance/instantiation
  - abstract classes cannot be used for, 462–463
  - defined, 544
- int** data type. See also Integer data
  - comparing pointer values with **int** variables, 151–152
  - converting strings to, 183
  - "cooked" literals and, 359
  - description and range of, 484
  - natural integer type, 245–246
  - pointer to, 148
  - range compared with **double**, 127
  - reading binary data, 209–210
  - storing numbers with, 485
  - swapping values of two **int** variables, 155–156
  - syntax of, 34
- Integer data
  - address expressions and, 162
  - char** type and, 171
  - comparing with floating point data, 33–34
  - converting strings to, 183
  - data types, 20–21
  - defined, 544
  - division of, 480
  - get\_int** function, 214
  - reading binary data, 209–210
  - short, long, and long long, 244–245
  - signed and unsigned, 245
  - suffixes in representation of, 486
  - two's complement format for signed integers, 487–489

## Interfaces

- abstract classes for specifying and enforcing a set of services, 463–464
- defined, 544
- implementing through class inheritance, 462
- relationship between GUIs and OOP, 279
- safe inheritance in GUIs, 448–451

**ios::app**, file mode flags, 530

**ios::ate**, file mode flags, 530

**ios::beg**, seek direction flags, 530

**ios::binary**, file mode flags, 213, 530

**ios::cur**, seek direction flags, 530

**ios::end**, seek direction flags, 530

**ios::in**, file mode flags, 216, 530

**ios::out**, file mode flags, 213, 530

**ios::trunc**, file mode flags, 530

**is\_open()**, description of file I/O functions, 529

Iteration. See also Loops

- applied to Fibonacci numbers, 250
- creating iterators for List template, 416–418, 534
- defined, 544
- iterative approach to linked list, 400
- pointers compared with iterators, 418
- recursion compared with, 401–402

Iterators, 416–418, 534

## J

join (,) operator

- associativity, precedence, and syntax of, 477
- as delimiters in text, 187
- uses of, 482

## K

Keywords

- defined, 545
- program syntax and, 3
- use by high-level languages, 7
- variable names and, 29

## L

**L** suffix, representing **long int** format, 486

Last-in-first-out. See LIFO (last-in-first-out)

Late binding, resolving address of virtual functions at runtime, 472

LCM (lowest common multiple)

- adding LCM function to Fraction class, 292
- computing from greatest common factors (GCFs), 101
- defined, 545

Left shift and assign (<<=) operator, 477

**left** stream manipulator, 527

Less than (<) operator

- associativity, precedence, and syntax of, 477
- ordered lists and, 419
- types of relational operators, 47

Less than or equal to (<=) operator, 47, 477

LF (linefeed), 513–514

Libraries, C++

- math library, 57
- standard library, 15
- STL (Standard Template Library). See STL (Standard Template Library)

LIFO (last-in-first-out)

- defined, 545
- function calls, 96
- stacks, 425

**#line** directive, 511

Linked lists

- alphabetical, 393–395
- implementing, 391–393
- list template for, 413
- memory leaks in, 399–400
- node design for, 390–391
- overview of, 389
- printing out names in alpha order, 395–399
- smart pointers for cleaning up (C++Ox only), 400–401
- summary, 411–412

Linkers, building a C++ program, 8–9

List classes (<list>)

creating, 415–416

in STL, 533–534

syntax of, 415

List template

continual sorting, 421–422

creating iterators for, 416–418

creating List class for, 415–416

overview of, 413–414

range-based for (for each) used in place of iterators, 418

writing ordered list program, 419–421

Lists, as container for range-based for, 257

Literals

64-bit literals (constants), 246–247

cooked literals, 359

data types of, 485–486

defined, 545

overview of, 357

raw string literals, 244, 273, 358

user-defined, 330–331, 464

**LL** suffix, representing **long long** format, 486

Local variables

declaring functions and, 93–95

defined, 545

Localizing numbers, 254–255

Logical (Boolean) operators

determining what is true, 55

precedence of, 54

testing a person's age (example of Boolean logic), 55–56

type of, 53–54

Logical negation (!) operator

associativity, precedence, and syntax of, 476

swap function and, 161

types of Boolean operators, 54

**long double** int, 484

**long** int

32-bit, 244–245

description and range of, 484

**l** suffix for, 486

**long long** int

64-bit, 244–245

challenges of, 247–248

C++0x specification supporting, 34, 244–246

description and range of, 484

formatting **long long** numbers, 248–249

**LL** suffix for, 486

overview of, 243

syntax of, 245

Loops

2-D arrays and, 142–143

in Card Dealer #3, 139

counting with, 67–68, 545

defined, 545

**do\_while**, 230–232

**for**. See **for** loops

increment operator (++) used in, 51–52

infinite, 46, 205

in prime factorization, 99–100

print 1 to N example, 46–49

testing randomness with, 126–127

using **strtok** function with, 188

using swap function for sorting, 157–161

using with arrays, 117, 121–123

**while** loops, 43–45

Lowest common multiple. See LCM (lowest common multiple)

Lukasiewicz, Jan, 424

Lvalue, 545

## M

Machine code

array indexing and, 120

defined, 5, 545–546

high-level languages and, 7

native language of computer (1s and 0s), 3

translating statements into, 170–171

Magic numbers, minimizing appearance of, 254

- main** function
  - defined, 546
  - prompting for filenames, 202
- Main memory (RAM)
  - defined, 546
  - nonpersistence of, 197
- Math library (cmath)
  - accessing, 57
  - functions in, 520
  - including, 181
- Matrix, 2-D arrays and, 142–143
- MAX\_PATH, setting for filename length, 202
- Member functions
  - constructors as, 307
  - declaring for Point class, 282–283
  - defined, 546
  - destructors as, 370
  - of Fraction class, 287
  - friend functions and, 337–338
  - inlining, 290–291
  - in List classes (<list>), 534
  - operators as, 333–334
  - overriding, 453–454
  - push\_back**, 415
  - push\_front**, 416
  - returning existing objects vs. returning new objects, 382
  - sort**, 421
  - in Stack classes (<stack>), 536
  - in string class (<string>), 532–533
  - syntax of, 283
- Members
  - assigning values to class data fields, 280
  - defined, 541, 546
  - initializing within a class (C++0x only), 309–310
  - private, 281–284
  - protected, 445–446
  - public, 279
  - relationship with objects and classes, 284
  - restricting access to, 287
  - structures and, 281
- Memory
  - allocating blocks of, 366–367
  - defined, 546
  - dynamic allocation. See Dynamic memory allocation
  - RAM (random access memory), 197
- Memory leaks
  - in linked lists, 399–400
  - overview of, 368
- Microsoft Visual Studio, 12–13
- Minus (-) operator. See Change sign of (-) operator
- Modules
  - advantages of multiple, 235–236
  - defined, 546
  - overview of, 234
  - source files as, 241
- Modulus or remainder operator (%)
  - associativity, precedence, and syntax of, 476
  - declaring, 335–336
  - prime number function and, 92
  - random number generation and, 113
  - using in Odd-or-Even program, 41–42
- mult function
  - adding arithmetic functions to Fraction class, 300–305
  - refining in Fraction class, 347–348
- Multi-dimensional arrays, 142–143
- Multiple constructors (overloading), 309
- Multiple modules, 234–236
- Multiply and assign (\*=) operator, 477
- Multiply (\*) operator, 476
- MyStack class, Tower of Hanoi example
  - creating, 403–404
  - using, 404–405
- N**
- NAK (no acknowledgment), 513–514
- Namespaces, **std** namespace, 414
- Nesting
  - defined, 546
  - nested loops, 160

- new** operator
  - allocating memory blocks with, 366–367
  - associativity, precedence, and syntax of, 476
  - creating node with, 391
  - dealing with problems in memory allocation, 368
  - dynamic memory allocation and, 363–364
  - example allocating array of any size, 369–370
  - pointers to objects and, 365–366
  - syntax of, 315
- Newline character
  - for advancing to next print line, 16–18
  - defined, 546
- NIM (Subtraction Game)
  - decision making example, 60–63
  - function for enhancing, 113–115
- nboolalpha** stream manipulator, 527
- Nodes, designing for linked lists, 390–391
- Normalize function
  - adding support functions to Fraction class, 293–296
  - overriding, 453–454, 457, 459–460
  - set function calling, 350
- noshowbase** stream manipulator, 527
- noshowpoint** stream manipulator, 527
- NOT (!) operator. See Logical negation (!) operator
- nounitbuf** stream manipulator, 527
- nouppercase** stream manipulator, 527
- Null-terminated strings, 189
- NULL values
  - NUL character code, 513–514
  - random number generator and, 112
  - use with **strtok()** function, 187
  - use with **time()** function, 112
- nullptr** keyword
  - in C++0x specification, 112, 187
  - linked lists and, 390–391
  - setting null pointers with, 244
  - uses of, 262–263
- num
  - protected members of FloatFraction class, 445–446
  - variable names and, 28
- Numbers
  - base 10. See Decimal notation (base 10)
  - base 16. See Hexadecimal notation (base 16)
  - base 2. See Binary notation (base 2)
  - converting numeric values into text characters, 169–170
  - counting, 67–68
  - Fibonacci numbers, 250–254
  - function for prime factorization, 96–100
  - function for prime numbers, 90–93
  - Get a Number program (example), 180–183
  - get\_number function, 181
  - localizing, 254–255
  - lowest divisor as prime number, 100–101
  - numeric data types, 20–21
  - numeric expressions in single quotes, 186
  - printing from 1 to N with **for** loop, 72–73
  - printing from 1 to N with **while** loop, 46–49
  - random number generator, 110–113
  - storing, 485
  - testing for prime numbers with **for** loops, 75–79
  - testing for prime numbers with **while** loops, 57–60
- O**
- Object containment, as alternative to inheritance, 447–448

Object independence. See Polymorphism

## Objects

- built-in behaviors, 453
- class destructors, 370–371
- in classes, 277–278
- console stream objects, 525–526
- defined, 178–179, 546
- as individual data items within classes, 277
- initializing from strings, 329–331
- pointers to, 365–366
- quasi-intelligence of, 278
- relationship with classes and members, 284
- this** keyword as pointer to current object, 378

**oct** stream manipulator, 527

Octal notation (base 8), 485

Odd-or-Even program, 39–42

Offsets, arrays as measure of, 119–120

**ofstream** (file-output), 198–200

One-based indexing, 120, 547

OOP (object-oriented programming)

- advantages of, 278
- classes in, 277
- comparing C++ with C, 7
- defined, 547
- history of, 278–279
- linked list example. See Linked lists
- multiple modules and, 236
- object independence. See Polymorphism
- overloading and, 228
- stream classes demonstrating
  - extensibility of, 464–466
- system orientation of, 472
- Tower of Hanoi animation example. See Tower of Hanoi, animated
- using objects without knowing type or what function it calls, 470–471

**open()**, file I/O function, 529

Operand, 547

**operator+** function, writing for String class, 381–386

Operators. See also by individual type

- associativity, precedence, and syntax of, 476–477
- declaring, 334–336
- defined, 547
- for Fraction class, 343–348, 352–357
- as global functions, 336–338
- overloading, 228, 348–349
- for Point class, 340–343
- print function for class, 351–352
- in Random-Access Write example, 213
- references used with, 338–340
- summary, 360–362
- syntax of, 333
- user-defined literals (C++Ox only), 357–359

Optimization, of programs, 26–27

OR (||) operator

- in Subtraction Game example (NIM), 63
- types of Boolean operators, 54

Ordered list program, 419–421

**ostream** class, 351–352

Output stream functions. See also I/O (input/output), 528

Overloading

- constructors, 309
- defined, 547
- functions, 227–228
- object orientation and, 228
- operators, 335, 348–349
- print\_array function (example), 228–230

**override** keyword, 461

Overriding

- member functions, 453–454
- normalize function, 453–454, 457, 459–460
- requiring explicit (C++Ox only), 460–461

- P**
- Pascal
- adding OOP extensions to, 279
  - purpose of high-level languages, 7
- Pathnames, in referencing disk files, 200
- peek()**, stream input function, 528
- Performance penalty, in use of virtual functions, 455–456
- Persistent memory
- defined, 547
  - nonpersistence of RAM, 197
  - polymorphism and, 459–460
- Placeholders, program syntax and, 3
- Point class
- constructors for, 315–317
  - copy constructors for, 324
  - declaring, 279–280
  - operators for, 340–343
  - private members of, 281–284
  - testing, 284–286
- Pointer arithmetic, 162
- Pointer indirection (\*), 149, 166
- Pointer-to-member (->\*) operator, 476
- Pointer-to-member (.\* ) operator, 476
- Pointers
- array processing and, 163–164
  - assigning values to pointer variables, 161–163
  - comparing pointer values, 151–152
  - concept of, 146
  - declaring and using, 148–150
  - defined, 547
  - delete**, 364–365
  - double\_it function and, 152–155
  - iterators compared with, 418
  - linked lists and, 391–393
  - new**, 364
  - null, see **nullptr** keyword
  - to objects, 365–366
  - overview of, 145–146
  - recasting, 209
  - smart pointers (C++Ox only), 400–401
  - string manipulation functions and, 172
  - summary of rules regarding, 168
  - swap function and, 155–156
  - swap function for sorting arrays, 156–161
  - this** keyword, 378
  - zero\_out\_array function, 165–167
- Polish Notation. See also RPN (Reverse Polish Notation), 424
- Polymorphism
- abstract classes, 462–464
  - benefits of OOP, 278
  - defined, 548
  - incomplete type information and, 228
  - making a floating point value persistent and recalculating as needed, 459–460
  - overriding member functions and, 453–454
  - Printable class example, 466–470
  - pure virtual functions, 461–462
  - requiring explicit overrides (C++Ox only), 460–461
  - revised FloatFraction class using virtual functions, 456–458
  - stream classes demonstrating extensibility of OOP, 464–466
  - summary, 472–473
  - system orientation of OOP and, 472
  - trade offs in use of virtual function calls, 455–456
  - using object without knowing type or what function it calls, 470–471
  - virtual functions in FloatFraction class, 454–455
- Precedence
- defined, 548
  - in evaluation of expressions, 166–167
  - of operators, 54, 476
- Precision of data types, 484
- precision()**, output stream function, 528

- Predefined constants
  - advantages of, 226
  - list of, 512
  - use of, 225
- Preprocessor directives
  - ## (concatenation)** operator, 507
  - #define**. See **#define** directive
  - defined function, 507
  - definition of, 542
  - #elif**, 507–508
  - #endif**, 508
  - #error**, 508
  - #if**, 508–509
  - #ifdef**, 510
  - #include**. See **#include**
  - #line**, 511
  - overview of, 505
  - #undef**, 511
- Prime factorization function, 96–100
- Prime numbers
  - function for, 90–93
  - lowest divisor as, 100–101
  - testing for with **for** loops, 75–79
  - testing for with **while** loops, 57–60
- Print function, as class operator, 351–352
- Printable class example, true polymorphism in, 466–470
- Print\_array function, example of function overloading, 228–230
- Printing
  - advancing to next print line (newline), 16–18
  - array elements, 121–123
  - building ability to print into objects, 465
  - multiple line programs, 16–18
  - names in alpha order, 395–399
  - numbers from 1 to N with **for** loop, 72–73
  - numbers from 1 to N with **while** loop, 46–49
  - printing a message (example), 11–14
- private** keyword
  - access levels in C++, 446
  - in class declaration, 502
- Private members
  - access levels in C++, 446
  - of Fraction class, 287
  - friend functions and, 337–338
  - of Point class, 281–284
- Private/public distinction, encapsulation and, 236
- Procedures. See Functions
- Processors. See CPUs (central processing units)
- Program-logic errors
  - exception handling, 237
  - testing for, 9–10
- Programming
  - computer do only what you tell them, 1
  - determining what a program will do, 1–2
  - exercises, 15
  - printing a message (example), 11–14
  - writing C++ statements, 2–3
- Programming, advanced
  - advantages of predefined constants, 226
  - command-line arguments, 221–222
  - displaying files from command line, 223–226
  - do\_while loops, 230–232
  - exception handling, 237–240
  - multiple modules, 234–236
  - overloading functions, 227–228
  - overview of, 221
  - print\_array function (example), 228–230
  - summary, 240–242
  - switch case statements, 232–234
- Programs
  - building a C++ program, 8–10
  - comments in, 23–24
  - compared with applications and code, 5
  - decision making in, 34–35
  - defined, 6, 548

- determining what a program will do, 1–2
- as list of things for computer to do, 1
- optimization of, 26–27
- printing multiple line programs, 16–18

Projects, Microsoft Visual Studio, 12–13

**protected** keyword

- in class declaration, 502
- overriding functions and, 455

Protected members, of `FloatFraction` class, 445–446

Prototypes

- `avg()` example, 87–88
- calling functions and, 235
- declaring functions, 85
- declaring global functions, 336
- defined, 548
- ending with semicolon, 119
- of `Fraction` class, 288–289
- syntax of, 501

Pseudocode, 3

Pseudorandom sequences, 112

**public** keyword

- access levels in C++, 446
- in class declaration, 502
- specifying access level for base classes, 437–438

Public members

- access levels in C++, 446
- declaring classes and, 280
- of `Fraction` class, 287
- of structures, 281

Public/private distinction, encapsulation and, 236

Pure virtual functions. See also Virtual functions, 461–462, 548

**push** function, 433

**push\_back** member function, 415

**push\_front** member function, 416

**put()**, output stream function, 528

**putback()**, input stream function, 528

## Q

Quotation marks (" ")

- distinguishing strings from individual characters, 185
- in **#include** syntax, 510

## R

RAM (random access memory)

- defined, 546
- nonpersistence of, 197

**rand** function

- in `Card Dealer #2`, 134
- for random number generation, 112–113
- testing randomness with arrays, 123–127

Random access

- Random-Access Read example, 214–217
- Random-Access Write example, 211–214

Random access memory (RAM)

- defined, 546
- nonpersistence of, 197

Random number generator, 110–113

Randomized functions, in standard library, 521

Randomness, testing with arrays, 123–127

Range-based `for` (for each)

- defined, 243
- overview of, 256–258
- setting array using, 258–261
- using with `List` template, 418

Ranges of data types, 484

Rational number class. See `Fraction` class

Raw string literals

- in C++0x specification, 273
- defining, 358
- overview of, 244

**read()**

- description of input stream functions, 528
- input and output of binary data and, 210

readfile commands, 224

**Reading**

- binary data from files, 214–217
- string input, 178–180

**Records, finding by number, 213–214****Recursion**

- applying to Fibonacci numbers, 250
- defined, 548
- function calling itself, 95–96
- iteration compared with, 401–402
- prime factorization, 96–100
- Tower of Hanoi puzzle, 106–110, 408

**References**

- copy constructors and, 325
- defined, 548–549
- operators used with, 338–340
- reference arguments, 322–323
- reference variables, 321–322

**register** variable modifier, 499–500**reinterpret\_cast** operator, 209**Relational operators**

- Boolean operators, 50
- precedence of, 54
- returning true or false values, 47

**return** statements

- returning values with, 18
- syntax of control structures, 497
- transferring control out of loop or function, 231

**Return \*this** statement, 379–380**Return values**

- compared with pointers, 321
- declaring functions, 85
- defining functions, 85–86
- from functions, 83

**Reusable code**

- inheritance and, 435
- object containment and, 447–448

**Reverse Polish Notation. See RPN (Reverse Polish Notation)****right shift and assign (>>=)** operator, 477**right** stream manipulator, 527**Rock, Paper, Scissors** game, 115, 267–272**RPN (Reverse Polish Notation)**

- designing calculator for, 422–424
- history of Polish Notation, 424
- RPN program, 428–432
- using stack for, 424–426
- using STL stack for, 427–428

**Runtime errors, 237****S****Scaling, pointers and, 162****scientific**, description of stream manipulators, 527**Scientific notation, 485****Scope**

- associativity, precedence, and syntax of, 476
- defined, 549
- uses of Scope (::) operator, 478

**Seek direction flags, file I/O functions, 530****seekg()**, file I/O function, 529**seekp()**, file I/O function, 529**seekp** function, for moving file pointer, 214, 216**Set** function, normalize function called by, 350**Shallow copying, 376–377****shared\_ptr** keyword, for smart pointers, 400–401**short**

- 16-bit integers (short), 244–245
- description and range of, 484

**Short-circuit logic, logical (Boolean) operators and, 54–55****showbase** stream manipulator, 527**showpoint** stream manipulator, 527**showpos** stream manipulator, 527**signed char, 484****signed int**

- overview of, 247
- two's complement format for, 487–489
- types of integer data, 245

- Signed numbers, representation of, 487-489
- Single-character functions, in standard library, 519
- Single-precision types. See **float**
- Single quotes ( ' '), distinguishing strings from individual characters, 185
- sizeof** operator
  - associativity, precedence, and syntax of, 476
  - returning size of specified type, variable, or array, 211
  - uses of, 478-479
- Smart pointers (C++0x only), 400-401
- sort**
  - as power member function, 421
  - sorting lists, 421-422
- Source code
  - compiling as machine code, 5
  - defined, 6
  - storing as text file, 170
- Source files
  - defined, 549
  - modules and, 235, 241
- Space penalty, in use of virtual functions, 455-456
- Spaces, as delimiters in text, 187
- Spaghetti code, 497
- sqrt** function
  - in math library, 57
  - testing for prime numbers with **for** loops, 75-79
  - testing for prime numbers with **while** loops, 57-60
- Square roots, Get a Number program (example), 180-183
- Stack classes (<stack>), in STL, 425, 427-428, 535-536
- Stacks
  - defined, 549
  - of function calls, 96
- Standard (infix) notation, 423
- Standard library
  - character conversion functions, 519
  - character-testing functions, 519
  - data-conversion functions, 518
  - math functions, 520
  - overview of, 15
  - randomized functions, 521
  - single-character functions, 519
  - str functions, 175
  - strftime** function, formats of, 523-524
  - strtok** (string token) function, 186-188
  - time functions, 521-523
- Statements. See also by individual type
  - compound. See Compound statements (blocks)
  - defined, 6, 549
  - entering program statements, 8
  - expressions compared with, 52-53
  - functions grouping related, 83
  - replacing control structures with statement blocks, 231
  - switch case statements, 232-234
  - syntax of, 492
  - translating into machine code, 170-171
  - writing C++ statements, 2-3
- static**
  - function modifiers, 501
  - variable modifiers, 499-500
- Static storage class, 549
- Static\_cast** conversion, 265-266
- std** namespace, 414
- STL (Standard Template Library)
  - continual sorting of list, 421-422
  - creating iterators for list, 416-418
  - creating List class, 415-416
  - defined, 549
  - List classes (<list>), 533-534
  - list template, 413-414
  - object-orientation of, 279

- STL (Standard Template Library) (*continued*)
  - overview of, 413
  - range-based for (for each) used in place of iterators, 418
  - Reverse Polish Notation (RPN)
    - calculator, 422–424
  - RPN program, 428–432
  - stack classes (<stack>), 425, 427–428, 535–536
  - string (C-strings) functions, 517–518
  - string class (<string>), 531–533
  - stringstream** (substr) class, 248–249
  - summary, 432–433
  - writing ordered list program, 419–421
  - writing templates, 414–415
- Storage
  - controlling using enum classes, 266–267
  - of data in files, 197
  - Storage classes, 550
- strcat** function, concatenation of strings, 172–173
- strcmp** function, comparing strings, 375
- strcpy**
  - building strings, 176
  - copying strings, 172–173
- Stream classes
  - demonstrating extensibility of OOP, 464–466
  - Printable class example, 466–470
- Stream input operator (>>), 180
- Streams
  - console input. See **cin**
  - console output. See **cout**
  - console stream objects, 525–526
  - file I/O functions, 529–530
  - input stream functions, 528
  - manipulators, 526–527
  - output stream functions, 528
  - stringstream** (substr) class, 248–249
- Strftime** function, in standard library, 523–524
- String class (C-strings)
  - complete version of, 382–386
  - deep copying, 377
  - shallow copying, 376–377
  - summary, 387–388
  - writing concatenation function for, 380–382
  - writing own, 371–376
- String class (<string>), 189–191, 531–533
- String concatenation
  - defined, 551
  - strcat** and **strncat** functions for, 172–174
  - working with string type and, 193
  - writing concatenation function for string class, 380–382
- String literals
  - defined, 550
  - format and escape sequences, 486–487
  - raw string literals, 244, 273
- String objects, as container for range-based for, 257
- Strings (C-strings)
  - arrays in Card Dealer #1, 129–132
  - arrays of, 128–129
  - based on **char** type, 171–172
  - building, 174–177
  - building with STL string type, 191–193
  - comparing (**strcmp**), 375
  - Convert to Uppercase program (example), 183–185
  - defined, 539, 550
  - distinguished from individual characters, 185–186
  - escape sequences, 177–178
  - format and escape sequences, 486–487
  - functions for manipulating, 172–174
  - functions in standard library, 517
  - Get a Number program (example), 180–183
  - including, 175, 181

- initializing Fraction objects from, 329–331
  - overview of, 169
  - reading string input, 178–180
  - storing text on computers, 169–170
  - string literals and string variables, 128
  - strtok** function for breaking up input, 186–188
  - summary, 194–195
  - of text, 18–19
  - text string data, 20–21
- Strings (<string>)
- building strings with, 191–193
  - declaring variables of, 189–190
  - input and output and, 191
  - new in C++, 189
  - new STL string class, 189–191
  - other operations on, 193–194
  - other operations on STL string type, 193–194
  - working with variables of, 190–191
- strlen** function, returning string length, 172
- strncat** function, concatenation of strings, 172, 174
- strncpy** function, copying strings, 172, 174
- Strongly typed enumerations, 244, 263–265
- Strousup, Bjarne, 243, 279
- strtok** (string token) function
- for breaking up text input, 186–188
  - returning null pointer, 330
  - setting using **nullptr** keyword, 263
- struct** keyword
- declaring structures, 281
  - issues with, 312–313
- Structures, classes compared with, 281
- Subclasses. See also Inheritance
- abstract classes and, 463–464
  - declaring, 279
  - defined, 550
  - how to subclass, 435–437
  - not inheriting constructors from base class, 440
  - principle of passing something specific (subclass) to something more general (base class), 466
  - virtual functions and, 455
- Subroutines. See Functions
- stringstream** (substr) class, 248–249
- Subtraction (-) operator
- adding to Point class, 342–343
  - associativity, precedence, and syntax of, 476
- Subtraction Game (NIM)
- decision making example, 60–63
  - function for enhancing, 113–115
- Suffixes
- operators, 358–359
  - in representation of integer values, 486
- Swap function
- overloading, 227–228
  - sorting arrays with, 156–161
  - swapping values of two **int** variables, 155–156
- switch-case** statements
- in advanced programming, 232–234
  - syntax of, 495–496
- Symbols
- automating assignment of symbolic constants, 264–265
  - defined, 550
  - enum** classes and, 266, 503
  - literals compared with, 485
- Syntax
- errors, 9–10, 237
  - summary of, 491–504
- Systems
- OOP and, 472
  - polymorphism and, 465
- T**
- tellg**( ) function, file I/O, 529
- tellp**( ) function, file I/O, 529
- temp variable, 155–156

- Temperature, converting Celsius to/from Fahrenheit, 22–26
  - Templates. See also STL (Standard Template Library)
    - defined, 550
    - as generalized classes, 413
    - writing own, 414–415
  - Testing
    - Fraction class, 296–300
    - Point class, 284–286
    - for prime numbers, 57–60
    - programs, 9–10
    - randomness with arrays, 123–127
  - Text
    - delimiters in, 186
    - displaying text files, 203–206
    - storing on computers, 169–170
    - strings of, 18–19
    - strtok** function for breaking up input, 186–188
    - text files vs. binary files, 206–208
    - text files vs. "binary" files, 206–208
    - writing to files, 200–203
  - Text editors
    - displaying text files, 203–206
    - entering program statements with, 8
    - viewing file contents, 201
  - Text string data. See Strings (C-strings)
  - this** keyword
    - as pointer to current object, 378
    - return \*this** statement as last statement in assignment operator function, 379–380
  - throw** statements
    - exception handling and, 239–240
    - syntax of control structures, 497
  - Time functions, in standard library, 521–523
  - Tokens, substrings, 186
  - tolower** (c) function, 184–185
  - toupper** (c) function, 184–185
  - Tower of Hanoi, animated version
    - building, 405–411
    - creating MyStack class, 403–404
    - overview of, 402–403
    - summary, 411–412
    - using MyStack class, 404–405
  - Tower of Hanoi, basic version, 106–110
  - Trigonometric functions, 520
  - True/false. See Boolean values (true/false)
  - try** keyword, exception handling and, 238–240
  - Two's complement
    - defined, 551
    - format for signed integers, 487–489
    - integers and, 33
  - Type casts. See Casts
  - Type checking, in OOP, 471
  - Types. See Data types
- ## U
- U** suffix, representing **unsigned int** format, 486
  - ULL** suffix, representing **unsigned long long** format, 486
  - #undef** directive, 511
  - Unicode, 170
  - unitbuf**, stream manipulator, 527
  - unsigned char**, 484
  - unsigned int**
    - description and range of, 484
    - overview of, 247
    - types of integer data, 245
    - u** suffix, 486
  - unsigned long**, 484
  - unsigned long long**, 484, 486
  - unsigned short**, 484
  - uppercase**, stream manipulator, 527
  - User-defined functions, 85
  - User-defined literals (C++0x only), 357–359, 464
  - Users, defined, 6, 542

using statement  
  accessing objects with, 16  
  working with string type and, 192

## V

### Variables

- assigning values to pointer variables, 161–163
- content vs. address of, 151–152
- declaring, 498–500
- declaring on the fly, 74–75
- declaring prior to use, 20
- declaring with **auto** keyword, 261–262
- defined, 551
- doubling with `double_it` function, 152–155
- local and global variables, 93–95
- naming rules and conventions, 28–29
- sharing, 235
- storing data with, 19–20
- string variables, 128, 189–191
- swapping values of two **int** variables, 155–156

### Virtual functions

- in abstract classes, 462–463
- declaring member functions that might be overridden **virtual**, 454–455
- defined, 551
- late binding, 472
- pure virtual functions, 461–462
- restrictions on use of, 455
- revised `FloatFraction` class using, 456–458
- trade offs in use of, 455–456

**virtual** keyword, as function modifiers, 454–455, 501

Visual Basic, 7

**volatile**, variable modifier, 499–500  
vtable pointer, for calling virtual functions, 456

## W

**wcerr**, stream object, 526

**wchar\_t**, 484

**wcin**, stream object, 526

**wclog**, stream object, 526

**wcout**, stream object, 526

**while** loops

- in Card Dealer #3, 140

- iterative approach to linked list, 400

- for** loops compared with, 71–72

- overview of, 43

- print 1 to N loop example, 46–49

- pseudo code for printing numbers from 1 to N, 43–45

- syntax of, 69

- true/false values in, 80

- using **strtok** function with, 188

**while** statements, as control structure, 231, 493–494

**width()** function, stream output, 528

Word processors, 201

**write()** function

- description of output stream functions, 528

- input and output of binary data and, 210

Writing

- binary data to files, 211–214

- text to files, 200–203

## Z

Zero-based indexes

- arrays and, 119–120

- defined, 551

`Zero_out_array` function, 165–166