

Contents

Preface xxv

Chapter 0 Notes to the Reader 1

- 0.1 The structure of this book 2
 - 0.1.1 General approach 3
 - 0.1.2 Drills, exercises, etc. 4
 - 0.1.3 What comes after this book? 5
- 0.2 A philosophy of teaching and learning 6
 - 0.2.1 The order of topics 9
 - 0.2.2 Programming and programming language 10
 - 0.2.3 Portability 11
- 0.3 Programming and computer science 12
- 0.4 Creativity and problem solving 12
- 0.5 Request for feedback 12
- 0.6 References 13
- 0.7 Biographies 13
 - Bjarne Stroustrup 14
 - Lawrence “Pete” Petersen 15

Chapter 1 Computers, People, and Programming 17

- 1.1 Introduction 18
- 1.2 Software 19
- 1.3 People 21
- 1.4 Computer science 24
- 1.5 Computers are everywhere 25
 - 1.5.1 Screens and no screens 26
 - 1.5.2 Shipping 26
 - 1.5.3 Telecommunications 28
 - 1.5.4 Medicine 30

1.5.5	Information	31
1.5.6	A vertical view	33
1.5.7	So what?	34
1.6	Ideals for programmers	34

Part I The Basics 41

Chapter 2 Hello, World! 43

2.1	Programs	44
2.2	The classic first program	45
2.3	Compilation	47
2.4	Linking	51
2.5	Programming environments	52

Chapter 3 Objects, Types, and Values 59

3.1	Input	60
3.2	Variables	62
3.3	Input and type	64
3.4	Operations and operators	66
3.5	Assignment and initialization	69
3.5.1	An example: detect repeated words	71
3.6	Composite assignment operators	73
3.6.1	An example: find repeated words	73
3.7	Names	74
3.8	Types and objects	77
3.9	Type safety	78
3.9.1	Safe conversions	79
3.9.2	Unsafe conversions	80

Chapter 4 Computation 89

4.1	Computation	90
4.2	Objectives and tools	92
4.3	Expressions	94
4.3.1	Constant expressions	95
4.3.2	Operators	97
4.3.3	Conversions	99
4.4	Statements	100
4.4.1	Selection	102
4.4.2	Iteration	109
4.5	Functions	113
4.5.1	Why bother with functions?	115
4.5.2	Function declarations	117

4.6	vector	117
4.6.1	Traversing a vector	119
4.6.2	Growing a vector	119
4.6.3	A numeric example	120
4.6.4	A text example	123
4.7	Language features	125

Chapter 5 Errors 133

5.1	Introduction	134
5.2	Sources of errors	136
5.3	Compile-time errors	136
5.3.1	Syntax errors	137
5.3.2	Type errors	138
5.3.3	Non-errors	139
5.4	Link-time errors	139
5.5	Run-time errors	140
5.5.1	The caller deals with errors	142
5.5.2	The callee deals with errors	143
5.5.3	Error reporting	145
5.6	Exceptions	146
5.6.1	Bad arguments	147
5.6.2	Range errors	148
5.6.3	Bad input	150
5.6.4	Narrowing errors	153
5.7	Logic errors	154
5.8	Estimation	157
5.9	Debugging	158
5.9.1	Practical debug advice	159
5.10	Pre- and post-conditions	163
5.10.1	Post-conditions	165
5.11	Testing	166

Chapter 6 Writing a Program 173

6.1	A problem	174
6.2	Thinking about the problem	175
6.2.1	Stages of development	176
6.2.2	Strategy	176
6.3	Back to the calculator!	178
6.3.1	First attempt	179
6.3.2	Tokens	181
6.3.3	Implementing tokens	183
6.3.4	Using tokens	185
6.3.5	Back to the drawing board	186

6.4	Grammars	188
6.4.1	A detour: English grammar	193
6.4.2	Writing a grammar	194
6.5	Turning a grammar into code	195
6.5.1	Implementing grammar rules	196
6.5.2	Expressions	197
6.5.3	Terms	200
6.5.4	Primary expressions	202
6.6	Trying the first version	203
6.7	Trying the second version	208
6.8	Token streams	209
6.8.1	Implementing <code>Token_stream</code>	211
6.8.2	Reading tokens	212
6.8.3	Reading numbers	214
6.9	Program structure	215

Chapter 7 Completing a Program 221

7.1	Introduction	222
7.2	Input and output	222
7.3	Error handling	224
7.4	Negative numbers	229
7.5	Remainder: <code>%</code>	230
7.6	Cleaning up the code	232
7.6.1	Symbolic constants	232
7.6.2	Use of functions	234
7.6.3	Code layout	235
7.6.4	Commenting	237
7.7	Recovering from errors	239
7.8	Variables	242
7.8.1	Variables and definitions	242
7.8.2	Introducing names	247
7.8.3	Predefined names	250
7.8.4	Are we there yet?	250

Chapter 8 Technicalities: Functions, etc. 255

8.1	Technicalities	256
8.2	Declarations and definitions	257
8.2.1	Kinds of declarations	261
8.2.2	Variable and constant declarations	262
8.2.3	Default initialization	263

- 8.3 Header files 264
- 8.4 Scope 266
- 8.5 Function call and return 272
 - 8.5.1 Declaring arguments and return type 272
 - 8.5.2 Returning a value 274
 - 8.5.3 Pass-by-value 275
 - 8.5.4 Pass-by-**const**-reference 276
 - 8.5.5 Pass-by-reference 279
 - 8.5.6 Pass-by-value vs. pass-by-reference 281
 - 8.5.7 Argument checking and conversion 284
 - 8.5.8 Function call implementation 285
 - 8.5.9 **constexpr** functions 290
- 8.6 Order of evaluation 291
 - 8.6.1 Expression evaluation 292
 - 8.6.2 Global initialization 293
- 8.7 Namespaces 294
 - 8.7.1 **using** declarations and **using** directives 296

Chapter 9 Technicalities: Classes, etc. 303

- 9.1 User-defined types 304
- 9.2 Classes and members 305
- 9.3 Interface and implementation 306
- 9.4 Evolving a class 308
 - 9.4.1 **struct** and functions 308
 - 9.4.2 Member functions and constructors 310
 - 9.4.3 Keep details private 312
 - 9.4.4 Defining member functions 314
 - 9.4.5 Referring to the current object 317
 - 9.4.6 Reporting errors 317
- 9.5 Enumerations 318
 - 9.5.1 “Plain” enumerations 320
- 9.6 Operator overloading 321
- 9.7 Class interfaces 323
 - 9.7.1 Argument types 324
 - 9.7.2 Copying 326
 - 9.7.3 Default constructors 327
 - 9.7.4 **const** member functions 330
 - 9.7.5 Members and “helper functions” 332
- 9.8 The **Date** class 334

Part II Input and Output 343

Chapter 10 Input and Output Streams 345

- 10.1 Input and output 346
- 10.2 The I/O stream model 347
- 10.3 Files 349
- 10.4 Opening a file 350
- 10.5 Reading and writing a file 352
- 10.6 I/O error handling 354
- 10.7 Reading a single value 358
 - 10.7.1 Breaking the problem into manageable parts 359
 - 10.7.2 Separating dialog from function 362
- 10.8 User-defined output operators 363
- 10.9 User-defined input operators 365
- 10.10 A standard input loop 365
- 10.11 Reading a structured file 367
 - 10.11.1 In-memory representation 368
 - 10.11.2 Reading structured values 370
 - 10.11.3 Changing representations 374

Chapter 11 Customizing Input and Output 379

- 11.1 Regularity and irregularity 380
- 11.2 Output formatting 380
 - 11.2.1 Integer output 381
 - 11.2.2 Integer input 383
 - 11.2.3 Floating-point output 384
 - 11.2.4 Precision 385
 - 11.2.5 Fields 387
- 11.3 File opening and positioning 388
 - 11.3.1 File open modes 388
 - 11.3.2 Binary files 390
 - 11.3.3 Positioning in files 393
- 11.4 String streams 394
- 11.5 Line-oriented input 395
- 11.6 Character classification 396
- 11.7 Using nonstandard separators 398
- 11.8 And there is so much more 406

Chapter 12 A Display Model 411

- 12.1 Why graphics? 412
- 12.2 A display model 413
- 12.3 A first example 414

- 12.4 Using a GUI library 418
- 12.5 Coordinates 419
- 12.6 **Shapes** 420
- 12.7 Using **Shape** primitives 421
 - 12.7.1 Graphics headers and **main** 421
 - 12.7.2 An almost blank window 422
 - 12.7.3 **Axis** 424
 - 12.7.4 Graphing a function 426
 - 12.7.5 **Polygons** 427
 - 12.7.6 **Rectangles** 428
 - 12.7.7 Fill 431
 - 12.7.8 **Text** 431
 - 12.7.9 **Images** 433
 - 12.7.10 And much more 434
- 12.8 Getting this to run 435
- 12.8.1 Source files 437

Chapter 13 **Graphics Classes** 441

- 13.1 Overview of graphics classes 442
- 13.2 **Point** and **Line** 444
- 13.3 **Lines** 447
- 13.4 **Color** 450
- 13.5 **Line_style** 452
- 13.6 **Open_polyline** 455
- 13.7 **Closed_polyline** 456
- 13.8 **Polygon** 458
- 13.9 **Rectangle** 460
- 13.10 Managing unnamed objects 465
- 13.11 **Text** 467
- 13.12 **Circle** 470
- 13.13 **Ellipse** 472
- 13.14 **Marked_polyline** 474
- 13.15 **Marks** 476
- 13.16 **Mark** 478
- 13.17 **Images** 479

Chapter 14 **Graphics Class Design** 487

- 14.1 Design principles 488
 - 14.1.1 Types 488
 - 14.1.2 Operations 490
 - 14.1.3 Naming 491
 - 14.1.4 Mutability 492

- 14.2 **Shape** 493
 - 14.2.1 An abstract class 495
 - 14.2.2 Access control 496
 - 14.2.3 Drawing shapes 500
 - 14.2.4 Copying and mutability 503
- 14.3 Base and derived classes 504
 - 14.3.1 Object layout 506
 - 14.3.2 Deriving classes and defining virtual functions 507
 - 14.3.3 Overriding 508
 - 14.3.4 Access 511
 - 14.3.5 Pure virtual functions 512
- 14.4 Benefits of object-oriented programming 513

Chapter 15 Graphing Functions and Data 519

- 15.1 Introduction 520
- 15.2 Graphing simple functions 520
- 15.3 **Function** 524
 - 15.3.1 Default Arguments 525
 - 15.3.2 More examples 527
 - 15.3.3 Lambda expressions 528
- 15.4 **Axis** 529
- 15.5 Approximation 532
- 15.6 Graphing data 537
 - 15.6.1 Reading a file 539
 - 15.6.2 General layout 541
 - 15.6.3 Scaling data 542
 - 15.6.4 Building the graph 543

Chapter 16 Graphical User Interfaces 551

- 16.1 User interface alternatives 552
- 16.2 The “Next” button 553
- 16.3 A simple window 554
 - 16.3.1 A callback function 556
 - 16.3.2 A wait loop 559
 - 16.3.3 A lambda expression as a callback 560
- 16.4 **Button** and other **Widgets** 561
 - 16.4.1 **Widgets** 561
 - 16.4.2 **Buttons** 563
 - 16.4.3 **In_box** and **Out_box** 563
 - 16.4.4 **Menus** 564
- 16.5 An example 565

- 16.6 Control inversion 569
- 16.7 Adding a menu 570
- 16.8 Debugging GUI code 575

Part III Data and Algorithms 581

Chapter 17 Vector and Free Store 583

- 17.1 Introduction 584
- 17.2 `vector` basics 586
- 17.3 Memory, addresses, and pointers 588
 - 17.3.1 The `sizeof` operator 590
- 17.4 Free store and pointers 591
 - 17.4.1 Free-store allocation 593
 - 17.4.2 Access through pointers 594
 - 17.4.3 Ranges 595
 - 17.4.4 Initialization 596
 - 17.4.5 The null pointer 598
 - 17.4.6 Free-store deallocation 598
- 17.5 Destructors 601
 - 17.5.1 Generated destructors 603
 - 17.5.2 Destructors and free store 604
- 17.6 Access to elements 605
- 17.7 Pointers to class objects 606
- 17.8 Messing with types: `void*` and casts 608
- 17.9 Pointers and references 610
 - 17.9.1 Pointer and reference parameters 611
 - 17.9.2 Pointers, references, and inheritance 612
 - 17.9.3 An example: lists 613
 - 17.9.4 List operations 615
 - 17.9.5 List use 616
- 17.10 The `this` pointer 618
 - 17.10.1 More link use 620

Chapter 18 Vectors and Arrays 627

- 18.1 Introduction 628
- 18.2 Initialization 629
- 18.3 Copying 631
 - 18.3.1 Copy constructors 633
 - 18.3.2 Copy assignments 634
 - 18.3.3 Copy terminology 636
 - 18.3.4 Moving 637

18.4	Essential operations	640
18.4.1	Explicit constructors	642
18.4.2	Debugging constructors and destructors	643
18.5	Access to <code>vector</code> elements	646
18.5.1	Overloading on <code>const</code>	647
18.6	Arrays	648
18.6.1	Pointers to array elements	650
18.6.2	Pointers and arrays	652
18.6.3	Array initialization	654
18.6.4	Pointer problems	656
18.7	Examples: palindrome	659
18.7.1	Palindromes using <code>string</code>	659
18.7.2	Palindromes using arrays	660
18.7.3	Palindromes using pointers	661

Chapter 19 Vector, Templates, and Exceptions 667

19.1	The problems	668
19.2	Changing size	671
19.2.1	Representation	671
19.2.2	<code>reserve</code> and <code>capacity</code>	673
19.2.3	<code>resize</code>	674
19.2.4	<code>push_back</code>	674
19.2.5	Assignment	675
19.2.6	Our <code>vector</code> so far	677
19.3	Templates	678
19.3.1	Types as template parameters	679
19.3.2	Generic programming	681
19.3.3	Concepts	683
19.3.4	Containers and inheritance	686
19.3.5	Integers as template parameters	687
19.3.6	Template argument deduction	689
19.3.7	Generalizing <code>vector</code>	690
19.4	Range checking and exceptions	693
19.4.1	An aside: design considerations	694
19.4.2	A confession: macros	696
19.5	Resources and exceptions	697
19.5.1	Potential resource management problems	698
19.5.2	Resource acquisition is initialization	700
19.5.3	Guarantees	701
19.5.4	<code>unique_ptr</code>	703
19.5.5	Return by moving	704
19.5.6	RAII for <code>vector</code>	705

Chapter 20 Containers and Iterators 711

- 20.1 Storing and processing data 712
 - 20.1.1 Working with data 713
 - 20.1.2 Generalizing code 714
- 20.2 STL ideals 717
- 20.3 Sequences and iterators 720
 - 20.3.1 Back to the example 723
- 20.4 Linked lists 724
 - 20.4.1 List operations 726
 - 20.4.2 Iteration 727
- 20.5 Generalizing `vector` yet again 729
 - 20.5.1 Container traversal 732
 - 20.5.2 `auto` 732
- 20.6 An example: a simple text editor 734
 - 20.6.1 Lines 736
 - 20.6.2 Iteration 737
- 20.7 `vector`, `list`, and `string` 741
 - 20.7.1 `insert` and `erase` 742
- 20.8 Adapting our `vector` to the STL 745
- 20.9 Adapting built-in arrays to the STL 747
- 20.10 Container overview 749
 - 20.10.1 Iterator categories 751

Chapter 21 Algorithms and Maps 757

- 21.1 Standard library algorithms 758
- 21.2 The simplest algorithm: `find()` 759
 - 21.2.1 Some generic uses 761
- 21.3 The general search: `find_if()` 763
- 21.4 Function objects 765
 - 21.4.1 An abstract view of function objects 766
 - 21.4.2 Predicates on class members 767
 - 21.4.3 Lambda expressions 769
- 21.5 Numerical algorithms 770
 - 21.5.1 Accumulate 770
 - 21.5.2 Generalizing `accumulate()` 772
 - 21.5.3 `Inner product` 774
 - 21.5.4 Generalizing `inner_product()` 775
- 21.6 Associative containers 776
 - 21.6.1 `map` 776
 - 21.6.2 `map` overview 779
 - 21.6.3 Another `map` example 782
 - 21.6.4 `unordered_map` 785
 - 21.6.5 `set` 787

21.7	Copying	789
21.7.1	Copy	789
21.7.2	Stream iterators	790
21.7.3	Using a <code>set</code> to keep order	793
21.7.4	<code>copy_if</code>	794
21.8	Sorting and searching	794
21.9	Container algorithms	797

Part IV Broadening the View 803

Chapter 22 Ideals and History 805

22.1	History, ideals, and professionalism	806
22.1.1	Programming language aims and philosophies	807
22.1.2	Programming ideals	808
22.1.3	Styles/paradigms	815
22.2	Programming language history overview	818
22.2.1	The earliest languages	819
22.2.2	The roots of modern languages	821
22.2.3	The Algol family	826
22.2.4	Simula	833
22.2.5	C	836
22.2.6	C++	839
22.2.7	Today	842
22.2.8	Information sources	844

Chapter 23 Text Manipulation 849

23.1	Text	850
23.2	Strings	850
23.3	I/O streams	855
23.4	Maps	855
23.4.1	Implementation details	861
23.5	A problem	864
23.6	The idea of regular expressions	866
23.6.1	Raw string literals	868
23.7	Searching with regular expressions	869
23.8	Regular expression syntax	872
23.8.1	Characters and special characters	872
23.8.2	Character classes	873
23.8.3	Repeats	874
23.8.4	Grouping	876
23.8.5	Alternation	876
23.8.6	Character sets and ranges	877
23.8.7	Regular expression errors	878

23.9 Matching with regular expressions 880
23.10 References 885

Chapter 24 Numerics 889

24.1 Introduction 890
24.2 Size, precision, and overflow 890
 24.2.1 Numeric limits 894
24.3 Arrays 895
24.4 C-style multidimensional arrays 896
24.5 The **Matrix** library 897
 24.5.1 Dimensions and access 898
 24.5.2 1D **Matrix** 901
 24.5.3 2D **Matrix** 904
 24.5.4 **Matrix** I/O 907
 24.5.5 3D **Matrix** 907
24.6 An example: solving linear equations 908
 24.6.1 Classical Gaussian elimination 910
 24.6.2 Pivoting 911
 24.6.3 Testing 912
24.7 Random numbers 914
24.8 The standard mathematical functions 917
24.9 Complex numbers 919
24.10 References 920

Chapter 25 Embedded Systems Programming 925

25.1 Embedded systems 926
25.2 Basic concepts 929
 25.2.1 Predictability 932
 25.2.2 Ideals 932
 25.2.3 Living with failure 933
25.3 Memory management 935
 25.3.1 Free-store problems 936
 25.3.2 Alternatives to the general free store 939
 25.3.3 Pool example 940
 25.3.4 Stack example 942
25.4 Addresses, pointers, and arrays 943
 25.4.1 Unchecked conversions 943
 25.4.2 A problem: dysfunctional interfaces 944
 25.4.3 A solution: an interface class 947
 25.4.4 Inheritance and containers 951
25.5 Bits, bytes, and words 954
 25.5.1 Bits and bit operations 955
 25.5.2 **bitset** 959

25.5.3	Signed and unsigned	961
25.5.4	Bit manipulation	965
25.5.5	Bitfields	967
25.5.6	An example: simple encryption	969
25.6	Coding standards	974
25.6.1	What should a coding standard be?	975
25.6.2	Sample rules	977
25.6.3	Real coding standards	983

Chapter 26 Testing 989

26.1	What we want	990
26.1.1	Caveat	991
26.2	Proofs	992
26.3	Testing	992
26.3.1	Regression tests	993
26.3.2	Unit tests	994
26.3.3	Algorithms and non-algorithms	1001
26.3.4	System tests	1009
26.3.5	Finding assumptions that do not hold	1009
26.4	Design for testing	1011
26.5	Debugging	1012
26.6	Performance	1012
26.6.1	Timing	1015
26.7	References	1016

Chapter 27 The C Programming Language 1021

27.1	C and C++: siblings	1022
27.1.1	C/C++ compatibility	1024
27.1.2	C++ features missing from C	1025
27.1.3	The C standard library	1027
27.2	Functions	1028
27.2.1	No function name overloading	1028
27.2.2	Function argument type checking	1029
27.2.3	Function definitions	1031
27.2.4	Calling C from C++ and C++ from C	1032
27.2.5	Pointers to functions	1034
27.3	Minor language differences	1036
27.3.1	struct tag namespace	1036
27.3.2	Keywords	1037
27.3.3	Definitions	1038
27.3.4	C-style casts	1040

27.3.5	Conversion of <code>void*</code>	1041
27.3.6	<code>enum</code>	1042
27.3.7	Namespaces	1042
27.4	Free store	1043
27.5	C-style strings	1045
27.5.1	C-style strings and <code>const</code>	1047
27.5.2	Byte operations	1048
27.5.3	An example: <code>strcpy()</code>	1049
27.5.4	A style issue	1049
27.6	Input/output: stdio	1050
27.6.1	Output	1050
27.6.2	Input	1052
27.6.3	Files	1053
27.7	Constants and macros	1054
27.8	Macros	1055
27.8.1	Function-like macros	1056
27.8.2	Syntax macros	1058
27.8.3	Conditional compilation	1058
27.9	An example: intrusive containers	1059

Part V Appendices 1071

Appendix A Language Summary 1073

A.1	General	1074
A.1.1	Terminology	1075
A.1.2	Program start and termination	1075
A.1.3	Comments	1076
A.2	Literals	1077
A.2.1	Integer literals	1077
A.2.2	Floating-point-literals	1079
A.2.3	Boolean literals	1079
A.2.4	Character literals	1079
A.2.5	String literals	1080
A.2.6	The pointer literal	1081
A.3	Identifiers	1081
A.3.1	Keywords	1081
A.4	Scope, storage class, and lifetime	1082
A.4.1	Scope	1082
A.4.2	Storage class	1083
A.4.3	Lifetime	1085

A.5	Expressions	1086
A.5.1	User-defined operators	1091
A.5.2	Implicit type conversion	1091
A.5.3	Constant expressions	1093
A.5.4	sizeof	1093
A.5.5	Logical expressions	1094
A.5.6	new and delete	1094
A.5.7	Casts	1095
A.6	Statements	1096
A.7	Declarations	1098
A.7.1	Definitions	1098
A.8	Built-in types	1099
A.8.1	Pointers	1100
A.8.2	Arrays	1101
A.8.3	References	1102
A.9	Functions	1103
A.9.1	Overload resolution	1104
A.9.2	Default arguments	1105
A.9.3	Unspecified arguments	1105
A.9.4	Linkage specifications	1106
A.10	User-defined types	1106
A.10.1	Operator overloading	1107
A.11	Enumerations	1107
A.12	Classes	1108
A.12.1	Member access	1108
A.12.2	Class member definitions	1112
A.12.3	Construction, destruction, and copy	1112
A.12.4	Derived classes	1116
A.12.5	Bitfields	1120
A.12.6	Unions	1121
A.13	Templates	1121
A.13.1	Template arguments	1122
A.13.2	Template instantiation	1123
A.13.3	Template member types	1124
A.14	Exceptions	1125
A.15	Namespaces	1127
A.16	Aliases	1128
A.17	Preprocessor directives	1128
A.17.1	#include	1128
A.17.2	#define	1129

Appendix B Standard Library Summary 1131

B.1	Overview	1132
B.1.1	Header files	1133
B.1.2	Namespace std	1136
B.1.3	Description style	1136
B.2	Error handling	1137
B.2.1	Exceptions	1138
B.3	Iterators	1139
B.3.1	Iterator model	1140
B.3.2	Iterator categories	1142
B.4	Containers	1144
B.4.1	Overview	1146
B.4.2	Member types	1147
B.4.3	Constructors, destructors, and assignments	1148
B.4.4	Iterators	1148
B.4.5	Element access	1149
B.4.6	Stack and queue operations	1149
B.4.7	List operations	1150
B.4.8	Size and capacity	1150
B.4.9	Other operations	1151
B.4.10	Associative container operations	1151
B.5	Algorithms	1152
B.5.1	Nonmodifying sequence algorithms	1153
B.5.2	Modifying sequence algorithms	1154
B.5.3	Utility algorithms	1156
B.5.4	Sorting and searching	1157
B.5.5	Set algorithms	1159
B.5.6	Heaps	1160
B.5.7	Permutations	1160
B.5.8	min and max	1161
B.6	STL utilities	1162
B.6.1	Inserters	1162
B.6.2	Function objects	1163
B.6.3	pair and tuple	1165
B.6.4	initializer_list	1166
B.6.5	Resource management pointers	1167
B.7	I/O streams	1168
B.7.1	I/O streams hierarchy	1170
B.7.2	Error handling	1171
B.7.3	Input operations	1172

B.7.4	Output operations	1173
B.7.5	Formatting	1173
B.7.6	Standard manipulators	1173
B.8	String manipulation	1175
B.8.1	Character classification	1175
B.8.2	String	1176
B.8.3	Regular expression matching	1177
B.9	Numerics	1180
B.9.1	Numerical limits	1180
B.9.2	Standard mathematical functions	1181
B.9.3	Complex	1182
B.9.4	valarray	1183
B.9.5	Generalized numerical algorithms	1183
B.9.6	Random numbers	1184
B.10	Time	1185
B.11	C standard library functions	1185
B.11.1	Files	1186
B.11.2	The printf() family	1186
B.11.3	C-style strings	1191
B.11.4	Memory	1192
B.11.5	Date and time	1193
B.10.6	Etc.	1194
B.12	Other libraries	1195

Appendix C Getting Started with Visual Studio 1197

C.1	Getting a program to run	1198
C.2	Installing Visual Studio	1198
C.3	Creating and running a program	1199
C.3.1	Create a new project	1199
C.3.2	Use the std_lib_facilities.h header file	1199
C.3.3	Add a C++ source file to the project	1200
C.3.4	Enter your source code	1200
C.3.5	Build an executable program	1200
C.3.6	Execute the program	1201
C.3.7	Save the program	1201
C.4	Later	1201

Appendix D Installing FLTK 1203

D.1	Introduction	1204
D.2	Downloading FLTK	1204
D.3	Installing FLTK	1205
D.4	Using FLTK in Visual Studio	1205
D.5	Testing if it all worked	1206

Appendix E GUI Implementation 1207

- E.1 Callback implementation 1208
- E.2 **Widget** implementation 1209
- E.3 **Window** implementation 1210
- E.4 **Vector_ref** 1212
- E.5 An example: manipulating **Widgets** 1213

Glossary 1217

Bibliography 1223

Index 1227