Contents

Chapter interdependencies xi

Preface xiii

I A common background 1

1 Introduction 3
1.1 An overview of the book . . . 3
1.2 Why C? . . . 3
1.3 Which version of C? . . . 4
1.4 Operating systems . . . 7
1.5 The compiler and other software . . . 7
1.6 Interfaces and implementations . . . 9
1.7 Advice on writing . . . 11
1.8 Special notations . . . 11

2 File organization 13

3 Streams and the Unix shell 15

4 Pointers and arrays 19
4.1 Pointers . . . 19
4.2 Pointer types . . . 20
4.3 The pointer to void . . . 20
4.4 Arrays . . . 21
4.5 Multidimensional arrays . . . 23
4.6 Strings . . . 24
4.7 The command-line arguments . . . 25

5 From strings to numbers 27
5.1 The function `strtod()` . . . 27
5.2 The function `strtol()` . . . 28
5.3 The functions `atof()`, `atol()`, and friends . . . 29

6 Make 31
6.1 Multifile programs . . . 31
6.2 Separate compilation and linking . . . 31
6.3 File dependencies . . . 32

6.4 *Makefile* version 1 34
6.5 How to run `make` 35
6.6 *Makefile* version 2 35
6.7 *Makefile* version 3 36
6.8 *Makefile*: The final version 38
6.9 Linking with external libraries 40
6.10 Multiple executables in one *Makefile* 40

II Projects 43

7 Allocating memory: `xmalloc()` 45
7.1 Introduction 45
7.2 A review of `malloc()` 45
7.3 The program 48
7.4 The interface and the implementation 49
7.5 *Project Xmalloc* 52

8 Dynamic memory allocation for vectors and matrices: *array.h* 53
8.1 Introduction 53
8.2 Constructing vectors of arbitrary types 54
8.3 A scheme for dynamically allocated matrices 56
8.4 Constructing matrices of arbitrary types 57
8.5 *Project array.h* 59

9 Reading lines: `fetch_line()` 63
9.1 Introduction 63
9.2 Reading one line at a time with `fgets()` 63
9.3 Trimming whitespace and comments 65
9.4 The program 66
9.5 The files *fetch-line.[ch]* 67
9.6 *Project fetch_line* 70

10 Generating random numbers 71
10.1 The `rand()` and `srand()` functions 71
10.2 Bitmap images 73
10.3 The program 74
10.4 The file *random-pbm.c* 75
10.5 *Project Random Bitmaps* 78

11 Storing sparse matrices 79
11.1 Introduction 79
11.2 The CCS format 80
11.3 The program 81
11.4 The files *sparse.[ch]* 81
11.5 *Project Sparse Matrix* 82

12 Sparse systems: The UMFPACK library 85
12.1 Introduction 85
12.2 The basics 85
12.3 The program 86

12.4 *umfpack-demo1.c* . . . 87
12.5 *umfpack-demo2.c* . . . 89
12.6 *umfpack-demo3.c* and the triplet form . . . 90
12.7 *Project* UMFPACK . . . 92

13 Haar wavelets **93**
13.1 A brief background . . . 93
13.2 The space $L^2(0,1)$ . . . 93
13.3 Haar's construction . . . 94
13.4 The decomposition $V_j = V_{j-1} \oplus W_{j-1}$ . . . 97
13.5 From functions to vectors . . . 98
13.6 The Haar wavelet transform . . . 100
13.7 Functions of two variables . . . 102
13.8 An overview of the *wavelet* module . . . 104
13.9 The file *wavelet.h* . . . 104
13.10 The file *wavelet.c* . . . 105
13.11 *Project Wavelets* . . . 109

14 Image I/O **113**
14.1 Digital images and image file formats . . . 113
14.2 Bitmaps and the PBM image format . . . 114
14.3 Grayscale images and the PGM image format . . . 116
14.4 Color images and the PPM image format . . . 117
14.5 The *libnetpbm* library . . . 118
14.6 A no-frills demo of *libnetpbm* . . . 121
14.7 The interface of the *image-io* module . . . 121
14.8 The implementation of the *image-io* module . . . 124
14.9 The file *image-io-test-0.c* . . . 129
14.10 *Project Image I/O* . . . 131

15 Image analysis **135**
15.1 Introduction . . . 135
15.2 The truncation error in a grayscale image . . . 137
15.3 The truncation error in a color image . . . 138
15.4 Image reconstruction . . . 138
15.5 The program . . . 139
15.6 The implementation of *image-analysis.c* . . . 139
15.7 *Project Image Analysis* . . . 144

16 Linked lists **147**
16.1 Linked lists . . . 147
16.2 The program . . . 148
16.3 The function `ll_push()` . . . 148
16.4 The function `ll_pop()` . . . 150
16.5 The function `ll_free()` . . . 151
16.6 The function `ll_reverse()` . . . 152
16.7 The function `ll_sort()` . . . 153
16.8 The function `ll_filter()` . . . 157
16.9 The function `ll_length()` . . . 159
16.10 *Project Linked Lists* . . . 159

17 The evolution of species **161**
17.1 Introduction . . . 161
17.2 A more detailed description . . . 162
17.3 The *World Definition File* . . . 165
17.4 The program's user interface . . . 166
17.5 The program's components . . . 167
17.6 The file *evolution.h* . . . 168
17.7 The files *read.[ch]* . . . 169
17.8 The files *write.[ch]* . . . 174
17.9 The files *world-to-eps.[ch]* . . . 175
17.10 Interlude (and a mini-project) . . . 176
17.11 The file *evolution.c* . . . 177
17.12 Experiments . . . 188
17.13 Animation . . . 190
17.14 *Project Evolution* . . . 191

18 The Nelder–Mead downhill simplex **193**
18.1 Introduction . . . 193
18.2 The algorithm . . . 193
18.3 Problems with the Nelder–Mead algorithm . . . 197
18.4 An overview of the program . . . 198
18.5 The interface . . . 198
18.6 The implementation . . . 200
18.7 *Project Nelder–Mead*: Unconstrained optimization . . . 207
18.8 Constrained optimization . . . 211
18.9 *Project Nelder–Mead*: Constrained optimization . . . 212
18.10 Appendix: Orthogonal projection onto $A\boldsymbol{x} = \boldsymbol{b}$ . . . 213

19 Trusses **215**
19.1 Introduction . . . 215
19.2 One-dimensional elasticity . . . 217
19.3 From energy to force . . . 221
19.4 The energy of a truss . . . 222
19.5 From energy to equilibrium . . . 223
19.6 The *Truss Description File* (*TDF*) . . . 224
19.7 An overview of the program . . . 226
19.8 The interface . . . 227
19.9 Reading and writing: *truss-io.[ch]* . . . 230
19.10 The files *truss-to-eps.[ch]* . . . 240
19.11 Interlude (and a mini-project) . . . 241
19.12 The file *truss.c* . . . 242
19.13 The file *truss-demo.c* . . . 247
19.14 *Project Truss* . . . 249

20 Finite difference schemes for the heat equation in one dimension **251**
20.1 The basic idea of finite differences . . . 251
20.2 An explicit scheme for the heat equation . . . 253
20.3 An implicit scheme for the heat equation . . . 256
20.4 The Crank–Nicolson scheme for the heat equation . . . 258
20.5 The Seidman sweep scheme for the heat equation . . . 260

20.6 Test problems . . . 263
20.7 The program . . . 266
20.8 The files *problem-spec.[ch]* . . . 267
20.9 The file *heat-implicit.c* . . . 272
20.10 *Project Finite Differences in One Dimension* . . . 280

21 The porous medium equation 283
21.1 Introduction . . . 283
21.2 Barenblatt's solution . . . 283
21.3 Generalizations . . . 284
21.4 The finite difference scheme . . . 285
21.5 The program . . . 286
21.6 The files *problem-spec.[ch]* . . . 288
21.7 The file *pme-seidman-sweep.c* . . . 288
21.8 *Project Porous Medium* . . . 289
21.9 Appendix: The porous medium equation as a population dynamics model . . . 289

22 Gaussian quadrature 291
22.1 Introduction . . . 291
22.2 Lagrange interpolation . . . 292
22.3 Legendre polynomials . . . 294
22.4 The Gaussian quadrature formula . . . 295
22.5 The program . . . 296
22.6 The files *gauss-quad.[ch]* . . . 297
22.7 *Project Gaussian Quadrature* . . . 299

23 Triangulation with the *Triangle* library 301
23.1 Introduction . . . 301
23.2 The program . . . 302
23.3 The file *problem-spec.h* . . . 303
23.4 The file *problem-spec.c* . . . 305
23.5 The files *mesh.h* and *mesh.c* . . . 311
23.6 The file *mesh-demo.c* . . . 313
23.7 Installing *Triangle* . . . 315
23.8 *Project Triangulate* . . . 316

24 Integration on triangles 319
24.1 Introduction . . . 319
24.2 The Taylor, Wingate, and Bos (TWB) quadrature . . . 321
24.3 The files *twb-quad.[ch]* . . . 322
24.4 The program . . . 326
24.5 The files *plot-with-geomview.[ch]* . . . 328
24.6 Modifying the file *problem-spec.c* . . . 329
24.7 The file *twb-quad-demo.c* . . . 330
24.8 *Project TWB Quadrature* . . . 334

25 Finite elements 337
25.1 The Poisson equation . . . 337
25.2 The weak formulation . . . 338
25.3 The Galerkin approximation . . . 340

25.4 An overview of the FEM . . . 341
25.5 Error analysis . . . 345
25.6 The program . . . 347
25.7 Changes in *problem-spec.c* . . . 349
25.8 The file *poisson.h* . . . 350
25.9 The file *poisson.c* . . . 351
25.10 The file *fem-demo.c* . . . 358
25.11 Further reading . . . 359
25.12 *Project FEM 1* . . . 360

26 Finite elements: Nonzero boundary data 361
26.1 The problem . . . 361
26.2 The weak formulation . . . 362
26.3 The Galerkin approximation . . . 364
26.4 The program . . . 366
26.5 The file *problem-spec.[ch]* . . . 366
26.6 The file *poisson.c* . . . 369
26.7 *Project FEM 2* . . . 373

A Barycentric coordinates 375
A.1 Barycentric coordinates . . . 375
A.2 Calculus on a triangle . . . 377

Bibliography 381

Index 387