

Contents

<i>Preface</i>	<i>page xi</i>
<i>Acknowledgments</i>	xvi
1 Computer Music, Euterpea, and Haskell	1
1.1 The Note versus Signal Dichotomy	2
1.2 Basic Principles of Programming	3
1.3 Computation by Calculation	4
1.4 Expressions and Values	8
1.5 Types	9
1.6 Function Types and Type Signatures	11
1.7 Abstraction, Abstraction, Abstraction	12
1.8 Haskell Equality versus Musical Equality	21
1.9 Code Reuse and Modularity	22
1.10 [Advanced] Programming with Numbers	23
2 Simple Music	27
2.1 Preliminaries	27
2.2 Notes, Music, and Polymorphism	29
2.3 Convenient Auxiliary Functions	34
2.4 Absolute Pitches	39
3 Polymorphic and Higher-Order Functions	42
3.1 Polymorphic Types	42
3.2 Abstraction over Recursive Definitions	44
3.3 Append	47
3.4 Fold	49
3.5 [Advanced] A Final Example: Reverse	54
3.6 Currying	56
3.7 Errors	60

4	A Musical Interlude	63
4.1	Transcribing an Existing Score	63
4.2	Modules	65
4.3	Transcribing a More Complex Score	67
4.4	Simple Algorithmic Composition	72
5	Syntactic Magic	74
5.1	Sections	74
5.2	Anonymous Functions	75
5.3	List Comprehensions	77
5.4	Function Composition	80
5.5	Higher-Order Thinking	81
5.6	Infix Function Application	82
6	More Music	84
6.1	Delay and Repeat	84
6.2	Inversion and Retrograde	85
6.3	Computing Duration	87
6.4	Super-Retrograde	87
6.5	<i>cut</i> and <i>remove</i>	88
6.6	Removing Zeros	89
6.7	Truncating Parallel Composition	91
6.8	Trills	93
6.9	Grace Notes	95
6.10	Percussion	95
6.11	A Map for Music	97
6.12	A Fold for Music	99
6.13	Complex Rhythms	100
6.14	Crazy Recursion	101
7	Qualified Types and Type Classes	104
7.1	Motivation	104
7.2	Equality	106
7.3	Defining Our Own Type Classes	108
7.4	Haskell's Standard Type Classes	113
7.5	Other Derived Instances	118
7.6	The Type of <i>play</i>	121
7.7	Reasoning with Type Classes	122
8	From Music to MIDI	125
8.1	An Introduction to MIDI	125

Contents	vii
8.2 MIDI Streams	128
8.3 Euterpea's Playback Framework	129
9 Interpretation and Performance	134
9.1 Abstract Performance	134
9.2 Players	139
9.3 Putting It All Together	144
10 Self-Similar Music	148
10.1 Self-Similar Melody	148
10.2 Self-Similar Harmony	152
10.3 Other Self-Similar Structures	153
11 Proof by Induction	156
11.1 Induction and Recursion	156
11.2 Examples of List Induction	157
11.3 Proving Function Equivalences	159
11.4 Useful Properties on Lists	162
11.5 Induction on the <i>Music</i> Data Type	166
11.6 [Advanced] Induction on Other Data Types	170
12 An Algebra of Music	175
12.1 Musical Equivalence	175
12.2 Some Simple Axioms	177
12.3 The Fundamental Axiom Set	180
12.4 Other Musical Properties	182
13 L-Systems and Generative Grammars	184
13.1 A Simple Implementation	185
13.2 A More General Implementation	187
13.3 An L-System Grammar for Music	189
14 Random Numbers, Probability Distributions, and Markov Chains	193
14.1 Random Numbers	193
14.2 Probability Distributions	196
14.3 Markov Chains	202
15 Basic Input/Output	205
15.1 IO in Haskell	205
15.2 do Syntax	206
15.3 Actions Are Just Values	208
15.4 Reading and Writing MIDI Files	210

16 Higher-Order Types and Monads	211
16.1 The <i>Functor</i> Class	211
16.2 The <i>Monad</i> Class	213
16.3 The <i>MonadPlus</i> Class	221
16.4 State Monads	222
16.5 Type Class Type Errors	225
17 Musical User Interfaces	227
17.1 Introduction	227
17.2 Basic Concepts	228
17.3 The UISF Arrow	233
17.4 Non-Widget Signal Functions	242
17.5 Musical Examples	246
17.6 Special Purpose and Custom Widgets	251
17.7 Advanced Topics	256
18 Sound and Signals	262
18.1 The Nature of Sound	262
18.2 Digital Audio	273
19 Euterpea's Signal Functions	282
19.1 The Type of Audio Signals	282
19.2 Generating Sound	289
19.3 Clipping	290
19.4 Instruments	292
20 Spectrum Analysis	299
20.1 Fourier's Theorem	299
20.2 The Discrete Fourier Transform	305
20.3 The Fast Fourier Transform	315
20.4 Further Pragmatics	317
21 Additive and Subtractive Synthesis	318
21.1 Additive Synthesis	319
21.2 Subtractive Synthesis	326
22 Amplitude and Frequency Modulation	331
22.1 Amplitude Modulation	331
22.2 Frequency Modulation	334
22.3 Examples	334
23 Physical Modeling	336
23.1 Introduction	336

Contents

ix

23.2	Delay Lines	336
23.3	Karplus-Strong Algorithm	340
23.4	Waveguide Synthesis	343
<i>Appendix A</i>	The PreludeList Module	346
<i>Appendix B</i>	Haskell's Standard Type Classes	355
<i>Appendix C</i>	Built-In Types Are Not Special	365
<i>Appendix D</i>	Pattern-Matching Details	367
<i>Appendix E</i>	Haskell Quick Reference	370
<i>Appendix F</i>	Euterpea Quick Reference	373
<i>Appendix G</i>	HSoM Quick Reference	377
	<i>Bibliography</i>	379
	<i>Index</i>	381