# Table of Contents

**Chapter 1: Patching One Sample at a Time ..... 1**

What is gen~? ..... 2
Using this book (and the software that comes with it) ..... 3
A Bestiary of signals and operators ..... 3
Signals ..... 4
Operators ..... 10
The “go” library ..... 18

**Chapter 2: Modular (Arithmetic of) Time ..... 19**

Counting by sample frames (accum) ..... 19
Playing a sound file ..... 22
Looping with modular arithmetic ..... 23
Thinking in rates and changes of phase (phasor) ..... 25
A phasor (using Hz) ..... 26
A drum loop (using BPM) ..... 28
Ramps as cyclical time ..... 29
Exploration ..... 31
Example: beat slicing ..... 33
A collection of ramp processors ..... 37
A phasor as a clock source ..... 37
Ramp clock multiplication ..... 37
From ramps to steps ..... 39
Shifting ramps (phase rotation) ..... 41
Getting the slope, frequency, period, and direction of a ramp ..... 42
Getting triggers from a cyclic ramp ..... 43
Ramp/clock division ..... 46
Ramp multiplications and divisions with musical ratios ..... 48
Modular arithmetic with rhythms ..... 50
Modulating ramps with ramps ..... 53

**Chapter 3: Unit Shaping ..... 57**

Swing and warping time ..... 58
From ramps to LFOs ..... 61

Triangles....62
Sinusoids....63
Pulse waves....66
Trapezoids....67
Shaping smooth-stepped interpolation for LFOs and smooth glides....70
LFOs from smoothed steps....71
Glides and portamento....76
Easing functions....77
Window envelope functions....78
Waveshaping bipolar signals....79
Audio waveshaping....81
Polynomial shapers....82
Sigmoids....84
Normalized sigmoids as unit shapers....87

**Chapter 4: Noise, Uncertainty, and Unpredictability....91**

Feel the noise....91
Random ranges....92
Rate control / stepped random....93
Smooth stepped random....93
Chance and conditions of probability....96
Bernoulli gate....97
Random periods....98
Random distributions....99
Random walks in nature....101
Random integers / quantized random....103
The urn model: pick a card, any card...104
A more flexible urn....110
Chaos (and why we like it)....112
A Lorenz attractor....112
Finding the limits....115
go.chaos....117
Balancing order and unpredictability....119
Example: adding natural looseness to a tempo clock....119
Example: injecting audio into chaos....121

**Chapter 5: Stepping in Time and Space....123**

Stepped pitches and logic gates....123
Creating step patterns by mixing logic signals....124
Sample and hold patterns....125
A shift register canon....127
Sequencing algorithms with binary shift registers....129
Looping....131
Evolving loops....131
Using xor for pseudo-random sequences....133
Binary decoding....134

Integers as patterns....136
Working with the bits of an integer....139
Euclidean rhythms (digitized ratios)....143
Euclidean Ramps....145
Refinements....148
Pitch spaces....150
Quantization....151
Euclidean patterns of length 12 produce common scales....152
The space between notes....154
Smooth-stepped quantization....155
Quantization as a timbral shaper....157

**Chapter 6: Filters, Diagrams, and the Balance of Time....159**

One-pole lowpass filter....159
From blocks to operators....159
Turning Heads....161
When is a filter more than a filter?....162
Setting the frequency....164
Half-lives: setting a filter decay in seconds....167
A lowpass gate (LPG)....169
A lowpass gives you a free highpass....172
Allpass filters....174
Phaser....176
Computing the allpass coefficient from a frequency....178
Biquad filters....178
Biquad Filter Coefficients....181
Cascades....182
Trapezoidal filters....184
A one-pole filter....186
State Variable Filter....188
Crossover filter....191
Block diagrams: between theory and practice....193
Smoothing control signals with lines and slews....193
Limiting a slope (slew limiting)....193
Drawing a line (lag generator)....195

**Chapter 7: The Effects of Delay....197**

A basic delay loop....198
Feedback....199
Setting the feedback decay time....201
Feedback filtering....202
Removing DC....203
Feedback limiting....204
Avoiding clicks....206
Smooth changes to delay time cause Doppler shifts....208
Changing delay time without pitch shift....209

A garden of earthly delays ..... 211
Filtering with delay: comb filters and allpass delay filters ..... 215
Enharmonic combs ..... 217
Strings ..... 218
What happens in the feedback loop? ..... 221
Damping ..... 222
Cleaner interpolation for a consistent sound ..... 223

**Chapter 8: Frequent Modulations ..... 227**

Amplitude modulation (AM) and Ring Modulation (RM) ..... 227
Sidebands ..... 229
Ring modulation ..... 230
Beyond sinusoids ..... 232
Frequency modulation (FM) and phase modulation (PM) ..... 232
Sidebands ..... 234
Frequency ratios and harmonicity ..... 236
Combinations (FM algorithms and beyond) ..... 237
Parallel carriers and parallel modulators ..... 237
Beyond sinusoidal modulators ..... 239
Modulating modulators: cascade modulators ..... 241
Feedback modulation ..... 242
Fixing FM going out of tune ..... 244
Cross-coupled feedback modulation ..... 246
Exploring hybrid algorithms ..... 247
Index amplitude/ring modulation ..... 248
Phase modulation: suppressing clicks ..... 248
Waveshaping modulators ..... 249
Exponential FM/PM ..... 250
Using AM for asymmetric PM spectra ..... 251
Things that can go wrong ..... 254
Removing inaudible frequencies to preserve headroom ..... 254
Aliasing and bandlimiting ..... 254
Delay as phase modulation ..... 257
Blending harmonic oscillators ..... 259
Blended harmonic AM/RM and PM ..... 261
Modified FM ..... 262

**Chapter 9: Navigating Waves of Data ..... 265**

Wavetables ..... 265
Morphing between waveforms ..... 267
2D wavetables ..... 268
Morphing in 2D ..... 270
3D wavetables ..... 273
Morphing in 3D ..... 275
Generating wavetables ..... 279
Band-limiting wavetables ..... 280

Sinc interpolation ..... 283
Mipmapping ..... 287
Wave terrains ..... 293
Generating terrains ..... 296
Basis Function Generator (BFG) terrains ..... 298
Navigating data space ..... 300
Polygonal orbits ..... 303
Taking things further ..... 307

**Chapter 10: Windows of Time ..... 309**

Sync ..... 309
Windowed Sync ..... 311
Sub-sample accuracy ..... 313
Pulsar Synthesis ..... 315
When the event duration is longer than the fundamental period ..... 318
Suppressing retriggers (subharmonics) ..... 318
Polyphony (distributing event triggers) ..... 321
Polyphonic notes ..... 323
Granulation ..... 325
Asynchronous and stochastic grains ..... 327
Subsample-accurate events from phasor ramps ..... 328
Overdubbing the future ..... 333
Whole grains at once ..... 336
Subsample-accurate grains ..... 342
A bandlimited saw with hard sync ..... 343
Adding hard sync ..... 350
Shaping ..... 352

**Onward ..... 355**

**Endnotes ..... 357**