

Contents

Foreword	xi
Preface	xiii
1 Sinusoids, Amplitude and Frequency	1
1.1 Measures of Amplitude	3
1.2 Units of Amplitude	4
1.3 Controlling Amplitude	6
1.4 Frequency	6
1.5 Synthesizing a Sinusoid	8
1.6 Superposing Signals	11
1.7 Periodic Signals	12
1.8 About the Software Examples	15
Quick introduction to Pd	16
How to find and run the examples	17
1.9 Examples	18
Constant amplitude scaler	18
Amplitude control in decibels	20
Smoothed amplitude control with an envelope generator	21
Major triad	22
Conversion between frequency and pitch	23
More additive synthesis	24
Exercises	25
2 Wavetables and Samplers	27
2.1 The Wavetable Oscillator	30
2.2 Sampling	33
2.3 Enveloping Samplers	36
2.4 Timbre Stretching	39
2.5 Interpolation	43

2.6	Examples	47
	Wavetable oscillator	47
	Wavetable lookup in general	48
	Using a wavetable as a sampler	51
	Looping samplers	52
	Overlapping sample looper	54
	Automatic read point precession	55
	Exercises	58
3	Audio and Control Computations	59
3.1	The Sampling Theorem	59
3.2	Control	61
3.3	Control Streams	63
3.4	Conversion from Audio Signals to Numeric Control Streams	68
3.5	Control Streams in Block Diagrams	69
3.6	Event Detection	69
3.7	Audio Signals as Control	71
3.8	Operations on Control Streams	74
3.9	Control Operations in Pd	76
3.10	Examples	78
	Sampling and foldover	78
	Converting controls to signals	80
	Non-looping wavetable player	81
	Signals to controls	82
	Analog-style sequencer	83
	MIDI-style synthesizer	83
	Exercises	86
4	Automation and Voice Management	89
4.1	Envelope Generators	89
4.2	Linear and Curved Amplitude Shapes	92
4.3	Continuous and Discontinuous Control Changes	94
	4.3.1 Muting	95
	4.3.2 Switch-and-ramp	96
4.4	Polyphony	98
4.5	Voice Allocation	99
4.6	Voice Tags	100
4.7	Encapsulation in Pd	102
4.8	Examples	104
	ADSR envelope generator	104
	Transfer functions for amplitude control	106
	Additive synthesis: Risset's bell	107

Additive synthesis: spectral envelope control	110
Polyphonic synthesis: sampler	112
Exercises	116
5 Modulation	119
5.1 Taxonomy of Spectra	119
5.2 Multiplying Audio Signals	122
5.3 Waveshaping	126
5.4 Frequency and Phase Modulation	132
5.5 Examples	135
Ring modulation and spectra	135
Octave divider and formant adder	137
Waveshaping and difference tones	138
Waveshaping using Chebychev polynomials	139
Waveshaping using an exponential function	141
Sinusoidal waveshaping: evenness and oddness	143
Phase modulation and FM	144
Exercises	146
6 Designer Spectra	149
6.1 Carrier/Modulator Model	150
6.2 Pulse Trains	153
6.2.1 Pulse trains via waveshaping	153
6.2.2 Pulse trains via wavetable stretching	154
6.2.3 Resulting spectra	155
6.3 Movable Ring Modulation	158
6.4 Phase-Aligned Formant (PAF) Generator	160
6.5 Examples	165
Wavetable pulse train	165
Simple formant generator	167
Two-cosine carrier signal	168
The PAF generator	170
Stretched wavetables	174
Exercises	174
7 Time Shifts and Delays	175
7.1 Complex Numbers	176
7.1.1 Complex sinusoids	178
7.2 Time Shifts and Phase Changes	180
7.3 Delay Networks	181
7.4 Recirculating Delay Networks	186
7.5 Power Conservation and Complex Delay Networks	190

7.6	Artificial Reverberation	195
7.6.1	Controlling reverberators	198
7.7	Variable and Fractional Shifts	198
7.8	Fidelity of Interpolating Delay Lines	202
7.9	Pitch Shifting	204
7.10	Examples	209
	Fixed, noninterpolating delay line	209
	Recirculating comb filter	210
	Variable delay line	210
	Order of execution and lower limits on delay times	212
	Order of execution in non-recirculating delay lines	215
	Non-recirculating comb filter as octave doubler	216
	Time-varying complex comb filter: shakers	218
	Reverberator	219
	Pitch shifter	222
	Exercises	222
8	Filters	225
8.1	Taxonomy of Filters	226
8.1.1	Low-pass and high-pass filters	226
8.1.2	Band-pass and stop-band filters	228
8.1.3	Equalizing filters	229
8.2	Elementary Filters	231
8.2.1	Elementary non-recirculating filter	231
8.2.2	Non-recirculating filter, second form	233
8.2.3	Elementary recirculating filter	234
8.2.4	Compound filters	235
8.2.5	Real outputs from complex filters	236
8.2.6	Two recirculating filters for the price of one	237
8.3	Designing Filters	238
8.3.1	One-pole low-pass filter	238
8.3.2	One-pole, one-zero high-pass filter	239
8.3.3	Shelving filter	240
8.3.4	Band-pass filter	242
8.3.5	Peaking and stop-band filter	243
8.3.6	Butterworth filters	244
8.3.7	Stretching the unit circle with rational functions	245
8.3.8	Butterworth band-pass filter	248
8.3.9	Time-varying coefficients	249
8.3.10	Impulse responses of recirculating filters	251
8.3.11	All-pass filters	253
8.4	Applications	254

8.4.1	Subtractive synthesis	254
8.4.2	Envelope following	256
8.4.3	Single sideband modulation	258
8.5	Examples	259
	Prefabricated low-, high-, and band-pass filters	259
	Prefabricated time-varying band-pass filter	260
	Envelope followers	261
	Single sideband modulation	263
	Using elementary filters directly: shelving and peaking	264
	Making and using all-pass filters	266
	Exercises	266
9	Fourier Analysis and Resynthesis	267
9.1	Fourier Analysis of Periodic Signals	267
9.1.1	Periodicity of the Fourier transform	269
9.1.2	Fourier transform as additive synthesis	269
9.2	Properties of Fourier Transforms	270
9.2.1	Fourier transform of DC	270
9.2.2	Shifts and phase changes	272
9.2.3	Fourier transform of a sinusoid	274
9.3	Fourier Analysis of Non-Periodic Signals	274
9.4	Fourier Analysis and Reconstruction of Audio Signals	279
9.4.1	Narrow-band companding	281
9.4.2	Timbre stamping (classical vocoder)	283
9.5	Phase	284
9.5.1	Phase relationships between channels	288
9.6	Phase Bashing	290
9.7	Examples	291
	Fourier analysis and resynthesis in Pd	291
	Narrow-band companding: noise suppression	293
	Timbre stamp (“vocoder”)	295
	Phase vocoder time bender	296
	Exercises	299
10	Classical Waveforms	301
10.1	Symmetries and Fourier Series	302
10.1.1	Sawtooth waves and symmetry	304
10.2	Dissecting Classical Waveforms	305
10.3	Fourier Series of the Elementary Waveforms	308
10.3.1	Sawtooth wave	309
10.3.2	Parabolic wave	310
10.3.3	Square and symmetric triangle waves	311

10.3.4	General (non-symmetric) triangle wave	311
10.4	Predicting and Controlling Foldover	313
10.4.1	Over-sampling	314
10.4.2	Sneaky triangle waves	314
10.4.3	Transition splicing	316
10.5	Examples	319
Combining	sawtooth waves	319
Strategies for	band-limiting sawtooth waves	320
Exercises	322
Bibliography		323
Index		327