

Contents

1	Introduction	1
1.1	Sound as a Science Material	1
1.2	Layout	2
1.3	Convention for Notation and Code	5
1.4	Book Compilation	6
2	What Is Sound?	7
2.1	A Debate Under a Dangerous Tree	7
2.2	Sound as a Mechanical Wave	9
2.2.1	Air Particle Motion	9
2.2.2	Air Pressure Variation	10
2.2.3	Amplitude	12
2.2.4	Phase	20
2.2.5	Duration	20
2.2.6	Frequency	21
2.2.7	Writing Sound with a Simple Equation	25
2.2.8	Amplitude and Frequency Modulations	26
2.3	Sound as a Time Series	29
2.4	Sound as a Digital Object	30
2.4.1	Sampling	30
2.4.2	Quantization	30
2.4.3	Issues in Sampling and Quantization	32
2.4.4	File Format	33
2.5	Sound as a Support of Information	34
3	What Is R?	37
3.1	A Brief Introduction to an Ocean of Tools	37
3.2	How to Get R	39
3.3	Do You Speak R?	40
3.3.1	Where Am I?	40
3.3.2	Objects	41
3.3.3	Operators	46

3.3.4	Functions	47
3.3.5	Controlling Flow	50
3.3.6	Manipulating Objects	54
3.3.7	Vectorization and Recycling	62
3.3.8	Handling Character Strings	64
3.3.9	Drawing a Graphic	65
3.3.10	Scripting	73
3.3.11	Calling External Software	74
3.4	R and Sound	75
3.4.1	To Use or Not to Use R for Sound Analysis?	75
3.4.2	Main Packages	76
3.4.3	How to Install <code>seewave</code>	79
4	Playing with Sound	81
4.1	Object Classes.....	81
4.1.1	<code>vector</code> , <code>matrix</code> , <code>data.frame</code> Classes	81
4.1.2	<code>ts</code> and <code>mts</code> Classes.....	82
4.1.3	<code>audioSample</code> Class of the Package <code>audio</code>	85
4.1.4	<code>sound</code> Class of the Package <code>phonTools</code>	86
4.1.5	<code>Wave</code> Class of the Package <code>tunerR</code>	87
4.2	How to Read (Load) a Sound	90
4.2.1	<code>.wav</code> Files.....	90
4.2.2	<code>.mp3</code> Files.....	92
4.2.3	From <code>.mp3</code> to <code>.wav</code> Files.....	93
4.2.4	<code>.flac</code> Files	94
4.2.5	Local Files	94
4.2.6	Online Files.....	95
4.2.7	Song Meter [©] Files	99
4.3	How to Listen to a Sound.....	100
4.3.1	With the Package <code>audio</code>	101
4.3.2	With the Package <code>phonTools</code>	105
4.3.3	With the Package <code>tunerR</code>	105
4.3.4	With the Package <code>seewave</code>	106
4.4	How to Record a Sound	107
4.5	How to Write (Save) a Sound	108
4.6	Tuning R.....	110
5	Display of the Wave	111
5.1	Oscillogram	112
5.1.1	Simple Oscillogram	112
5.1.2	Axes.....	114
5.1.3	Colors	116
5.1.4	Decoration and Annotation	119
5.1.5	Zoom In.....	121
5.1.6	A Bit of Interactivity	123
5.1.7	Multiple Oscillogram	123

5.2	Amplitude Envelope	125
5.2.1	Principle	125
5.2.2	In Practice with seewave	128
5.2.3	Smoothing	129
5.2.4	In Practice with phonTools	136
5.3	Combining Oscillogram and Envelope	138
6	Edition	139
6.1	Resampling	139
6.2	Channels Managing	142
6.3	Manipulating Sound Sections	146
6.3.1	Extract	146
6.3.2	Delete	149
6.3.3	Paste	150
6.3.4	Repeat	154
6.3.5	Reverse	155
6.4	Removing and Inserting Silence Sections	155
6.5	Changing Amplitude	159
6.5.1	Offset	159
6.5.2	Amplitude Level	161
6.5.3	Fade-In and Fade-Out	163
7	Amplitude Parametrization	167
7.1	Linear Relative Scale	167
7.2	Logarithm Relative Scale	173
7.2.1	Signal-to-Noise Ratio	173
7.2.2	dB Weightings	174
7.2.3	dB Arithmetic	175
7.2.4	Sound Attenuation Through Spreading Losses	177
7.3	Absolute Scale	181
8	Time-Amplitude Parametrization	185
8.1	What and How to Measure?	185
8.2	Manual Measurements	186
8.3	Automatic Measurements	191
8.3.1	The Cicada Case	193
8.3.2	The Frog Case	198
8.4	Amplitude Modulation Analysis	205
8.4.1	The Cicada Case	205
8.4.2	The Frog Case	209
9	Introduction to Frequency Analysis: The Fourier Transformation ...	213
9.1	From Time to Frequency and Back	213
9.2	Fourier Series	214
9.2.1	Periodicity	214
9.2.2	Trigonometric Fourier Series	217

9.2.3	Compact Fourier Series	219
9.2.4	Exponential Fourier Series	222
9.3	Fourier Transform	224
9.4	Frequency Scales	229
9.4.1	Bark and Mel Scales	229
9.4.2	Musical Scale	231
9.5	Amplitude Scales	235
9.6	Fourier Windows	236
9.7	Inverse Fourier Transform	240
9.8	Cepstrum	241
10	Frequency, Quefrency, and Phase in Practice	247
10.1	Frequency Spectrum	247
10.1.1	Functions of the Package <code>tuner</code>	248
10.1.2	Functions of the Package <code>seewave</code>	249
10.1.3	Identification of Peaks	265
10.1.4	Profile Analysis	275
10.1.5	Symbolic Analysis	286
10.1.6	Parametrization	293
10.2	Quefrency Cepstrum	302
10.3	Phase Portrait	303
11	Spectrographic Visualization	309
11.1	Short-Time Fourier Transform	309
11.1.1	Principle	309
11.1.2	The Uncertainty Principle	312
11.2	Computation and Display of the Spectrogram	315
11.3	Function of the Package <code>signal</code>	319
11.4	Functions of the Package <code>tuner</code>	320
11.5	Function of the Package <code>phonTools</code>	324
11.6	Function of the Package <code>soundgen</code>	325
11.7	Functions of the Package <code>seewave</code>	326
11.7.1	2D Spectrogram	326
11.7.2	External Computing of the Short-Time Fourier Transform	349
11.7.3	Inverse Short-Time Fourier Transform	351
11.8	Measurements and Annotations on the Spectrogram	353
11.8.1	Simple Measure	353
11.8.2	Fancy Measure and Annotation	353
11.8.3	Automatic Parametrization	358
11.9	Complex Display and Printing	362
11.9.1	Multi-Spectrogram Graphic	362
11.9.2	Printing in a File	364
11.9.3	Long Spectrogram Graphic	365
11.10	Dynamic Spectrogram	366
11.11	Movie	368

11.12	Waterfall Display	370
11.13	3D Spectrogram	372
11.14	Mean Spectrum	375
11.15	Soundscape Spectrum	377
12	Mel-Frequency Cepstral and Linear Predictive Coefficients	381
12.1	Mel-Frequency Cepstral Coefficients (MFCCs)	381
12.1.1	Theory	381
12.1.2	Practice	385
12.2	Linear Predictive Coefficients (LPCs)	394
12.2.1	Theory	394
12.2.2	Practice	395
13	Frequency and Energy Tracking	399
13.1	Frequency Tracking	400
13.1.1	Dominant Frequency	400
13.1.2	Fundamental Frequency	405
13.1.3	Formants	416
13.1.4	Instantaneous Frequency	418
13.2	Energy Tracking	427
14	Frequency Filters	435
14.1	Preemphasis Filter	440
14.2	Comb Filter	443
14.3	Butterworth Filter	445
14.4	Wave Smoothing Filter	449
14.5	DFT and STDFT Filter	451
14.5.1	Principle	451
14.5.2	<code>ffilter()</code> Function	451
14.5.3	Examples	452
14.6	FIR Filter	455
14.6.1	Principle	455
14.6.2	<code>fir()</code> Function	455
14.6.3	Examples	456
14.6.4	Setting the Transfer Function	459
15	Other Modifications	465
15.1	Setting the Amplitude Envelope	465
15.2	Echoes and Reverberation	467
15.3	Amplitude Filtering	468
15.4	Modifications Using the ISTDFT	470
15.5	Modifications Using the Hilbert Transform	474
16	Indices for Ecoacoustics	479
16.1	α Indices	482
16.1.1	Functions	482
16.1.2	Batch Processing: How to Obtain a List of α Indices for a Set of Sounds	492

16.2	β Indices.....	494
16.2.1	Functions	494
16.2.2	Batch Processing: How to Obtain and Analyze a Matrix of β Indices.....	505
17	Comparison and Automatic Detection	521
17.1	Cross-Correlation	521
17.2	Frequency Coherence	528
17.3	Dynamic Time Warping	530
17.4	Automatic Identification	534
17.4.1	Principle	534
17.4.2	In Practice with the Package <code>monitor</code>	538
18	Synthesis	555
18.1	Silence	555
18.2	Noise.....	557
18.3	Non-sinusoidal Sound	558
18.3.1	Pulse Wave	558
18.3.2	Square Wave.....	560
18.3.3	Triangle and Sawtooth Waves	561
18.4	Sinusoidal Sound: Additive Synthesis	564
18.4.1	Principle	564
18.4.2	In Practice with <code>tuner</code>	566
18.4.3	In Practice with <code>seewave</code>	569
18.5	Sinusoidal Sound: Modulation Synthesis.....	574
18.5.1	Principle	574
18.5.2	In Practice with <code>signal</code>	574
18.5.3	In Practice with <code>seewave</code>	574
18.5.4	Examples	578
18.6	Tonal Synthesis	598
18.6.1	Principle	598
18.6.2	In Practice with <code>seewave</code>	598
18.6.3	Examples	600
18.7	Speech.....	604
18.7.1	Solution with the Package <code>phonTools</code>	604
18.7.2	Solution with the Package <code>soundgen</code>	605
A	List of R Functions.....	611
B	Sound Samples.....	619
	References.....	627
	Index.....	633