Contents

	Fore	word		page xv
	Prefe	ace		xix
Part I	Sound	Analysis and Representation Overview		1
1	Intro	duction		5
	1.1	On Vision and Hearing à la David Marr		8
	1.2	Top-Down versus Bottom-Up Analysis		11
	1.3	The Neuromimetic Approach		13
	1.4	Auditory Images		14
	1.5	The Ear as a Frequency Analyzer?		16
		The Third Sound		18
	1.7	Sound Understanding and Extraction of Meaning		18
	1.8	Leveraging Techniques from Machine Vision and		
		Machine Learning		19
	1.9	Machine Hearing Systems "by the Book"		20
2	Theo	ries of Hearing		23
	2.1	A "New" Theory of Hearing		23
		Newer Theories of Hearing		26
		Active and Nonlinear Theories of Hearing		27
	1			28
		The Auditory Image Theory of Hearing		29
		A THE TENTH - SEED		
3	On Lo	ogarithmic and Power-Law Hearing		33
		tral Equations and Homogeneous Solutions another lett		33
	3.1	Logarithms and Power Laws		33
	3.2	Log Frequency		35
	3.3	Log Power		37
	3.4	Bode Plots		38
	3.5	Perceptual Mappings		41
	3.6	Constant-Q Analysis		44
	3.7	Use Logarithms with Caution		44

1	4	Huma	an Hearing Overview	46
+		4.1	Human versus Machine	46
		4.2	Auditory Physiology	46
		4.3	Key Problems in Hearing	48
		4.4	Loudness	50
		4.5	Critical Bands, Masking, and Suppression	52
		4.6	Pitch Perception	56
		4.7	Timbre	65
		4.8	Consonance and Dissonance	66
		4.9	Speech Perception	69
		4.10	Binaural Hearing	72
		4.11	Auditory Streaming	74
		4.12	Nonlinearity	75
		4.13	A Way Forward	76
	-	A		
	5	Acou	stic Approaches and Auditory Influence	78
		5.1	Sound, Speech, and Music Modeling	78
		5.2	Short-Time Spectral Analysis	79
		5.3	Smoothing and Transformation of Spectra	83
		5.4	The Source–Filter Model and Homomorphic Signal Processing	85
		5.5	Backing Away from Logarithms	88
		5.6	Auditory Frequency Scales	88
		5.7	Mel-Frequency Cepstrum	89
		5.8	Linear Predictive Coding	91
		5.9	PLP and RASTA	92
		5.10	Auditory Techniques in Automatic Speech Recognition	93
		5.11	Improvements Needed	94
	Part II	System	s Theory for Hearing	05
	raitii	bystom	s Ineory for Hearing	95
	6	Introd	luction to Linear Systems	07
	00	maroc	addition to Linear Systems	91
		6.1	Smoothing: A Good Place to Start	98
		6.2	Linear Time-Invariant Systems	99
		6.3	Filters and Frequencies	101
		6.4	Differential Equations and Homogeneous Solutions	103
		6.5	Impulse Responses	103
		6.6	Causality and Stability	105
		6.7	Convolution	106
		6.8	Eigenfunctions and Transfer Functions	107
		6.9	Frequency Response	111
		6.10	Transforms and Operational Methods	113
		6.11	Rational Functions, and Their Poles and Zeros	116

	6.12	Graphical Computation of Transfer Function Gain and Phase	119
	6.13	Convolution Theorem	120
	6.14	Interconnection of Filters in Cascade, Parallel, and Feedback	121
	6.15	Summary and Next Steps	125
7	Discr	ete-Time and Digital Systems	126
	7.1	Simulating Systems in Computers	126
	7.2	Discrete-Time Linear Shift-Invariant Systems	126
	7.3	Impulse Response and Convolution	127
	7.4	Frequency in Discrete-Time Systems	127
	7.5	Z Transform and Its Inverse	128
	7.6	Unit Advance and Unit Delay Operators	129
	7.7	Filters and Transfer Functions	131
	7.8	Sampling and Aliasing	134
	7.9	Mappings from Continuous-Time Systems	136
	7.10	Filter Design	138
	7.11	Digital Filters	138
	7.12	Multiple Inputs and Outputs	141
	7.13	Fourier Analysis and Spectrograms	142
	7.14	Perspective and Further Reading	144
8	Resor	nators	145
	8.1	Bandpass Filters	145
	8.2	Four Resonant Systems	149
	8.3	Resonator Frequency Responses	152
	8.4	Resonator Impulse Responses	154
	8.5	The Complex Resonator and the Universal	
		Resonance Curve	157
	8.6	Complex Zeros from a Parallel System	159
	8.7	Keeping It Real	163
	8.8	Digital Resonators	165
ES	17/4	Byrea/ Distortion Response Patterns	
9	Gamn	natone and Related Filters	169
	9.1	Compound Resonators as Auditory Models	169
	9.2	Multiple Poles	170
	9.3	The Complex Gammatone Filter	172
	9.4	The Real Gammatone Filter	175
	9.5	All-Pole Gammatone Filters	178
	9.6	Gammachirp Filters	181
	9.7	Variable Pole Q	184
	9.8	Noncoincident Poles	184
	9.9	Digital Implementations	185

10	Nonli	near Systems		189
	10.1	Volterra Series and Other Descriptions		189
	10.2	The state of the second of the		191
		Hopf Bifurcation		192
		Distributed Bandpass Nonlinearity		194
		Response Curves of Nonlinear Systems		195
		Two-Tone Responses		198
		Nonlinearity and Aliasing		199
	10.8	Cautions		201
11	Autor	natic Gain Control		202
	11.1	Input-Output Level Compression		202
	11.2	Nonlinear Feedback Control		204
	11.3	AGC Compression at Equilibrium		205
	11.4	Multiple Cascaded Variable-Gain Stages		207
	11.5	Gain Control via Damping Control in	MAN TO SERVICE STATE OF THE PARTY OF THE PAR	
		Cascaded Resonators		209
	11.6	AGC Dynamics		210
		AGC Loop Stability		215
	11.8	Multiple-Loop AGC		218
12	Wave	s in Distributed Systems		219
2 1	wave	o III Diotributou Oyotoillo		21)
	12.1	Waves in Uniform Linear Media		221
	12.2	Transfer Functions from Wavenumbers		226
	12.3	Nonuniform Media		230
	12.4	Nonuniform Media as Filter Cascades		234
	12.5	Impulse Responses		235
	12.6	Group Velocity and Group Delay		235
FAL				
Part III	The Au	ditory Periphery		237
10	Adit	owy Filton Modele		220
13	Audit	ory Filter Models		239
	13.1	What Is an Auditory Filter?		241
	13.2	From Resonance to Gaussian Filters		243
	13.3	Ten Good Properties for Auditory Filter Models		244
	13.4	Representative Auditory Filter Models		246
	13.5	Complications: Time-Varying and Nonlinear		
		Auditory Filters		252
	13.6	Fitting Parameters of Filter Models		255
	13.7	Suppression		257
	13.8	Impulse Responses from Physiological Data		260
	13.9	Summary and Application to Cochlear Models		264

14	Modeli	ing the Cochlea		265
	14.1	On the Structure of the Cochlea		266
	14.2	The Traveling Wave		268
	14.3	1D, 2D, and 3D Hydrodynamics		273
	14.4	Long Waves, Short Waves, and 2D Models		276
	14.5	Active Micromechanics		279
	14.6	Scaling Symmetry and the Cochlear Map		280
	14.7	Filter-Cascade Cochlear Models		281
	14.8	Outer Hair Cells as Active Gain Elements		284
	14.9	Dispersion Relations from Mechanical Models and Experin	nents	287
	14.10	Inner Hair Cells as Detectors		288
	14.11	Adaptation to Sound via Efferent Control		288
	14.12	Summary and Further Reading		291
15	The CA	RFAC Digital Cochlear Model		293
	15.1	Putting the Pieces Together		293
	15.1	The CARFAC Framework		294
	15.2	Physiological Elements		294
	15.4	Analog and Bidirectional Models		297
	15.5	Open-Source Software		298
	15.6	Detailing the CARFAC		298
	24.8	Detailing the Criticist		270
16	The Ca	scade of Asymmetric Resonators		299
	16.1	The Linear Cochlear Model		299
	16.2	Coupled-Form Filter Realization		300
	10.2	Coupicu-i offit i fitter recalization		300
17	The Ou	ter Hair Cell		309
206				307
	17.1	Multiple Effects in One Mechanism		309
	17.2	The Nonlinear Function		311
	17.3	AGC Effect of DOHC		313
	17.4	Typical Distortion Response Patterns		315
	17.5	Completing the Loop		319
18	The Inn	ner Hair Cell		320
	18.1	Rectification with a Sigmoid		322
	18.2	Adaptive Hair-Cell Models		324
	18.3	A Digital IHC Model		328
19	The AG	C Loop Filter		331
	19.1	The CARFAC's AGC Loop		331
	19.1	AGC Filter Structure		332
	17.2	Tion bulletine		332

	19.3	Smoothing Filter Pole–Zero Analysis		332
	19.4	AGC Filter Temporal Response		335
	19.5	AGC Filter Spatial Response		337
	19.6	Time-Space Smoothing with Decimation		338
	19.7	Adapted Behavior		341
	19.8	Binaural or Multi-Ear Operation		341
	19.9	Coupled and Multistage AGC in CARFAC and		
		Other Systems		342
Part IV	The Aud	ditory Nervous System		345
20	Audito	ry Nerve and Cochlear Nucleus	OLDY William	347
	20.1	From Hair Cells to Nerve Firings	14.12	347
	20.2	Tonotopic Organization		350
	20.3	Fine Time Structure in Cochleagrams		351
	20.4	Cell Types in the Cochlear Nucleus		352
	20.5	Inhibition and Other Computation		353
	20.6	Spike Timing Codes		354
21	The Au	Iditory Image		355
	21.1	Movies of Sound	d. Zi	355
	21.2	History		356
	21.3	Stabilizing the Image		357
	21.4	Triggered Temporal Integration		360
	21.5	Conventional Short-Time Autocorrelation		365
	21.6	Asymmetry		367
	21.7	Computing the SAI		367
	21.8	Pitch and Spectrum		369
	21.9	Auditory Images of Music		369
	21.10	Auditory Images of Speech		369
	21.11	Summary SAI Tracks: Pitchograms		371
	21.12	Cochleagram from SAI		373
el,	21.13	The Log-Lag SAI		376
22	Binaur	al Spatial Hearing		379
	22.1	Rayleigh's Duplex Theory: Interaural Level and Phase		379
	22.2	Interaural Time and Level Differences	18.2	385
	22.3	The Head-Related Transfer Function		386
	22.4	Neural Extraction of Interaural Differences		389
	22.5	The Role of the Cochlear Nucleus and the Trapezoid Body		392
	22.6	Binaural Acoustic Reflex and Gain Control		394
	22.7	The Precedence Effect		395

	22.8	Completing the Model	397
	22.9	Interaural Coherence	397
	22.10	Binaural Applications	398
		at Matching Parity Matching	
23	The Au	Iditory Brain	400
	23.1	Scene Analysis: ASA and CASA	400
	23.2	Attention and Stream Segregation	402
	23.3	Stages in the Brain	407
	23.4	Higher Auditory Pathways	410
	23.5	Prospects	415
Part V	Learning	and Applications	417
24	Neural	Networks for Machine Learning	419
24		of latter of latter of latter to a mismal marrorsy inquisitions.	ek Lyen
	24.1	Learning from Data	419
	24.2	The Perceptron	420
	24.3	The Training Phase	421
	24.4	Nonlinearities at the Output	423
	24.5	Nonlinearities at the Input	426
	24.6	Multiple Layers	428
	24.7	Neural Units and Neural Networks	428
	24.8	Training by Error Back-Propagation	429
	24.9	Cost Functions and Regularization	432
	24.10	Multiclass Classifiers	434
	24.11	Neural Network Successes and Failures	436
		Statistical Learning Theory	437
	24.13	Summary and Perspective	439
25	Feature	e Spaces	441
	25.1	Feature Engineering	442
	25.2	Automatic Feature Optimization by Deep Networks	443
	25.3	Bandpass Power and Quadratic Features	444
	25.4	Quadratic Features of Cochlear Filterbank Outputs	445
	25.5	Nonlinearities and Gain Control in Feature Extraction	446
	25.6	Neurally Inspired Feature Extraction	448
	25.7	Sparsification and Winner-Take-All Features	448
	25.8	Which Approach Will Win?	449
26	Sound	Search	450
	26.1	Modeling Sounds	451
	26.2	Ranking Sounds Given Text Queries	457
	26.3	Experiments	461

	26.4	Results			463
	26.5	Conclusions and Followup			465
27	Musica	al Melody Matching			467
	27.1	A 1 i + 1			160
	27.1	Algorithm			469
	27.2	L'Aperilles			475
	27.3	Discussion			478
	27.4	Summary and Conclusions			480
28	Other /	Applications			481
	28.1	Auditory Physiology and Psychoacou	ustics		481
	28.2	Audio Coding and Compression			482
	28.3	Hearing Aids and Cochlear Implants		/	483
	28.4	Visible Sound		15TUBIN	489
	28.5	Diagnosis			491
	28.6	Speech and Speaker Recognition			493
	28.7	Music Information Retrieval			493
	28.8	Security, Surveillance, and Alarms			494
	28.9	Diarization, Summarization, and Inde	exing		495
	28.10		Adultiple Layers		495
				T.48	
	Bibliog	graphy			497
	Author				545
	Subjec	t Index			557
	,				