

Contents

1	Elements of the Description	1
1.1	Sound	1
1.1.1	A Metaphor	1
1.1.2	Getting Serious	2
1.1.3	Sound as a Physical Phenomenon	3
1.1.4	Sound Waves	5
1.1.5	Detecting Sound	6
1.2	Frequency and Amplitude	7
1.2.1	Periodic Signals vs. Noise	7
1.2.2	Intensity of Sound	9
1.3	Harmonics and Superposition	9
1.3.1	Beyond Frequency and Amplitude: Timbre	9
1.3.2	Adding up Waves	11
1.4	Sonograms	13
1.4.1	Onomatopoeias	13
1.4.2	Building a Sonogram	14
2	Sources and Filters	17
2.1	Sources of Sound	17
2.1.1	Flow, Air Density and Pressure	17
2.1.2	Mechanisms for Generating Sound	20
2.2	Filters and Resonances	22
2.2.1	Same Source, Different Sounds	22
2.2.2	Traveling Waves	23
2.2.3	Resonances	25
2.2.4	Modes and Natural Frequencies	26
2.2.5	Standing Waves	28
2.3	Filtering a Signal	32
2.3.1	Conceptual Filtering	32
2.3.2	Actual Filtering	33
2.3.3	The Emission from a Tube	34

3	Anatomy of the Vocal Organ	37
3.1	Morphology and Function	37
3.1.1	General Mechanism of Sound Production	37
3.1.2	Morphological Diversity	38
3.1.3	The Richness of Birdsong	38
3.2	The Oscine Syrinx	41
3.2.1	The Source of Sound	41
3.2.2	The Role of the Muscles	42
3.2.3	Vocal Learners and Intrinsic Musculature	44
3.3	The Nonoscine Syrinx	44
3.3.1	The Example of the Pigeons	45
3.4	Respiration	46
4	The Sources of Sound in Birdsong	47
4.1	Linear Oscillators	47
4.1.1	A Spring and a Swing	47
4.1.2	Energy Losses	49
4.2	Nonlinear Oscillators	50
4.2.1	Bounding Motions	50
4.2.2	An Additional Dissipation	50
4.2.3	Nonlinear Forces and Nonlinear Oscillators	51
4.3	Oscillations in the Syrinx	54
4.3.1	Forces Acting on the Labia	54
4.3.2	Self-Sustained Oscillations	56
4.3.3	Controlling the Oscillations	58
4.4	Filtering the Signal	59
5	The Instructions for the Syrinx	61
5.1	The Structure of a Song	61
5.1.1	Syllables	61
5.1.2	Bifurcations	63
5.2	The Construction of Syllables	66
5.2.1	Cyclic Gestures	66
5.2.2	Paths in Parameter Space	68
5.3	The Active Control of the Airflow: a Prediction	70
5.4	Experimental Support	72
5.5	Lateralization	76
6	Complex Oscillations	79
6.1	Complex Sounds	79
6.1.1	Instructions vs. Mechanics	79
6.1.2	Subharmonics	81
6.2	Acoustic Feedback	82
6.2.1	Source-Filter Separation	82
6.2.2	A Time-Delayed System	82

6.2.3	Coupling Between Source and Vocal Tract	83
6.3	Labia with Structure	86
6.3.1	The Role of the Dynamics	86
6.3.2	The Two-Mass Model	87
6.3.3	Asymmetries	89
6.4	Choosing Between Two Models	91
6.4.1	Signatures of Interaction Between Sources	93
6.4.2	Modeling Two Acoustically Interacting Sources	95
6.4.3	Interact, Don't Interact	96
7	Synthesizing Birdsong	99
7.1	Numerical Integration and Sound	99
7.1.1	Euler's Method	100
7.1.2	Runge-Kutta Methods	100
7.1.3	Listening to Numerical Solutions	102
7.2	Analog Integration	103
7.2.1	Operational Amplifiers: Adding and Integrating	103
7.2.2	An Electronic Syrnix	105
7.3	Playback Experiments	108
7.4	Why Numerical Work?	108
7.4.1	Definition of Impedance	109
7.4.2	Impedance of a Pipe	110
8	From the Syrnix to the Brain	113
8.1	The Motor Pathway	114
8.2	The AFP Pathway	115
8.3	Models for the Motor Pathway: What for?	116
8.3.1	Building Blocks for Modeling Brain Activity	117
8.4	Conceptual Models and Computational Models	119
8.4.1	Simulating the Activity of HVC Neurons	120
8.4.2	Simulating the Activity of RA Neurons	124
8.4.3	Qualitative Predictions	126
8.5	Sensorimotor Control of Singing	126
8.6	Computational Models and Learning	127
8.7	Rate Models	129
8.8	Lights and Shadows of Modeling Brain Activity	132
9	Complex Rhythms	133
9.1	Linear vs. Nonlinear <i>Forced</i> Oscillators	133
9.2	Duets	135
9.2.1	Hornero Duets	135
9.2.2	A Devil's Staircase	136
9.2.3	Test Duets	137
9.3	Nonlinear Dynamics	140
9.3.1	A Toy Nonlinear Oscillator	140

X Contents

9.3.2	Periodic Forcing	141
9.3.3	Stable Periodic Solutions	142
9.3.4	Locking Organization	143
9.4	Respiration	146
9.4.1	Periodic Stimulation for Respiratory Patterns	146
9.4.2	A Model	146
9.5	Body and Brain	148
References		151