

Contents

Foreword	vii
Preface	ix
Acknowledgments	xi
1 Introduction	1
1.1 For whom is this book?	1
1.2 What is in the book?	2
1.3 Do I need a computer for this book?	3
Software	3
1.4 Why learn this now?	4
1.5 What is the subtext?	5
1.6 How is the book organized?	6
I Perspectives	9
2 Computational Neuroscience and You	11
2.1 Why learn this?	11
2.2 Brain metaphors	11
2.3 Compare and contrast computer and brain	12
2.4 Origins of computer science and neuroscience	14
2.5 Levels	15

	Levels of organization	16
	Levels of investigation	18
2.6	New engineering vs. old engineering	18
2.7	The neural code	20
2.8	The goals and methods of computational neuroscience	22
2.9	Summary and thoughts	23
3	Basic Neuroscience	25
3.1	Why learn this?	25
3.2	Microscopic view of the nervous system	26
3.3	Macroscopic view of the nervous system	29
	Slicing the brain	29
3.4	Parts of the brain	31
3.5	How do we learn about the brain?	34
	Anatomical methods	35
3.6	Neurophysiology	36
3.7	Molecular biology and neuropharmacology	37
3.8	Psychophysics	38
3.9	Clinical neurology and neuropsychology	39
	Ablative diseases	39
	Intrinsic diseases	40
3.10	Summary and thoughts	41
II	Computers	43
4	Computer Representations	45
4.1	Why learn this?	45
4.2	Calculator or typewriter	47
4.3	Punch cards and Boolean algebra	48
4.4	Analog vs. digital representations	50
4.5	Types of computer representations	51
4.6	Representation of numbers	52
	Representation of letters and words	55
4.7	Representation of pictures	56
4.8	Neurospeculation	59
4.9	Summary and thoughts	62
5	The Soul of an Old Machine	63
5.1	Why learn this?	63
5.2	The art of the hack	64
5.3	Software and hardware	65
5.4	Basic computer design	66
	Pointers come from computer memory design	67
	Sequential algorithms come from computer control flow	67

	CPU: machine commands	69
5.5	Programs and hacks	69
	Conditionals	71
5.6	Pointer manipulation	74
	A kludge	75
	A computer virus	76
5.7	Neurospeculation	77
5.8	Summary and thoughts	82

III Cybernetics 83

6 Concept Neurons 87

6.1	Why learn this?	87
6.2	History and description of McCulloch-Pitts neurons . . .	88
6.3	Describing networks by weights and states	90
	Calculating total-summed-input by dot product	92
	Calculating state	94
6.4	From single unit to network of units	95
6.5	Network architecture	102
6.6	Summary and thoughts	104

7 Neural Coding 105

7.1	Why learn this?	105
7.2	Coding in space: ensemble codes	106
	Local vs. distributed ensemble coding	108
7.3	Coding with volts and chemicals: neural state code . . .	110
7.4	Coding in time: temporal and rate codes	111
	Temporal integration	112
	Clocking	113
7.5	Frequency coding	114
7.6	Summary and thoughts	118

8 Our Friend the Limulus 121

8.1	Why learn this?	121
8.2	The biology	122
8.3	What we can ignore	122
8.4	Why the eye lies: the problem	123
8.5	Design issues	126
	Making the model small — scaling	126
	Making the model small — dimensional reduction	127
	Eliminating edge effects — wraparound	128
	Presenting the input — parameterization	130
	Parameterizing the activation function	132
	Parameterizing the weight matrix	132

8.6	The limulus equation	134
8.7	State calculation	135
8.8	Life as a limulus	137
8.9	Summary and thoughts	139
9	Supervised Learning: Delta Rule and Back-Propagation	141
9.1	Why learn this?	141
9.2	Supervised learning	142
9.3	The delta rule	145
	The energy analogy	146
	The delta rule solves AND	147
9.4	Backward propagation	149
9.5	Distributed representations	151
9.6	Distributed representation in eye movement control . . .	152
	Design of the model	154
	Results from the model: generalization	157
	Exploration of the model: hidden unit analysis	159
	Computer modeling vs. traditional mathematical modeling	161
9.7	Summary and thoughts	162
10	Associative Memory Networks	163
10.1	Why learn this?	163
10.2	Memories in an outer product	164
	Association across a single synapse	164
	The outer product of two vectors	165
	Making hetero- and autoassociative memories	167
	Limit cycles	171
	Instantaneous vs. gradual learning and recall	174
10.3	Critique of the Hopfield network	176
10.4	Summary and thoughts	177
IV	Brains	179
11	From Soap to Volts	189
11.1	Why learn this?	189
11.2	Basic cell design	190
11.3	Morphing soap and salt to batteries and resistors	192
11.4	Converting the RC circuit into an equation	194
	Capacitance and current	195
	Adding up the currents	196
11.5	Parameter dependence	198
	Advantages and disadvantages of numerical integration .	200
11.6	Time constant and temporal summations	201
11.7	Slow potential theory	205

	Averaging by adding PSPs	208
11.8	Summary and thoughts	211
12	Hodgkin-Huxley Model	213
12.1	Why learn this?	213
12.2	From passive to active	213
	The resting membrane potential is about -70 mV	214
	The membrane is insulator, capacitor, and battery	214
	Synaptic inputs aren't current injections	215
12.3	History of the action potential	216
	Hodgkin and Huxley	216
12.4	The parallel-conductance model	217
	The circuit	217
	Currents	219
	Calculations	220
	Where do the batteries come from?	221
12.5	Behavior of the active channels	223
	Feedback systems	224
	Particle duality	226
	Particle dynamics	227
12.6	The particle equations	228
	State variables define a state	229
12.7	Simulation	231
12.8	Implications for signaling	233
	The threshold and channel memory	233
	Rate coding redux	234
12.9	Summary and thoughts	237
13	Compartment Modeling	239
13.1	Why learn this?	239
13.2	Dividing into compartments	241
	Building the model	242
13.3	Chemical synapse modeling	245
	Shunting inhibition	246
	GABA and glutamate	248
13.4	Passive neuron model	250
	Synaptic responses	253
13.5	Back-propagating spikes and the Hebb synapse	254
13.6	Summary and thoughts	257
14	From Artificial Neural Network to Realistic Neural Network	259
14.1	Why learn this?	259
14.2	Hopfield revisited	259
14.3	Suppression model for reducing interference	261

14.4	A digression into philosophy	262
14.5	Acetylcholine has multiple effects	264
	The dual-matrix hypothesis	265
	True confessions	266
14.6	Summary and thoughts	267
15	Neural Circuits	269
15.1	Why learn this?	269
15.2	The basic layout	269
15.3	Hippocampus	270
15.4	Thalamus	272
15.5	Cerebellum	273
15.6	Basal ganglia	275
15.7	Neocortex	277
15.8	Summary and thoughts	278
16	The Basics	281
16.1	Why learn this?	281
16.2	Units	282
	Scientific notation	282
	Numerical prefixes	282
	Units and abbreviations	283
	Unit conversions	285
	Dimensional analysis	286
16.3	Binary	287
	Translating back and forth	287
	Addition and subtraction	289
	Octal and hex	289
	Boolean algebra	290
16.4	Linear algebra	290
	What is algebra? Why linear?	291
	Addition and subtraction	292
	Dot product	292
	Orthogonality	293
	Outer product	293
	Matrix multiplication	294
16.5	Numerical calculus	295
	Infinitesimals	296
	Numerical solutions	297
	Mathematical symbols	299
	Analytic solution to the charging curve	299
16.6	Electrical engineering	300
	The three big laws: Ohm, Kirchhoff, and the other one	301
	Ohm's law	301
	Capacitance	304

References	307
Glossary	313
Index	357