

# Contents

<b>Foreword</b>	<b>vii</b>
<b>Preface</b>	<b>ix</b>
<b>Acknowledgments</b>	<b>xi</b>
<b>1 Introduction</b>	<b>1</b>
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
<b>I Perspectives</b>	<b>9</b>
<b>2 Computational Neuroscience and You</b>	<b>11</b>
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
<b>3</b>	<b>Basic Neuroscience</b>	<b>25</b>
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
<b>II</b>	<b>Computers</b>	<b>43</b>
<b>4</b>	<b>Computer Representations</b>	<b>45</b>
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
<b>5</b>	<b>The Soul of an Old Machine</b>	<b>63</b>
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
<b>III Cybernetics</b>		<b>83</b>
<b>6</b>	<b>Concept Neurons</b>	<b>87</b>
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
<b>7</b>	<b>Neural Coding</b>	<b>105</b>
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
<b>8</b>	<b>Our Friend the Limulus</b>	<b>121</b>
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
<b>9</b>	<b>Supervised Learning: Delta Rule and Back-Propagation</b>	<b>141</b>
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
<b>10</b>	<b>Associative Memory Networks</b>	<b>163</b>
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
<b>IV</b>	<b>Brains</b>	<b>179</b>
<b>11</b>	<b>From Soap to Volts</b>	<b>189</b>
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
<b>12</b>	<b>Hodgkin-Huxley Model</b>	<b>213</b>
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
<b>13</b>	<b>Compartment Modeling</b>	<b>239</b>
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
<b>14</b>	<b>From Artificial Neural Network to Realistic Neural Network</b>	<b>259</b>
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
<b>15</b>	<b>Neural Circuits</b>	<b>269</b>
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
<b>16</b>	<b>The Basics</b>	<b>281</b>
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



<http://www.springer.com/978-0-387-95526-1>

From Computer to Brain  
Foundations of Computational Neuroscience  
Lytton, W.W.  
2002, XX, 364 p., Softcover  
ISBN: 978-0-387-95526-1