

<b>2 Computational Neuroscience and You</b>	<b>2–1</b>
2.1 Origins of computer science and neuroscience . . . . .	2–7
2.2 Levels . . . . .	2–9
2.3 The neural code . . . . .	2–16
2.4 The goals and methods of computational neuroscience . . . . .	2–19
<b>3 Basic Neuroscience</b>	<b>3–1</b>
3.1 Microscopic view of the nervous system . . . . .	3–1
3.1.1 A typical pyramidal cell of the mammalian cortex: . . . . .	3–2
3.1.2 The synapse . . . . .	3–3
3.1.3 The action potential . . . . .	3–4
3.1.4 Synaptic mechanisms . . . . .	3–5
3.2 Macroscopic view of the nervous system . . . . .	3–6
3.2.1 Seven main parts of the Central Nervous System (CNS): . . . . .	3–6
3.2.2 Simplified view at parts of the brain . . . . .	3–8
3.2.3 Another view at major brain divisions . . . . .	3–9
3.2.4 Coordinate systems . . . . .	3–10
3.2.5 The three planes of body sectioning: . . . . .	3–11
3.2.6 Another view at neuronal axes . . . . .	3–13
3.3 Organization and functions of main brain areas . . . . .	3–14
3.3.1 The cortex . . . . .	3–15
3.3.2 The columnar organization of the neocortex . . . . .	3–17
3.3.3 Olfactory cortex and hippocampus . . . . .	3–18
3.3.4 The thalamus . . . . .	3–19
3.3.5 The basal ganglia and the cerebellum . . . . .	3–20
3.3.6 The autonomic and enteric nervous systems . . . . .	3–21
3.4 How do we learn about the brain? . . . . .	3–22
3.4.1 Anatomical methods and related imaging . . . . .	3–24
3.5 Neurophysiology — the study of function . . . . .	3–27
3.6 Molecular biology . . . . .	3–30
3.7 Neuropharmacology . . . . .	3–31
3.8 Psychophysics . . . . .	3–32
3.9 Clinical neurology and neuropsychology . . . . .	3–33

3.9.1 Ablative diseases . . . . .	3–34
3.9.2 Intrinsic diseases . . . . .	3–37
3.10 Summary and thoughts . . . . .	3–39
<b>4 Concept neurons — Introduction to artificial neural networks</b>	<b>4–1</b>
4.1 Typical neuron/nerve cell: . . . . .	4–1
4.2 A simplistic model of a biological neuron . . . . .	4–3
4.3 Models of artificial neurons . . . . .	4–4
4.3.1 The NAND gate . . . . .	4–6
4.3.2 Electronics of the NAND gate . . . . .	4–7
4.4 A layer of neurons . . . . .	4–9
4.5 Static and Dynamic Systems — General Concepts . . . . .	4–11
4.6 Continuous-time dynamic systems . . . . .	4–12
4.6.1 Discrete-time dynamic systems . . . . .	4–13
4.6.2 Example: A continuous-time generator of a sinusoid . . . . .	4–15
4.6.3 Example: A discrete-time generator of a sinusoid . . . . .	4–17
<b>5 Model of a simple vision system</b>	<b>5–1</b>
5.1 The Limulus . . . . .	5–1
5.2 Lateral inhibition . . . . .	5–4
5.3 One-dimensional model of the limulus vision . . . . .	5–5
5.3.1 1-D feedforward model of lateral inhibition . . . . .	5–5
5.3.2 Maths of lateral inhibition. A Mexican hat mask . . . . .	5–6
5.3.3 Designing a good Mexican hat mask . . . . .	5–9
5.3.4 Sigmoidal activation function . . . . .	5–11
5.3.5 Feedforward and recurrent networks . . . . .	5–12
5.3.6 1-D recurrent model of limulus vision . . . . .	5–13
5.4 Recurrent 2-D model . . . . .	5–17
5.4.1 2-D structure of the limulus vision . . . . .	5–17
5.4.2 2-D masks and convolution . . . . .	5–19
5.4.3 2-D recurrent network operations . . . . .	5–20
5.5 Images in MATLAB . . . . .	5–23

<b>6 Learning and Self-Organization</b>	<b>6-1</b>
6.1 Introduction to learning . . . . .	6-1
6.2 Supervised and Unsupervised Learning . . . . .	6-3
6.3 Hebbian learning . . . . .	6-8
6.3.1 Introductory concepts . . . . .	6-8
6.3.2 Basic structure of Hebbian learning neural networks . . . . .	6-11
6.3.3 Stable Hebbian learning. Oja's rule . . . . .	6-13
6.4 Competitive learning . . . . .	6-18
6.4.1 The Similarity-Measure Layer . . . . .	6-19
6.4.2 The Competitive Layer . . . . .	6-23
6.4.3 Simple Competitive Learning . . . . .	6-26
6.4.4 Example of simple competitive learning . . . . .	6-28
6.5 Self-Organizing Feature Maps . . . . .	6-29
6.5.1 Structure of Self-Organizing Feature maps . . . . .	6-29
6.5.2 Feature Maps . . . . .	6-31
6.5.3 Learning Algorithm for Self-Organizing Feature Maps . . . . .	6-32
6.5.4 Example of a Self-Organizing Feature Map formation . . . . .	6-36
6.5.5 Higher dimension Kohonen maps — Categorization of data . . . . .	6-39
6.6 Supervised Learning . . . . .	6-42
6.6.1 Detailed structure of a Two-Layer Perceptron — the most commonly used feedforward neural network . . . . .	6-43
6.6.2 The structure of the two-layer back-propagation network with learning . . . . .	6-44
6.7 Model of eye movement control . . . . .	6-45
6.7.1 The two-layer perceptron model . . . . .	6-48
6.7.2 Learning procedure . . . . .	6-51
<b>7 Associative Memory Networks</b>	<b>7-1</b>
7.1 Introductory concepts . . . . .	7-1
7.1.1 Encoding and decoding single memories . . . . .	7-3
7.1.2 Feedforward Associative Memory . . . . .	7-4
7.1.3 Encoding multiple memories . . . . .	7-5
7.1.4 Decoding operation . . . . .	7-6
7.1.5 Numerical examples . . . . .	7-8
7.2 Recurrent Associative Memory — Discrete Hopfield networks . . . . .	7-9

7.2.1 Structure . . . . .	7-9
7.2.2 Example of the Hopfield network behaviour for $m = 3$ . . . . .	7-12
7.2.3 Another example of Hopfield network (from Lytton) . . . . .	7-14
7.2.4 Retrieval of numerical patterns stored in a Recurrent Binary Associative Memory (Hopfield network) . . . . .	7-16
7.3 The energy landscape . . . . .	7-20
7.3.1 Example of a two-neuron recurrent associative memory . . . . .	7-22
<b>8 From Soap to Volts — Hardware of the brain</b>	<b>8-1</b>
8.1 The cell . . . . .	8-1
8.1.1 Neurons and their connections . . . . .	8-2
8.1.2 Cell Bio-Chemistry . . . . .	8-3
8.2 Basic cell design . . . . .	8-7
8.3 Morphing soap and salt to batteries and resistors . . . . .	8-11
8.4 Analysis of the RC circuit . . . . .	8-15
8.4.1 Charge and current . . . . .	8-16
8.4.2 Resistors . . . . .	8-17
8.4.3 Capacitors . . . . .	8-17
8.4.4 Summing currents — Kirchhoff's law . . . . .	8-18
8.4.5 Equation of the RC circuit . . . . .	8-19
8.4.6 Time constant of the RC circuit . . . . .	8-20
8.5 Rate (frequency) coding . . . . .	8-22
8.6 Temporal integration . . . . .	8-23
8.6.1 Temporal integration of two current pulses . . . . .	8-24
8.6.2 Temporal integration of many current pulses . . . . .	8-25
8.6.3 Membrane as a frequency detector . . . . .	8-26
8.7 Slow potential theory . . . . .	8-27
8.8 A synapse — Postsynaptic potential . . . . .	8-29
8.8.1 Realistic model of Post-Synaptic Potentials . . . . .	8-30
8.9 More on frequency coding . . . . .	8-32
8.10 Summary and thoughts . . . . .	8-36
<b>9 Generation of Action Potential — Hodgkin-Huxley Model</b>	<b>9-1</b>
9.1 Passive and active membrane models . . . . .	9-1

9.2	Ion channels . . . . .	9–2
9.3	From passive to the active membrane model . . . . .	9–3
9.4	Parallel-conductance model of the membrane . . . . .	9–4
9.5	Where do the batteries come from? . . . . .	9–5
9.5.1	Sodium battery — Nernst potential . . . . .	9–6
9.6	The membrane voltage equation . . . . .	9–10
9.6.1	Calculating the resting potential . . . . .	9–12
9.7	Modelling the active channels . . . . .	9–13
9.7.1	The potassium channel — $n$ particles . . . . .	9–14
9.7.2	The sodium channel — $m$ and $h$ particles . . . . .	9–16
9.7.3	Action potential — the pulse . . . . .	9–18
9.7.4	The threshold and channel memory . . . . .	9–22
9.7.5	Rate coding redux . . . . .	9–25
9.8	Summary and thoughts . . . . .	9–29
<b>13</b>	<b>Compartment modeling</b>	<b>13–1</b>
13.1	Why learn this? . . . . .	13–1
13.2	Dividing into compartments . . . . .	13–5
13.2.1	Building the model . . . . .	13–8
13.3	Chemical synapse modeling . . . . .	13–14
13.3.1	Shunting inhibition . . . . .	13–22
13.3.2	GABA and glutamate . . . . .	13–25
13.4	Passive neuron model . . . . .	13–29
13.4.1	Synaptic responses . . . . .	13–33
13.5	Back-propagating spikes and the Hebb synapse . . . . .	13–37
13.6	Summary and thoughts . . . . .	13–41