

Contents

	<i>List of Figures</i>	page xii
	<i>Preface</i>	xv
	<i>Acknowledgments</i>	xix
	<i>List of Abbreviations</i>	xxi
1	Introduction to the World of Vision	1
	1.1 Evolution of the Visual System	2
	1.2 The Future of Vision	4
	1.3 Why Is Vision Difficult?	5
	1.4 Four Key Features of Visual Recognition	6
	1.5 The Travels and Adventures of a Photon	8
	1.6 Tampering with the Visual System	11
	1.7 Functions of Circuits in the Visual Cortex	12
	1.8 Toward the Neural Correlates of Visual Consciousness	14
	1.9 Toward a Theory of Visual Cognition	16
	1.10 Summary	18
	Further Reading	19
2	The Travels of a Photon: Natural Image Statistics and the Retina	20
	2.1 Natural Images Are Special	20
	2.2 Efficient Coding by Allocating More Resources Where They Are Needed	22
	2.3 The Visual World Is Slow	23
	2.4 We Continuously Move Our Eyes	24
	2.5 The Retina Extracts Information from Light	26
	2.6 It Takes Time for Information to Reach the Optic Nerve	32
	2.7 Visual Neurons Respond to a Specific Region within the Visual Field	32
	2.8 The Difference-of-Gaussians Operator Extracts Salient Information and Discards Uniform Surfaces	34
	2.9 Visual Neurons Show Transient Responses	35
	2.10 On to the Rest of the Brain	36
	2.11 Digital Cameras versus the Eye	38
	2.12 Summary	39
	Further Reading	39
		vii

3	The Phenomenology of Seeing	41
	3.1 What You Get Ain't What You See	41
	3.2 Perception Depends on Adequately Grouping Parts of an Image through Specific Rules	42
	3.3 The Whole Can Be More than the Sum of Its Parts	44
	3.4 The Visual System Tolerates Large Image Transformations	45
	3.5 Pattern Completion: Inferring the Whole from Visible Parts	48
	3.6 Visual Recognition Is Very Fast	49
	3.7 Spatial Context Matters	53
	3.8 The Value of Experience	54
	3.9 People Are Approximately the Same Wherever You Go, with Notable Exceptions	57
	3.10 Animals Excel at Vision Too	58
	3.11 Summary	60
	Further Reading	61
4	Creating and Altering Visual Percepts through Lesions and Electrical Stimulation	62
	4.1 Correlations and Causality in Neuroscience	63
	4.2 A Panoply of Lesion Tools to Study the Functional Role of Brain Areas in Animals	63
	4.3 Some Tools to Study the Functional Role of Brain Areas in Humans	67
	4.4 Partial Lesions in the Primary Visual Cortex Lead to Localized Scotomas	69
	4.5 <i>What</i> and <i>Where</i> Pathways	71
	4.6 Dorsal Stream Lesions in the <i>Where</i> Pathway	72
	4.7 The Inferior Temporal Cortex Is Critical for Visual Object Recognition in Monkeys	73
	4.8 Lesions Leading to Shape Recognition Deficits in Humans	74
	4.9 Invasive Electrical Stimulation of the Human Brain	78
	4.10 Electrical Stimulation in the Primate Visual Cortex	82
	4.11 Summary	85
	Further Reading	86
5	Adventures into <i>Terra Incognita</i>: Probing the Neural Circuits along the Ventral Visual Stream	87
	5.1 About the Neocortex	87
	5.2 Connectivity to and from the Primary Visual Cortex	89
	5.3 The Gold Standard to Examine Neural Function	91
	5.4 Neurons in the Primary Visual Cortex Respond Selectively to Bars Shown at Specific Orientations	92
	5.5 Complex Neurons Show Tolerance to Position Changes	93
	5.6 Nearby Neurons Show Similar Properties	96

5.7	Quantitative Phenomenological Description of the Responses in the Primary Visual Cortex	96
5.8	A Simple Model of Orientation Selectivity in the Primary Visual Cortex	97
5.9	Many Surprises Left in V1	99
5.10	Divide and Conquer	101
5.11	We Cannot Exhaustively Study All Possible Visual Stimuli	102
5.12	We Live in the Visual Past: Response Latencies Increase along the Ventral Stream	104
5.13	Receptive Field Sizes Increase along the Ventral Visual Stream	105
5.14	What Do Neurons beyond V1 Prefer?	106
5.15	Brains Construct Their Interpretation of the World: The Case of Illusory Contours	107
5.16	A Colorful V4	108
5.17	Attentional Modulation	109
5.18	Summary	110
	Further Reading	111
6	From the Highest Echelons of Visual Processing to Cognition	112
6.1	A Well-Connected Area	112
6.2	ITC Neurons Show Shape Selectivity	113
6.3	Selectivity in the Human Ventral Visual Cortex	115
6.4	What Do ITC Neurons <i>Really</i> Want?	117
6.5	ITC Neurons Show Tolerance to Object Transformations	118
6.6	Neurons Can Complete Patterns	119
6.7	IT Takes a Village	120
6.8	ITC Neurons Are More Concerned with Shape than Semantics	123
6.9	Neuronal Responses Adapt	125
6.10	Representing Visual Information in the Absence of a Visual Stimulus	127
6.11	Task Goals Modulate Neuronal Responses	128
6.12	The Role of Experience in Shaping Neuronal Tuning Preferences	129
6.13	The Bridge between Vision and Cognition	130
6.14	Summary	131
	Further Reading	132
7	Neurobiologically Plausible Computational Models	133
7.1	Why Bother with Computational Models?	133
7.2	Models of Single Neurons	135
7.3	Network Models	140
7.4	Firing-Rate Network Models	143
7.5	The Convolution Operation	143
7.6	Hopfield Networks	145
7.7	Neural Networks Can Solve Vision Problems	148

x	Contents	
	7.8 Extreme Biological Realism: The “Blue Brain” Project	150
	7.9 Summary	151
	Further Reading	151
8	Teaching Computers How to See	152
	8.1 Recap and Definitions	152
	8.2 Common Themes in Modeling the Ventral Visual Stream	155
	8.3 A Panoply of Models	156
	8.4 A General Scheme for Object Recognition Tasks	158
	8.5 Bottom-Up Hierarchical Models of the Ventral Visual Stream	159
	8.6 Learning the Weights	162
	8.7 Labeled Databases	167
	8.8 Cross-Validation Is Essential	169
	8.9 A Cautionary Note: Lots of Parameters!	170
	8.10 A Famous Example: Digit Recognition in a Feedforward Network Trained by Gradient Descent	171
	8.11 A Deep Convolutional Neural Network in Action	171
	8.12 To Err Is Human and Algorithmic	176
	8.13 Predicting Eye Movements	179
	8.14 Predicting Neuronal Firing Rates	183
	8.15 All Models Are Wrong; Some Are Useful	185
	8.16 Horizontal and Top-Down Signals in Visual Recognition	186
	8.17 Predictive Coding	187
	8.18 Summary	190
	Further Reading	191
9	Toward a World with Intelligent Machines That Can Interpret the Visual World	192
	9.1 The Turing Test for Vision	193
	9.2 Computer Vision Everywhere	195
	9.3 Incorporating Temporal Information Using Videos	199
	9.4 Major Milestones in Object Classification	200
	9.5 Real-World Applications of Computer Vision Algorithms for Object Classification	203
	9.6 Computer Vision to Help People with Visual Disabilities	207
	9.7 Deep Convolutional Neural Networks Work Outside of Vision Too	209
	9.8 Image Generators and GANs	210
	9.9 DeepDream and XDream: Elucidating the Tuning Properties of Computational Units and Biological Neurons	211
	9.10 Reflections on Cross-Validation and Extrapolation	213
	9.11 Adversarial Images	216
	9.12 Deceptively Simple Tasks That Challenge Computer Vision Algorithms	217

9.13	Challenges Ahead	218
9.14	Summary	223
	Further Reading	224
10	Visual Consciousness	225
10.1	A Non-exhaustive List of Possible Answers	227
10.2	The Search for the NCC: The Neuronal Correlates of Consciousness	230
10.3	The Representation of Conscious Content Must Be Explicit	231
10.4	Experimental Approaches to Study Visual Consciousness	233
10.5	Neurophysiological Correlates of Visual Consciousness during Binocular Rivalry	237
10.6	Desiderata for the NCC	239
10.7	Integrated Information Theory	240
10.8	Summary	243
	Further Reading	243
	<i>Index</i>	244