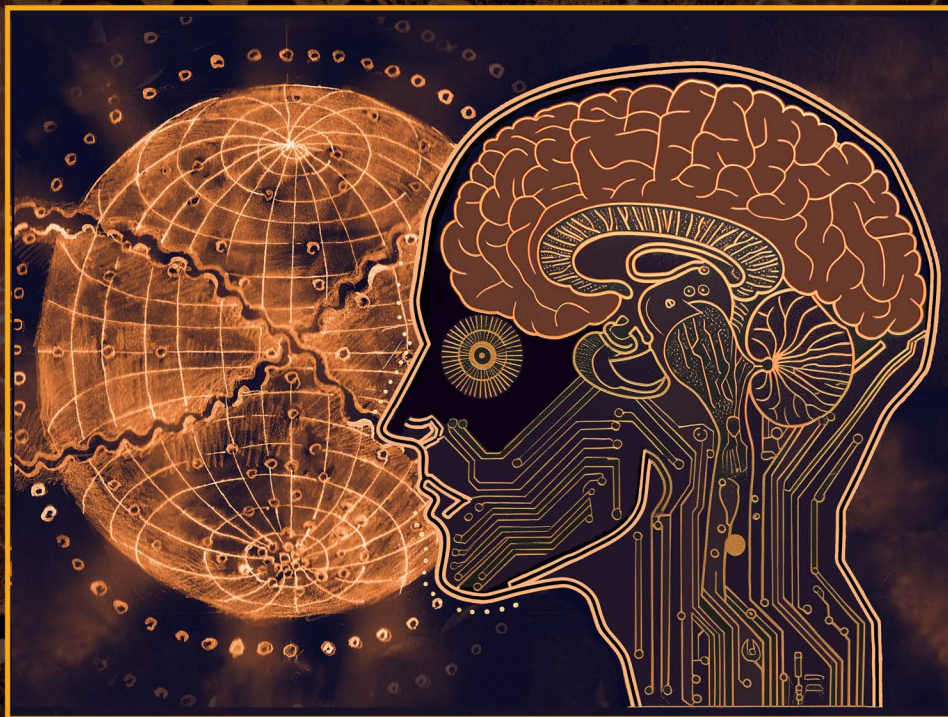


THEORETICAL NEUROSCIENCE

Understanding Cognition



XIAO-JING WANG



CRC Press
Taylor & Francis Group

Larry Abbott, William Bloor Professor of Theoretical Neuroscience, Columbia University; co-author with Peter Dayan of the textbook "Theoretical Neuroscience"

"In this textbook, Xiao-Jing Wang takes the reader on a remarkable journey from cellular and synaptic biophysics to memory, decision making, psychiatry and large-scale brain structure. His insights on how to apply theoretical methods to higher cognitive functions will be valuable to anyone thinking about thinking."

Jean-Pierre Changeux, Institute Pasteur, Paris; author of "Neuronal Man: the Biology of Mind"

"X-J Wang book illuminates how in the past decades a new field has emerged from the theoretical modeling of a wide diversity of neural processes which has successfully contributed to our understanding of brain functions up to Cognition. The book progresses from the most elementary building blocks of the brain, neurons, synapses and their molecular components up to global executive functions and the new field of computational psychiatry. The immense knowledge recently acquired and beautifully presented in the book is a must for anybody concerned by the higher functions of the brain: a bible for the students, a grandiose panorama for the educated scientists."

Anne Churchland, Professor of Neurobiology, University of California, Los Angeles

"This compelling book explains foundational concepts in theory and modeling in a way that marries rigor with intuition. It furnishes readers with powerful theory and modeling tools that are critically needed to tackle problems in modern neuroscience. Wang's explanations of network dynamics, normalization and attractor models for cognition are certain to inspire experimentalists and theorists alike."

Robert Desimone, Director of the McGovern Institute for Brain Research, Doris and Donald Berkey Professor of Neuroscience, MIT

"In Theoretical Neuroscience: Understanding Cognition, Xiao-Xing Wang explains that while the brain is not a computer, all of its elements, from synapses to circuits, obey computational principles that underlie our cognitive functions. As a leader in the computational field, he gives an insider's account of these principles at both a mathematical and conceptual level. This should be required reading for any student of modern neuroscience."

Stanislas Dehaene, Chair of Experimental Cognitive Psychology, Collège de France, Paris

"In the 20th century, Molecular Biology decoded the intricate mechanisms of DNA and RNA, the "logic of life" celebrated by Nobel Prize Laureate François Jacob. Understanding the logic of neural circuits of cognition is an equivalent goal for 21st century in Neuroscience. This important book represents a fundamental step forward : it provides a synthesis of elemental circuit building blocks of core cognitive functions, how their operation can be mathematically modeled, and how their composition may account for a variety of cognitive processes and behavioral tasks."

Brent Doiron, Heinrich Kluver Professor of Neurobiology, Director of the Grossman Center for Quantitative Biology and Human Behavior, University of Chicago

"Understanding the brain needs an appreciation of its components and activity over a wide range of spatial and temporal scales: from synapses to whole brain circuits, from rapid sensory and motor responses to lifetime memory. In this book Xiao-Jing Wang beautifully shows how theoretical and mathematical thinking can provide the needed abstraction to not only describe the brain at each scale, but synthesize these across scales into a compelling and deep understanding of neural function. At whatever stage you are in your neuroscience journey, from novice to expert, this is now required reading."

John Duncan, University of Cambridge and the Medical Research Council; author of "How Intelligence Happens"

"Nobody understands better than Xiao-Jing Wang how the events of the mind are built from the dynamic activity of neural populations, and in this book, he explains the state of the art from top to bottom. With extraordinary depth and scope, the story moves from the fundamentals of the neuron to the highest levels of human intelligence. Anybody aiming to understand the union of mind and brain can start right here."

Ann Graybiel, Institute Professor, MIT

"Xiao-Jing Wang has written a remarkable book, melding together viewpoints of a physicist/mathematician and those of a neuroscientist to produce a unique account of how the brain and its vast number of networks could operate to produce behavior. Wang has undertaken the job of bridging these two worlds, and the result is a grand success. This volume will be invaluable not only to academics, but also to all who have an interest in how the brain does its work. Xiao-Jing Wang has created a book to read and re-read, culminating in an introduction to brain-wide modeling to address the unsolved mysteries of the normal brain and the need for computational psychiatry to alleviate mental illness."

John Krystal, Chair of the Department of Psychiatry, Robert L. McNeil, Jr. Professor of Translational Research, Yale University School of Medicine

"This book is a remarkable opus from Dr. X-J Wang, a pioneering computational neuroscientist whose work continues to surprise and inspire me. This book is logically organized. It builds from a model neuron, to networks, to cognition/behavior, and it integrates all of this in considering issues of "computational psychiatry", i.e., behavioral pathology. Written with clarity and an accessible style, this wonderful book is useful for people entering the field of computational neuroscience. It is also a wonderful resource for clinical investigators hoping to learn about the formalism of computational models."

Eve Marder, University Professor, Brandeis University; Former President of the Society for Neuroscience

"Theoretical Neuroscience: Understanding Cognition by X-J. Wang is a remarkable book. It reads easily, and puts much of the field of quantitative and computational neuroscience into frameworks that allow the reader to see the etiology and genesis of the particular methods and findings being discussed. The book is comprehensive and moves seamlessly from the details of the biophysics of single neurons and synapses to some of the most complex puzzles in the neuroscience of cognition. This book will be useful for trainees and for established investigators as its breadth and depth will be helpful for everyone as they wish to gain access to the conceptual frameworks of large areas of neuroscience and their quantitative analyses."

William Newsome, Harman Family Provostial Professor of Neurobiology, the inaugural Director of Wu Tsai Neuroscience Institute, Stanford University, Co-chair of the US Brain Initiative

"In a rapidly advancing field, Xiao-Jing Wang provides a beautiful and timely account of where we have been, where we are now, and where we are likely heading. From biophysical models of single neurons, through network models of neural circuits, to macro-level models of communication between brain areas, Wang sure-handedly guides the reader with clear, incisive exposition of each topic. For dessert, we are treated to Wang's forward-looking views on computational psychiatry and future interactions between artificial intelligence and natural intelligence. This book is a must-read for anyone intrigued with the nexus between neuroscience, cognitive science, and computational theory."

Mu-ming Poo, Scientific Director of Institute of Neuroscience, Chinese Academy of Sciences; Paul Licht Distinguished Professor in Biology Emeritus, University of California, Berkeley

"This monumental treatise by Xiao-Jing Wang, one of the leading computational neuroscientists in the world, offers a thorough survey and critical synthesis of both experimental and theoretical works on various cognitive processes in the brain. A valuable book for consultation by researchers and students of neuroscience."

Matthew Rushworth, Chair of Psychology Department, Oxford University, Britain

"Xiao-Jing Wang has been a leader in theoretical neuroscience for many years. The approaches and models that he has devised have inspired the field. Even more importantly, however, Xiao-Jing Wang has had an impact on cognitive science and neuroscience more generally that has changed how scientists working with brain and behavioural data think about the issues that they are investigating. Theoretical Neuroscience: Understanding Cognition provides an accessible but comprehensive guide not just to how this happened but also to the very latest ideas emerging at the field's frontier."

Doris Tsao, University of California at Berkeley

"If a genie were to grant me a wish, I might ask for a guided tour of the brain—starting in the microscopic world of neurons and synapses, traveling through the vast landscapes of large-scale cortical interactions underlying higher cognitive functions, and culminating in our modern era of AI. A tour with a master at my side who could cut through the dense jungle of thousands of scientific papers and explain the key findings with clarity, putting them in a precise conceptual and mathematical framework. Xiao-Jing Wang's remarkable book is exactly that wish come true. This book is an invaluable guide for young researchers and anyone who wants to truly understand what is known about the brain."

Theoretical Neuroscience

This textbook is an introduction to Systems and Theoretical/Computational Neuroscience, with a particular emphasis on cognition. It consists of three parts: Part I covers fundamental concepts and mathematical models in computational neuroscience, along with cutting-edge topics. Part II explores the building blocks of cognition, including working memory (how the brain maintains and manipulates information "online" without external input), decision making (how choices are made among multiple options under conditions of uncertainty and risk) and behavioral flexibility (how we direct attention and control actions). Part III is dedicated to frontier research, covering models of large-scale multi-regional brain systems, Computational Psychiatry and the interface with Artificial Intelligence. The author highlights the perspective of neural circuits as dynamical systems, and emphasizes a cross-level mechanistic understanding of the brain and mind, from genes and cell types to collective neural populations and behavior. Overall, this textbook provides an opportunity for readers to become well versed in this highly interdisciplinary field of the twenty-first century.

Xiao-Jing Wang is Distinguished Global Professor of Neural Science at New York University, where he is also affiliated with the Courant Institute of Mathematical Sciences and Department of Physics. Before joining New York University, he was Professor at Yale University. His honors include a Guggenheim Fellowship, the Swartz Prize for Theoretical and Computational Neuroscience and the Goldman-Rakic Prize for Outstanding Achievement in Cognitive Neuroscience.

Theoretical Neuroscience

Understanding Cognition

Xiao-Jing Wang



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

First edition published 2025
by CRC Press
2385 NW Executive Center Drive, Suite 320, Boca Raton, FL 33431

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

© 2025 Xiao-Jing Wang

Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, access www.copyright.com or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. For works that are not available on CCC please contact mpkbookspermissions@tandf.co.uk

Trademark notice: Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Names: Wang, Xiao-Jing, author.

Title: Theoretical neuroscience : understanding cognition / Xiao-Jing Wang.

Description: Boca Raton : CRC Press, 2025. | Includes bibliographical references and index.

Identifiers: LCCN 2024019547 (print) | LCCN 2024019548 (ebook) | ISBN 9781032604824 (hardback) | ISBN 9781032604817 (paperback) | ISBN 9781003459361 (ebook)

Subjects: LCSH: Neural networks (Neurobiology)—Textbooks | Human information processing—Textbooks | Computational neuroscience—Textbooks | Cognition—Textbooks

Classification: LCC QP355.2 .W36 2025 (print) | LCC QP355.2 (ebook) | DDC 612.8—dc23/eng/20240430

LC record available at <https://lcn.loc.gov/2024019547>

LC ebook record available at <https://lcn.loc.gov/2024019548>

ISBN: 978-1-032-60482-4 (hbk)

ISBN: 978-1-032-60481-7 (pbk)

ISBN: 978-1-003-45936-1 (ebk)

DOI: 10.1201/9781003459361

Typeset in ITC Leawood
by Apex CoVantage, LLC

Access the Support Material: www.routledge.com/9781032604817

CONTENTS

Preface	ix	2.7 SHORT-TERM SYNAPTIC PLASTICITY	50
Part I	1	2.7.1 Short-Term Synaptic Depression	52
		2.7.2 Short-Term Synaptic Facilitation	53
		2.8 Summary	55
Chapter 1		Chapter 3	
Understanding the Cognitive Brain	3	Neural Networks	57
1.1 INTRODUCTION	3	3.1 INTRODUCTION	57
1.2 ON EPISTEMOLOGY	5	3.2 NETWORK DYNAMICS OF SPIKING NEURONS	61
1.3 THE MIND-BRAIN SOCIETY	7	3.2.1 Signal Propagation in a Feedforward Network	61
1.4 CROSS-LEVEL MECHANISTIC THEORY	10	3.2.2 Excitation and Inhibition Balance and Asynchronous State in a Recurrent Network	63
1.5 LAYOUT OF THE BOOK	14	3.2.3 Neuronal Correlations	65
Chapter 2		3.3 POPULATION RATE MODELS	66
Neurons and Synapses	17	3.3.1 Formulations of Rate Models	67
2.1 INTRODUCTION	17	3.3.2 Neural Integrator	69
2.2 INTEGRATE-AND-FIRE NEURON	20	3.3.3 Inhibition-Stabilization and Balanced Amplification	71
2.2.1 Neuronal Membrane as an RC Circuit	21	3.4 COHERENT NEURAL CIRCUIT OSCILLATIONS	73
2.2.2 LIF as a Simple Spiking Neuron Model	23	3.4.1 Synchronization of Neural Oscillators	75
2.2.3 Spiking Variability	24	3.4.2 Sparsely Synchronous Rhythm	77
2.3 CONDUCTANCE-BASED MODELS OF SINGLE NEURONS	27	3.4.3 At the Edge of Criticality	78
2.3.1 Hodgkin-Huxley Formalism of Action Potential	27	3.5 NETWORK MODELS OF INFORMATION REPRESENTATION	82
2.3.2 Type I and Type II Neurons	30	3.5.1 Feedforward Continuous Network Model	83
2.4 TIME-DEPENDENT NEURONAL FIRING PATTERNS	32	3.5.2 Normalization	84
2.4.1 Resonance in Response to Time-Dependent Noisy Inputs	32	3.5.3 Recurrent Continuous Network Model	86
2.4.2 Spike Rate Adaptation	33	3.6 COMPUTING WITH SPATIOTEMPORAL DYNAMICS	90
2.4.3 Input Decorrelation	36	3.6.1 Time Integration	90
2.5 BURST FIRING	38	3.6.2 Spatial Navigation	91
2.5.1 Ping-Pong Interplay between Soma and Dendrite	38	3.6.3 Propagating Waves	93
2.5.2 Postinhibitory Rebound	41	3.7 RESERVOIR COMPUTING	95
2.5.3 Clustered and Irregular Spiking	42	3.7.1 State Space, Dimensionality and Manifolds	95
2.6 SINGLE SYNAPSE MODELS	45	3.7.2 Feedforward Random Networks	98
2.6.1 Kick Synapses	46	3.7.3 Recurrent Random Networks	99
2.6.2 Filter and Kinetic Models of Synaptic Transmission	47	3.8 Summary	101
2.6.3 NMDA Receptor-Mediated Synaptic Excitation	49		

Chapter 4 Plasticity, Learning and Memory 105

4.1 INTRODUCTION	105
4.2 SUPERVISED LEARNING	107
4.3 REINFORCEMENT LEARNING	111
4.3.1 The Rescorla-Wagner Rule and Reward Prediction Error	111
4.3.2 Reward Signaling by the Dopamine System	112
4.3.3 Action Valuation and Selection	113
4.3.4 Temporal-Difference Learning	115
4.4 UNSUPERVISED LEARNING	117
4.4.1 Hebbian Plasticity Rules	118
4.4.2 Pattern Formation during Brain Development	120
4.4.3 Spike-Timing Dependent Plasticity	122
4.4.4 A Calcium-Based Plasticity Model	124
4.4.5 Molecular Basis of Memories	126
4.4.6 Homeostasis, Non-Hebbian and Non-Synaptic Plasticity	128
4.5 STORAGE CAPACITY AND MEMORY RETRIEVAL	129
4.5.1 Ideal Observer Analysis of Memory Capacity	129
4.5.2 Hopfield Model of Associative Memory	131
4.5.3 Plasticity-Stability Dilemma	133
4.6 MEMORY CONSOLIDATION	135
4.7 Summary	138

Part II 141

Chapter 5 Working Memory 143

5.1 INTRODUCTION	143
5.2 NEURAL REPRESENTATION OF WORKING MEMORY	145
5.2.1 Delay-Dependent Task and Self-Sustained Mnemonic Activity	145
5.2.2 Three Types of Neuronal Working Memory Coding	146
5.2.3 Feedback Mechanisms of Persistent Activity	151
5.3 ATTRACTOR NETWORK MODEL OF WORKING MEMORY	152
5.3.1 A Simple Rate Model	152
5.3.2 Network Model of Stimulus-Selective Persistent Activity	154
5.3.3 How Many Parameters Does This Model Have?	156

5.3.4 Emergence of Self-Sustained Activity from a Bifurcation	157
5.3.5 Inverted U-Shape of Dopamine Dependence	160

5.4 CONTINUOUS ATTRACTOR MODEL FOR SPATIAL WORKING MEMORY 162

5.4.1 A Model of the Oculomotor Delayed Response Task	162
5.4.2 Stochastic Gamma Oscillations during Delay Period Activity	164
5.4.3 Drifts of Neural Representation across the Delay	165
5.4.4 Resistance against Distractors	166

5.5 LINE ATTRACTORS: PARAMETRIC WORKING MEMORY 167

5.6 YIN AND YANG OF NEURONAL REVERBERATION 169

5.6.1 The Excitation-Inhibition Balance	169
5.6.2 The Role of NMDA Receptors	170
5.6.3 The Importance of Being Slow But Not Too Slow	172
5.6.4 Cannabinoid Modulation and Cross-Trial Serial Effect	174
5.6.5 Disinhibition Motif by Three Subtypes of Inhibitory Cells	176

5.7 LIMITED WORKING MEMORY CAPACITY 180

5.8 DYNAMICAL NATURE OF MNEMONIC REPRESENTATION 183

5.8.1 Dynamical Coding and Heterogenous Delay Activity	183
5.8.2 Self-Sustained or Decaying Transient?	188
5.8.3 Persistent Activity Is Required for Manipulation of Information in Working Memory	190

5.9 Summary 192

Chapter 6 Decision Making 195

6.1 INTRODUCTION	195
6.2 MATHEMATICAL MODELS OF DECISION MAKING	196
6.2.1 Signal Detection Theory	196
6.2.2 Drift Diffusion Model	199
6.2.3 Race Models	202
6.2.4 Bayesian Modeling	203
6.3 NEURAL CIRCUIT MECHANISM OF DECISION MAKING	206
6.3.1 Neural Correlates	206
6.3.2 A Recurrent Neural Circuit Model	209
6.3.3 State-Space Trajectories of Population Dynamics	212

6.4	TERMINATION RULE FOR A DECISION PROCESS	216	Chapter 8	285
6.4.1	Ramping-to-Threshold in the Brain	216	Executive Function	285
6.4.2	Chronometric Function and Scale Invariance of Reaction Times	218	8.1 INTRODUCTION	285
6.4.3	The Biological Substrate of a Decision Threshold	219	8.2 RESPONSE INHIBITION	287
6.4.4	Speed-Accuracy Tradeoff	223	8.2.1	Race Model and Neurophysiology of a Stop-Signal Task 288
6.5	MULTI-ALTERNATIVE DECISIONS	226	8.2.2	A Neural Circuit Model of Countermanding 290
6.6	DIVERSE TYPES OF PERCEPTUAL DECISIONS	228	8.2.3	Role of Basal Ganglia in “Holding the Horse” 295
6.6.1	Detection	228	8.2.4	Pro- versus Anti-Response 298
6.6.2	Comparison and Discrimination	230	8.3 TIMING	300
6.6.3	Pattern Match Decisions	232	8.4 SELECTIVE ATTENTION	303
6.7	CONFIDENCE AND CHANGES OF MIND	235	8.4.1	Biased Competition and Multiplicative Gain Modulation 304
6.8	DUALITY OF COGNITIVE-TYPE NEURAL CIRCUITS	242	8.4.2	An Integrative Circuit Model of Selective Attention 307
6.9	Summary	245	8.4.3	Attention Modulation of Network Synchrony and Noise Correlation 312
Chapter 7	Value-Based Economic Choice	247	8.5 TASK SWITCHING	314
7.1	INTRODUCTION	247	8.6 BEHAVIORAL FLEXIBILITY AND MIXED SELECTIVITY	319
7.2	NEUROECONOMICS AND FORAGING THEORY	248	8.7 Summary	324
7.3	NEURAL CIRCUIT MECHANISM FOR VALUE-BASED CHOICE	253	Part III	327
7.3.1	Dopamine and Synaptic Plasticity	253	Chapter 9	329
7.3.2	A Decision-Making Network Model Endowed with Reward-Dependent Learning	255	Large-Scale Multi-Regional Brain	329
7.3.3	Computation of Returns by Synapses: Matching Law through Melioration	257	9.1 INTRODUCTION	329
7.4	VALUATION	262	9.2 CORTEX-WIDE CONNECTIVITY	332
7.4.1	Computation of Common Currency	262	9.2.1	Connectome 332
7.4.2	Cost and Regret	265	9.2.2	Directed and Weighted Inter-Areal Cortical Connections 334
7.4.3	Predictive Valuation	266	9.2.3	Exponential Distance Rule 335
7.4.4	Multi-Attribute Choice	267	9.2.4	A Generative Model of Spatially Embedded Neocortex 337
7.5	PROBABILISTIC REASONING	269	9.2.5	Cortical Hierarchy 339
7.6	SOCIAL DECISION MAKING	274	9.3 MACROSCOPIC GRADIENTS	340
7.6.1	Random Choice Behavior in Matching Pennies Game	274	9.3.1	Heterogeneous Variations of a Canonical Circuit 340
7.6.2	Volatility and Reinforcement Learning on Multiple Timescales	275	9.3.2	Macroscopic Gradients of Synaptic Excitation 341
7.6.3	Cooperation	278	9.3.3	Macroscopic Gradient of Input-versus Output-Controlling Inhibition 344
7.7	Summary	281	9.4 A HIERARCHY OF TIMESCALES	346
			9.4.1	A Dynamical Model of Multi-Regional Monkey Cortex 346
			9.4.2	A Spatial Localization Measure 348
			9.4.3	Experimental Observations of Timescale Hierarchy 350

9.5 FUNCTIONAL CONNECTIVITY AND INTER-AREAL COMMUNICATION	352	10.7 BIG DATA AND MODEL-AIDED DIAGNOSIS	410
9.5.1 Functional Connectivity in a Resting State	352	10.8 Summary	412
9.5.2 Layer-Dependent Feedforward and Feedback Processes	355		
9.5.3 Gating of Inter-Areal Communication	358	Chapter 11	
9.6 DISTRIBUTED WORKING MEMORY	361	Biological and Artificial Intelligence	419
9.6.1 The Parieto-Frontal Loop	361		
9.6.2 Distributed Mnemonic Activity in the Cortex	363	11.1 INTRODUCTION	419
9.6.3 Bifurcation in Space: Emergence of Modularity	367	11.2 DEEP FEEDFORWARD NEURAL NETWORKS	421
9.6.4 A Diversity of Spatially Distributed Persistent States	368	11.2.1 Basic Methods of Deep Neural Network Models	421
9.6.5 Macroscopic Gradient of Dopamine Modulation	370	11.2.2 Deep Neural Network Modeling and the Brain	425
9.7 DISTRIBUTED DECISION MAKING	373	11.3 COGNITIVE-TYPE RECURRENT NEURAL NETWORKS	428
9.8 Summary	376	11.4 ABSTRACTION	435
		11.4.1 Categorization	436
Chapter 10		11.4.2 Factorized Code for Abstract Knowledge	441
Computational Psychiatry	379	11.4.3 Task Set	443
10.1 INTRODUCTION	379	11.5 LEARNING-TO-LEARN	446
10.2 MENTAL DISORDER CLASSIFICATION VERSUS DIMENSIONAL PSYCHIATRY	381	11.6 REASONING AND FLUID INTELLIGENCE	453
10.3 REINFORCEMENT LEARNING MODELS OF BEHAVIORAL DISORDERS	385	11.6.1 Compositionality	453
10.3.1 Task Design and Behavioral Quantification	385	11.6.2 Inference and Cognitive Maps	454
10.3.2 Mood and Depression	385	11.6.3 Mental Programming and Intelligence	458
10.3.3 Addiction	388	11.6.4 Cross-Scale Brain Basis of Intelligence	461
10.4 DEFICITS OF EXECUTIVE CONTROL	391	11.7 Summary	465
10.4.1 Loss of Control in Addiction and Depression	391		
10.4.2 Negative Bias in Anxiety and Obsessive-Compulsive Disorder	393	Chapter 12	
10.4.3 Reactive versus Proactive Control in Schizophrenia	395	Looking Back and Ahead	467
10.5 NEURAL CIRCUIT MODELS OF COGNITIVE DEFICITS	397		
10.5.1 Working Memory	398	12.1 BUILDING BLOCKS OF BEHAVIOR AND COGNITION	467
10.5.2 Decision Making	400	12.2 TAKE-HOME MESSAGES	469
10.5.3 Critical Role of E/I Balance	402	12.3 SHIFTING PERSPECTIVES	470
10.6 DEFICITS IN MULTI-REGIONAL BRAIN SYSTEMS	404	12.4 LESS CHARTED TERRITORIES	471
10.6.1 Abnormal Default-Mode Network	405		
10.6.2 Altered Macroscopic Gradients	406	References	475
10.6.3 Deficits in Top-Down Signaling	409	Index	551