

# CONTENTS

PREFACE	xi
ACKNOWLEDGMENTS	xix

<b>1</b>	<b>NEURONS: THE COMPUTATIONAL CELLS OF BRAINS</b>	<b>1</b>
	Introduction,	1
	Neural Networks and Their Analysis	1
	Neurons	3
	Other Types of Neural Activity	9
	Summary	15
	Suggested Readings	16
	Appendix 1: The Mathematics of Neural Interactions	16
	Discussion	20
	Reference	21
<b>2</b>	<b>INFORMATION: ITS MOVEMENT AND TRANSFORMATION</b>	<b>22</b>
	Introduction	22
	Static and Dynamic Patterns	22
	Control and Content Patterns	23
	Information Transmission	24
	Information Encoding	25
	Neural Information Patterns	28
	Some Neural Networks	32
	Categories of Information Transformation Networks	38

vi CONTENTS

Summary 39  
Suggested Readings 41

**3 INFORMATION STORAGE 42**

Introduction 42  
Addressed Computer Storage Systems 42  
Associative Computer Storage Systems 47  
Storage in Neural Networks 50  
Mixed Modality Memory Stores 63  
Summary 69  
References 70  
Suggested Readings 70  
Appendix 2: A Model for Cortical Memory 70  
The Model 72  
Discussion 77  
References 81

**4 THE CONTROL OF ASSOCIATIVE STORAGE SYSTEMS 82**

Introduction 82  
Control of a Memory Store 82  
An Access Control Network 84  
An Associative Store with Adaptive Access 87  
Forgetting Caused by Adaptive Access 87  
Access to Individual Items of Information 88  
Levels of Access Control 92  
Summary 93  
Suggested Reading 93

**5 INFORMATION ENCODING AND MODALITY 94**

Introduction 94  
Positive and Negative Values in Neural Networks 94  
Tagged Information 96  
Information Modality 100  
Spatial Organization of Neural Patterns 100  
Dimensionality of Encoded Patterns 104  
Storage Networks for Encoding and Transforming Information 105  
Naming and Imaging 106  
Temporal Organization of Neural Patterns 107  
Summary 108  
Reference 108

<b>6</b>	<b>INFORMATION STORAGE AND HUMAN MEMORY</b>	<b>109</b>
	Introduction	109
	The Stores of Experience	110
	Naming Stores	120
	Stores for Hand-Eye Coordination	126
	Summary	131
	References	131
	Suggested Readings	132
 <b>7</b>	 <b>THE VISUAL SYSTEM</b>	 <b>134</b>
	Introduction	134
	The Anatomy of the Human Visual System	134
	Low-Level Visual Processing	140
	Intermediate-Level Visual Processing	155
	Summary	165
	References	166
 <b>8</b>	 <b>VISUAL EXPERIENCES AND MENTAL IMAGERY</b>	 <b>169</b>
	Introduction	169
	Modes of Visual Recognition	170
	Syndromes of the Visual System	171
	Mental Imagery	176
	Visual Storage Representations	180
	Mental Images	191
	Summary	210
	References	213
	Appendix 3: A Neural Realization of Spatial Memory	215
	The Control of Spatial Memory	219
	Representing Three-Dimensional Rotations	225
	Visual Flow in Spatial Memory	227
	Quaternions and Rotation	228
	References	231
 <b>9</b>	 <b>ACCESSING VISUAL MEMORIES AND VISUAL RECOGNITION</b>	 <b>232</b>
	Introduction	232
	The Spatial Organization of Visual Experiences	232
	Temporal Organization of Visual Experiences	238
	Canonical Storage Representations	239
	Activating, Recalling Visual Experiences	241
	Gestalt versus Sequential Recognition	247

Summary 251  
References 253  
Suggested Readings 253  
Appendix 4: Simulating Human Facial Recognition 254  
The Initial Data 254  
Locating Eyes in a Digitized Image 255  
The Data Base 257  
Face Recognition 261  
Computer Face Recognition Experiments 262  
Significance of the Stimulation Results 263  
References 264

**10 THE AUDITORY SYSTEM 265**

Introduction 265  
Low-Level Auditory Encoding Machinery 266  
High-Level Auditory Encodings 286  
Storage of Auditory Experience 290  
Summary 291  
References 291  
Suggested Readings 292

**11 COGNITION, UNDERSTANDING, AND LANGUAGE 293**

Introduction 293  
Visual and Auditory Experiences 294  
Symbolic Tokens, Naming, and Imaging 294  
Naming Stores 295  
Understanding 300  
Mental Procedures 301  
Understanding Simple Sentences 309  
Reading and Speech Understanding 312  
The Onset of Language 314  
Summary 318  
References 319  
Suggested Readings 319

**12 THE ANATOMY AND PHYSIOLOGY OF THE SENSORY-MOTOR SYSTEM 321**

Introduction 321  
Skeletal Muscle Tissue 321  
The Spinal Reflex Circuitry 330  
Muscle Action 333  
The Architecture of the Sensory-Motor System 335

The Spinal Pathways	336
The Sensory and Motor Areas of the Cerebral Cortex	340
The Cerebellum	345
Motor Nuclei of the Basal Ganglia	354
Summary	354
References	355
Suggested Readings	356

## 13 THE BODY IN SPACE 358

Introduction	358
The Postural Buffer	358
Predicting the Outcome of a Movement	364
The Cutaneous Senses	365
Tactile Identification of Objects	366
The Vestibular System	367
Summary	371
References	372
Suggested Readings	372

## 14 THE CONTROL OF CONFIGURATION AND SIMPLE MOVEMENTS 373

Introduction	373
Motor Patterns for Control of Movement	373
Storage Systems for Motor Patterns	375
The Control of Configuration	377
Controlling Simple Movements	387
Summary	400
References	401
Suggested Readings	401

## 15 THE HIGH-LEVEL CONTROL OF MOVEMENTS 402

Introduction	402
Perceptions, Decisions, and Intentions	402
Understanding	402
Decision Making, Intentions and Plans	404
Time and the Control Hierarchy	407
Procedures and Subprocedures	409
The Distribution of Computational Efforts	411
Motor Programs for Movement Control	412
Intentions as Initial Conditions	423
Summary	451
References	452

<b>16</b>	<b>SENSATIONS, AFFECTS, AND BEHAVIOR</b>	<b>453</b>
	Introduction	453
	Sensations, Feeling, and Emotions	453
	Affect Centers	458
	Control of the Affect States	460
	Primary Affects	460
	Time and the Affect Hierarchy	470
	Architecture of the Stores of Experience	473
	Summary	474
	References	475
	Suggested Readings	475
<b>17</b>	<b>THE THREE COGNITIVE SYSTEMS AND LEARNING</b>	<b>476</b>
	Introduction	476
	Computational Systems of the Brain	476
	The Computational Topology of the Brain	485
	Innate Control Functions	490
	Stages of Learning	495
	Adaptive Processes in Learning	501
	Summary	503
	References	503
	<b>POSTSCRIPT</b>	<b>505</b>
	Neurons and Neural Activity	505
	Fan-In and Fan-Out of Information	506
	Computation and Its Architecture	506
	Analog versus Digital Computations	507
	The Mathematics of the Mind	507
	Information	508
	Objects	508
	Maintaining a World Model	509
	Perceptual and Control Hierarchies	510
	Specifying Mental Procedures	512
	Predictions	512
	Memory and Learning	513
	Clinical Studies	513
	Brain and Mind	514
	<b>AUTHOR INDEX</b>	<b>516</b>
	<b>SUBJECT INDEX</b>	<b>521</b>