# **CONTENTS**

Comment of Americal value Report Vistem our Symbolic of Name of Americal of Systems of Sing

Intell

to a rething Friedly Anton

er e Vicencias Procepto Bu

VIDOST A SECTION OF TROOTY

WARRIED A STRUMBER OF THE TRAIN OF THE TRAIN

	FUHEWUHD by Lotfi A. Zadeh	XVI
	FOREWORD by James A. Anderson	xix
	PREFACE	XXV
1	NEURAL NETWORKS AND FUZZY SYSTEMS	1
	Neural and Fuzzy Machine Intelligence 2	
	Neural Pre-Attentive and Attentive Processing, 2	
	Fuzziness as Multivalence 3	
	Bivalent Paradoxes as Fuzzy Midpoints, 4	
	Fuzziness in the Twentieth Century, 5	
	Sets as Points in Cubes, 7	
	Subsethood and Probability, 9	

38

39

		The Dynamical-Systems Approach to Machine Intelligence The Brain as a Dynamical System 12	ce:
		Neural and Fuzzy Systems as Function Estimators, 13 Neural Networks as Trainable Dynamical Systems, 14 Fuzzy Systems and Applications, 18	
		Intelligent Behavior as Adaptive Model-Free Estimation	19
		Generalization and Creativity, 20 Learning as Change, 22 Symbols vs. Numbers: Rules vs. Principles, 24 Expert-System Knowledge as Rule Trees, 24 Symbolic vs. Numeric Processing, 25 Fuzzy Systems as Structured Numerical Estimators, 26 Generating Fuzzy Rules with Product-Space Clustering, 28 Fuzzy Systems as Parallel Associators, 29 Fuzzy Systems as Principle-Based Systems, 32	
		References 34	
		Problems 36	
Part 1	Ne	ural Network Theory	
	2	NEURONAL DYNAMICS I: ACTIVATIONS AND SIGNA	LS
		Neurons as Functions 39	
		Signal Monotonicity 40	
		Signal and Activation Velocities, 41	
		Biological Activations and Signals 41	32
		Competitive Neuronal Signals, 43	
		Neuron Fields 44	
		Neuronal Dynamical Systems 44	*
		Neuronal State Spaces, 45 Signal State Spaces as Hypercubes, 46 Neuronal Activations as Short-Term Memory, 47	
		Common Signal Functions 48	
		Pulse-Coded Signal Functions 50	
		Velocity-Difference Property of Pulse-Coded Signals, 51	
		References 52	
		Problems 53	

_				
2	MEHDAMAL	DYNAMICS II:	A CTILLATION	MADELO
J	NEUNUNAL	DINAMICS II:	ACHVAHUN	MUIII

Neuronal Dynamical Systems 55

Additive Neuronal Dynamics 56

Passive Membrane Decay, 56 Membrane Time Constants, 57 Membrane Resting Potentials, 57 Additive External Input, 58

Additive Neuronal Feedback 59

Synaptic Connection Matrices, 59
Bidirectional and Unidirectional Connection Topologies,
60

Additive Activation Models 61

Additive Bivalent Models 63

Bivalent Additive BAM, 63 Bidirectional Stability, 68 Lyapunov Functions, 69 Bivalent BAM Theorem, 73

BAM Connection Matrices 79

Optimal Linear Associative Memory Matrices, 81 Autoassociative OLAM Filtering, 83 BAM Correlation Encoding Example, 85 Memory Capacity: Dimensionality Limits Capacity, 91 The Hopfield Model, 92

Additive Dynamics and the Noise-Saturation Dilemma 94

Grossberg's Saturation Theorem, 95

General Neuronal Activations: Cohen-Grossberg and Multiplicative Models 99

References 103

Problems 106

Software Problems 108

Part I: Discrete Additive Bidirectional Associative Memory (BAM), 108 Part II, 109

4	SYNAPTIC	DYNAMICS	I: UNSUPERVISED	I FARNING

### Learning as Encoding, Change, and Quantization 111

Supervised and Unsupervised Learning in Neural Networks, 113

#### Four Unsupervised Learning Laws 115

Four Deterministic Unsupervised Learning Laws, 116 Brownian Motion and White Noise. 118

## Probability Spaces and Random Processes 119

Measurability and Sigma-Algebras, 119
Probability Measures and Density Functions, 122
Gaussian White Noise as a Brownian Pseudoderivative
Process, 127

# Stochastic Unsupervised Learning and Stochastic Equilibrium 131

Stochastic Equilibrium, 133

### Signal Hebbian Learning 138

Recency Effects and Forgetting, 138 Asymptotic Correlation Encoding, 138 Hebbian Correlation Decoding, 140

## Competitive Learning 145

Competition as Indication, 146 Competition as Correlation Detection, 147 Asymptotic Centroid Estimation, 148 Competitive Covariance Estimation, 149

## Differential Hebbian Learning 152

Fuzzy Cognitive Maps, 152 Adaptive Causal Inference, 158 Klopf's Drive Reinforcement Model, 159 Concomitant Variation as Statistical Covariance, 161 Pulse-Coded Differential Hebbian Learning, 163

## Differential Competitive Learning 166

Differential Competitive Learning as Delta Modulation, 168

References 170

Problems 173

CONTENTS xi

	Software Problems 1/5	
	Part 1: Competitive Learning, 175 Part II: Differential Competitive Learning, 176	
5	SYNAPTIC DYNAMICS II: SUPERVISED LEARNING	179
	Supervised Function Estimation 180	
	Supervised Learning as Operant Conditioning 181	
	Supervised Learning as Stochastic Pattern Learning with Known Class Memberships 183	
	Supervised Learning as Stochastic Approximation 185	
	The Perceptron: Learn Only If Misclassify, 187 The LMS Algorithm: Linear Stochastic Approximation, 190	
•	The Backpropagation Algorithm 196	
	History of the Backpropagation Algorithm, 196 Feedforward Sigmoidal Representation Theorems, 199 Multilayer Feedforward Network Architectures, 201 Backpropagation Algorithm and Derivation, 203 Backpropagation as Stochastic Approximation, 210 Robust Backpropagation, 211 Other Supervised Learning Algorithms, 212	
	References 213	
	Problems 215	
	Software Problems 218	
	Part I: Exclusive-OR (XOR), 218 Part II: Sine Function, 219 Part III: Training Set versus Test Set, 220	
6	ARCHITECTURES AND EQUILIBRIA	221
	Neural Networks as Stochastic Gradient Systems 221	
	Global Equilibria: Convergence and Stability 223	
	Synaptic Convergence to Centroids: AVQ Algorithms 225	
	Competitive AVQ Stochastic Differential Equations, 225 Competitive AVQ Algorithms, 227 Unsupervised Competitive Learning (UCL), 227 Supervised Competitive Learning (SCL), 228	

Bayesian Polemics, 289

	Differential Competitive Learning (DCL), 228 Stochastic Equilibrium and Convergence, 228	
	Global Stability of Feedback Neural Networks 232	
	ABAMs and the Stability-Convergence Dilemma, 233 Stability-Convergence Dilemma, 235 The ABAM Theorem, 236 Higher-Order ABAMs, 239 Adaptive Resonance ABAMs, 240 Differential Hebbian ABAMS, 241	
	Structural Stability of Unsupervised Learning 242	
	Random Adaptive Bidirectional Associative Memories 243	
	Noise-Saturation Dilemma and the RABAM  Noise-Suppression Theorem, 247  RABAM Noise-Suppression Theorem, 248  RABAM Annealing, 253	
	References 255	
	Problems 257	
	Software Problems 258	
	Part I: Random Adaptive Bidirectional Associative Memory (RABAM), 258 Part II: Binary Adaptive Resonance Theory (ART-1), 259	
Part 2	Adaptive Fuzzy Systems	262
7	7 FUZZINESS VERSUS PROBABILITY	263
	Fuzzy Sets and Systems 263	
	Fuzziness in a Probabilistic World 264	
	Randomness vs. Ambiguity: Whether vs. How Much 265	
	The Universe as a Fuzzy Set 268	<i>্</i>
	The Geometry of Fuzzy Sets: Sets as Points 269	-
	Paradox at the Midpoint, 273 Counting with Fuzzy Sets, 274	
	The Fuzzy Entropy Theorem 275	
	The Subsethood Theorem 278	

CONTENTS xiii

	The Entropy-Subsethood Theorem 293	
	References 294	
	Problems 296	
8	FUZZY ASSOCIATIVE MEMORIES	299
	Fuzzy Systems as Between-Cube Mappings 299	
	Fuzzy and Neural Function Estimators 302	
	Neural vs. Fuzzy Representation of Structured Knowledge, 304	
	FAMs as Mappings, 306 Fuzzy Vector-Matrix Multiplication: Max-Min Composition, 307	
	Fuzzy Hebb FAMs 308	
	The Bidirectional FAM Theorem for Correlation-Minimum Encoding, 310 Correlation-Product Encoding, 311 Superimposing FAM Rules, 313	
	Recalled Outputs and "Defuzzification", 314	
	FAM System Architecture, 316 Binary Input-Output FAMs: Inverted-Pendulum Example, 317	
	Multiantecedent FAM Rules: Decompositional Inference, 322	
	Adaptive Decompositional Inference, 326	
	Adaptive FAMs: Product-Space Clustering in FAM Cells 327	
	Adaptive FAM-Rule Generation, 328 Adaptive BIOFAM Clustering, 329 Adaptive BIOFAM Example: Inverted Pendulum, 333	
	References 335	
	Problems 336	
	Software Problems 337	
9	COMPARISON OF FUZZY AND NEURAL TRUCK BACKER-UPPER CONTROL SYSTEMS	339
	Fuzzy and Neural Control Systems 339	
	Backing up a Truck 340	
	Fuzzy Truck Backer-Upper System, 340	

Neural Truck Backer-Upper System, 345 Comparison of Fuzzy and Neural Systems, 346 Sensitivity Analysis, 347 Adaptive Fuzzy Truck Backer-Upper, 348 Fuzzy Truck-and-Trailer Controller, 352 BP Truck-and-Trailer Control Systems, 356 AFAM Truck-and-Trailer Control Systems, 356 Conclusion, 360

References 361

### 10 FUZZY IMAGE TRANSFORM CODING

363

Transform Image Coding with Adaptive Fuzzy Systems 363

Adaptive Cosine Transform Coding of Images, 365

Adaptive FAM systems for Transform Coding 366

Selection of Quantizing Fuzzy-Set Values, 367 Product-Space Clustering to Estimate FAM Rules, 368 Differential Competitive Learning, 370 Simulation, 373 Conclusion, 374

References 377

Problems 378

## 11 COMPARISON OF FUZZY AND KALMAN-FILTER TARGET-TRACKING CONTROL SYSTEMS

379

Fuzzy and Math-Model Controllers 379

Real-Time Target Tracking 381

Fuzzy Controller 382

Fuzzy-Centroid Computation, 386 Fuzzy-Controller Implementation, 390

Kalman-Filter Controller 392

Fuzzy and Kalman-Filter Control Surfaces, 394

Simulation Results 396

Sensitivity Analysis, 399 Adaptive FAM (AFAM), 402

Conclusion 406

References 406

1. 医神经囊内外侧部

Faces Thank Broken

13.63

CONTENTS XV

APPENDIX:	NEURAL	AND	<b>FUZZY</b>	SOFTWARE
INSTRUCTIO	าพร			

407

Neural Network Software Instructions: Using the OWL Demonstration Programs (IBM-PC/AT) 408

General, 408 ART, 409 BAM, 411 BKP, 413 CL, 414 RABAM, 416

er was much with an a

to place or construction

or children to be

Fuzzy-Associative-Memory Software Instructions 418

Fuzzy Truck Backer-Upper Control System, 418 Fuzzy Target-Tracking Demonstration, 419 Adaptive Fuzzy Control of Inverted Pendulum, 421

INDEX 425

of this icathook. Ban Rodo the broid of subject, adaptive fluxly systems, certain for the section of themse cognition and colors to investain and

WALL OF THE REAL PROPERTY.

rav en symbol

a large to

se and ferrorder

The and ferrorder

The animal financia

This process in expenses

The animal ferrorder

The animal ferrorder

The animal ferrorder

This process

This p

de much ....