Contents

Preface xv

1 INTRODUCTION TO ARTIFICIAL INTELLIGENCE SYSTEMS 1–7
1.1 Neural Networks 2
1.2 Fuzzy Logic 3
1.3 Genetic Algorithms 4
1.4 Structure of This book 5
Summary 6
References 6

Part 1 NEURAL NETWORKS 11–33

FUNDAMENTALS OF NEURAL NETWORKS 11–33
2.1 Basic Concepts of Neural Networks 11
2.2 Human Brain 12
2.3 Model of an Artificial Neuron 13
2.4 Neural Network Architectures 16
2.4.1 Single Layer Feedforward Network 17
2.4.2 Multilayer Feedforward Network 18
2.4.3 Recurrent Networks 18
2.5 Characteristics of Neural Networks 19
2.6 Learning Methods 19
2.7 Taxonomy of Neural Network Architectures 27
2.8 History of Neural Network Research 22
2.9 Early Neural Network Architectures 23
2.9.1 Rosenblatt’s Perceptron 23
2.9.2 ADALINE Network 28
2.9.3 MADALINE Network 28
2.10 Some Application Domains 30
Summary 31
Programming Assignment 31
Suggested Further Reading 32
References 32

3 BACKPROPAGATION NETWORKS 34–86
3.1 Architecture of a Backpropagation Network 35
3.1.1 The Perceptron Model 35
3.1.2 The Solution 36
## Contents

3.1.3 Single Layer Artificial Neural Network 39  
3.1.4 Model for Multilayer Perceptron 41  

3.2 Backpropagation Learning 42  
3.2.1 Input Layer Computation 43  
3.2.2 Hidden Layer Computation 43  
3.2.3 Output Layer Computation 44  
3.2.4 Calculation of Error 45  
3.2.5 Training of Neural Network 45  
3.2.6 Method of Steepest Descent 47  
3.2.7 Effect of Learning Rate \( \eta \) 51  
3.2.8 Adding a Momentum Term 52  
3.2.9 Backpropagation Algorithm 53  

3.3 Illustration 56  

3.4 Applications 59  
3.4.1 Design of Journal Bearing 59  
3.4.2 Classification of Soil 64  
3.4.3 Hot Extrusion of Steel 65  

3.5 Effect of Tuning Parameters of the Backpropagation Neural Network 69  

3.6 Selection of Various Parameters in BPN 72  
3.6.1 Number of Hidden Nodes 72  
3.6.2 Momentum Coefficient \( \alpha \) 73  
3.6.3 Sigmoidal Gain \( \lambda \) 74  
3.6.4 Local Minima 74  
3.6.5 Learning Coefficient \( \eta \) 74  

3.7 Variations of Standard Backpropagation Algorithm 75  
3.7.1 Decremental Iteration Procedure 75  
3.7.2 Adaptive Backpropagation (Accelerated Learning) 76  
3.7.3 Genetic Algorithm Based Backpropagation 77  
3.7.4 Quick Prop Training 77  
3.7.5 Augmented BP Networks 77  
3.7.6 Sequential Learning Approach for Single Hidden Layer Neural Networks 80  

3.8 Research Directions 80  
3.8.1 New Topologies 80  
3.8.2 Better Learning Algorithms 81  
3.8.3 Better Training Strategies 81  
3.8.4 Hardware Implementation 81  
3.8.5 Conscious Networks 81  

**Summary** 82  
**Programming Assignment** 82  
**References** 85  

4 ASSOCIATIVE MEMORY 87–116  
4.1 Autocorrelators 89  
4.2 Heterocorrelators: Kosko’s Discrete BAM 91  
4.2.1 Addition and Deletion of Pattern Pairs 91  
4.2.2 Energy Function for BAM 92  
4.3 Wang et al.’s Multiple Training Encoding Strategy 95
4.4 Exponential BAM 99
   4.4.1 Evolution Equations 99
4.5 Associative Memory for Real-coded Pattern Pairs 101
   4.5.1 Input Normalization 101
   4.5.2 Evolution Equations 101
4.6 Applications 105
   4.6.1 Recognition of Characters 105
   4.6.2 Fabric Defect Identification 107
4.7 Recent Trends 110
Summary 111
Programming Assignment 111
References 114

5 ADAPTIVE RESONANCE THEORY 117
5.1 Introduction 117
   5.1.1 Cluster Structure 117
   5.1.2 Vector Quantization 118
   5.1.3 Classical ART Networks 125
   5.1.4 Simplified ART Architecture 126
5.2 ART1 127
   5.2.1 Architecture of ART1 128
   5.2.2 Special Features of ART1 Models 129
   5.2.3 ART1 Algorithm 133
   5.2.4 Illustration 135
5.3 ART2 140
   5.3.1 Architecture of ART2 140
   5.3.2 ART2 Algorithm 141
   5.3.3 Illustration 144
5.4 Applications 145
   5.4.1 Character Recognition Using ART1 145
   5.4.2 Classification of Soil 146
   5.4.3 Prediction of Load from Yield Line Patterns of Elastic-Plastic
        Clamped Square Plate 147
   5.4.4 Chinese Character Recognition—Some Remarks 151
5.5 Sensitivities of Ordering of Data 151
Summary 152
Programming Assignment 153
Suggested Further Reading 153
References 153

Part 2 FUZZY LOGIC 157

6 FUZZY SET THEORY 157
6.1 Fuzzy versus Crisp 157
6.2 Crisp sets 159
   6.2.1 Operations on Crisp Sets 161
   6.2.2 Properties of Crisp Sets 163
   6.2.3 Partition and Covering 166
6.3 Fuzzy Sets 168
   6.3.1 Membership Function 169
   6.3.2 Basic Fuzzy Set Operations 171
   6.3.3 Properties of Fuzzy Sets 176
6.4 Crisp Relations 179
   6.4.1 Cartesian Product 179
   6.4.2 Other Crisp Relations 180
   6.4.3 Operations on Relations 180
6.5 Fuzzy Relations 182
   6.5.1 Fuzzy Cartesian Product 182
   6.5.2 Operations on Fuzzy Relations 183
Summary 185
Programming Assignment 186
Suggested Further Reading 186
Reference 186.

7 FUZZY SYSTEMS 187–221
7.1 Crisp Logic 187
   7.1.1 Laws of Propositional Logic 189
   7.1.2 Inference in Propositional Logic 191
7.2 Predicate Logic 193
   7.2.1 Interpretations of Predicate Logic Formula 195
   7.2.2 Inference in Predicate Logic 196
7.3 Fuzzy Logic 198
   7.3.1 Fuzzy Quantifiers 201
   7.3.2 Fuzzy Inference 202
7.4 Fuzzy Rule based System 204
7.5 Defuzzification Methods 205
7.6 Applications 210
   7.6.1 Greg Viot's Fuzzy Cruise Controller 210
   7.6.2 Air Conditioner Controller 216
Summary 219
Programming Assignment 220
Suggested Further Reading 220
References 220

Part 3 GENETIC ALGORITHMS 225–252

8 FUNDAMENTALS OF GENETIC ALGORITHMS 225–252
8.1 Genetic Algorithms: History 227
8.2 Basic Concepts 228
   8.2.1 Biological Background 228
8.3 Creation of Offsprings 229
   8.3.1 Search Space 229
8.4 Working Principle 230
8.5 Encoding 230
  8.5.1 Binary Encoding 231
  8.5.2 Octal Encoding (0 to 7) 234
  8.5.3 Hexadecimal Encoding (0123456789ABCDEF) 234
  8.5.4 Permutation Encoding 235
  8.5.5 Value Encoding 236
  8.5.6 Tree Encoding 236

8.6 Fitness Function 237

8.7 Reproduction 242
  8.7.1 Roulette-wheel Selection 242
  8.7.2 Boltzmann Selection 245
  8.7.3 Tournament Selection 245
  8.7.4 Rank Selection 247
  8.7.5 Steady-state Selection 248
  8.7.6 Elitism 248
  8.7.7 Generation Gap and Steady-state Replacement 249

Summary 250

Programming Assignment 251

References 252

9 GENETIC MODELLING 253–293

9.1 Inheritance Operators 253

9.2 Cross Over 254
  9.2.1 Single-site Cross Over 254
  9.2.2 Two-point Cross Over 255
  9.2.3 Multi-point Cross Over 255
  9.2.4 Uniform Cross Over 256
  9.2.5 Matrix Cross Over (Two-dimensional Cross Over) 257
  9.2.6 Cross Over Rate 258

9.3 Inversion and Deletion 259
  9.3.1 Inversion 259
  9.3.2 Deletion and Duplication 259
  9.3.3 Deletion and Regeneration 260
  9.3.4 Segregation 260
  9.3.5 Cross Over and Inversion 261

9.4 Mutation Operator 261
  9.4.1 Mutation 261
  9.4.2 Mutation Rate $P_m$ 262

9.5 Bit-wise Operators 263
  9.5.1 One’s Complement Operator 263
  9.5.2 Logical Bit-wise Operators 263
  9.5.3 Shift Operators 264

9.6 Bit-wise Operators Used in GA 265

9.7 Generational Cycle 265

9.8 Convergence of Genetic Algorithm 271
Part 4 HYBRID SYSTEMS

10 INTEGRATION OF NEURAL NETWORKS, FUZZY LOGIC, AND GENETIC ALGORITHMS  
10.1 Hybrid Systems 298  
10.1.1 Sequential Hybrid Systems 298  
10.1.2 Auxiliary Hybrid Systems 298  
10.1.3 Embedded Hybrid Systems 299  
10.2 Neural Networks, Fuzzy Logic, and Genetic Algorithms Hybrids 300  
10.2.1 Neuro-Fuzzy Hybrids 300  
10.2.2 Neuro-Genetic Hybrids 300  
10.2.3 Fuzzy-Genetic Hybrids 301  
10.3 Preview of the Hybrid Systems to be Discussed 301  
10.3.1 Genetic Algorithm based Backpropagation Network 302  
10.3.2 Fuzzy-Backpropagation Network 302  
10.3.3 Simplified Fuzzy ARTMAP 302  
10.3.4 Fuzzy Associative Memories 302  
10.3.5 Fuzzy Logic Controlled Genetic Algorithms 303  
Summary 303  
References 303  

11 GENETIC ALGORITHM BASED BACKPROPAGATION NETWORKS 305–327  
11.1 GA Based Weight Determination 306  
11.1.1 Coding 306  
11.1.2 Weight Extraction 308  
11.1.3 Fitness Function 309  
11.1.4 Reproduction 311  
11.1.5 Convergence 313  
11.2 Applications 322  
11.2.1 K-factor Determination in Columns 322  
11.2.2 Electrical Load Forecasting 323
12 FUZZY BACKPROPAGATION NETWORKS 328–357

12.1 LR-type Fuzzy numbers 328
   12.1.1 Operations on LR-type Fuzzy Numbers 330
12.2 Fuzzy Neuron 330
12.3 Fuzzy BP Architecture 331
12.4 Learning in Fuzzy BP 333
12.5 Inference by Fuzzy BP 339
12.6 Applications 347
   12.6.1 Knowledge Base Evaluation 348
   12.6.2 Earthquake damage Evaluation 353

Summary 355
Programming Assignment 356
References 357

13 SIMPLIFIED FUZZY ARTMAP 358–388

13.1 Fuzzy ARTMAP: A Brief Introduction 358
13.2 Simplified Fuzzy ARTMAP 359
   13.2.1 Input Normalization 360
   13.2.2 Output Node Activation 361
13.3 Working of Simplified Fuzzy ARTMAP 364
13.4 Application: Image Recognition 370
   13.4.1 Feature Extraction—Moment Based Invariants 372
   13.4.2 Computation of Invariants 375
   13.4.3 Structure of the Simplified Fuzzy ARTMAP Based
       Pattern Recognizer 380
   13.4.4 Experimental Study 381
13.5 Recent Trends 384

Summary 384
Programming Assignment 385
References 387

14 FUZZY ASSOCIATIVE MEMORIES 389–416

14.1 FAM—An Introduction 389
14.2 Single Association FAM 390
   14.2.1 Graphical Method of Inference 392
   14.2.2 Correlation Matrix Encoding 393
14.3 Fuzzy Hebb FAMs 395
14.4 FAM Involving a Rule Base 400
14.5 FAM Rules with Multiple Antecedents/Consequents 401
   14.5.1 Decomposition Rules 404
14.6 Applications 406
  14.6.1 Balancing an Inverted Pendulum 406
  14.6.2 Fuzzy Truck Backer-upper System 411

Summary 414

Programming Assignment 415

Suggested Further Reading 416
References 416

15 FUZZY LOGIC CONTROLLED GENETIC ALGORITHMS 417–435

15.1 Soft Computing Tools 417
  15.1.1 Fuzzy Logic as a Soft Computing Tool 417
  15.1.2 Genetic Algorithm as a Soft Computing Tool 418

15.2 Problem Description of Optimum Design 418

15.3 Fuzzy Constraints 419

15.4 Illustrations 420
  15.4.1 Optimization of the Weight of a Beam 420
  15.4.2 Optimal Mix Design for High Performance Concrete 422

15.5 GA in Fuzzy Logic Controller Design 424

15.6 Fuzzy Logic Controller 425
  15.6.1 Components of a Fuzzy Logic Controller (FLC) 425
  15.6.2 Fuzzy IF-THEN Rules 426

15.7 FLC-GA Based Structural Optimization 429

15.8 Applications 429
  15.8.1 Optimum Truss 429
  15.8.2 112 Bar Dome Space Truss 431

Summary 432

Programming Assignment 433

Suggested Further Reading 435
References 435

INDEX 437–439