Contents

1 Introduction to Computational Intelligence 1
1.1 Intelligent Systems 1
1.2 Computational Intelligence 2
1.3 About the Second Edition of This Book 4
References 5

Part I Neural Networks

2 Introduction to Neural Networks 9
2.1 Motivation 9
2.2 Biological Background 11
References 13

3 Threshold Logic Units 15
3.1 Definition and Examples 15
3.2 Geometric Interpretation 17
3.3 Limitations 19
3.4 Networks of Threshold Logic Units 20
3.5 Training the Parameters 23
3.6 Variants 33
3.7 Training Networks 33
References 34

4 General Neural Networks 37
4.1 Structure of Neural Networks 37
4.2 Operation of Neural Networks 40
4.3 Training Neural Networks 44

5 Multilayer Perceptrons 47
5.1 Definition and Examples 47
5.2 Function Approximation 53
5.3 Logistic Regression 59
5.4 Gradient Descent 61
5.5 Error Backpropagation 65

5.6 Gradient Descent Examples 68
5.7 Variants of Gradient Descent 72
5.7.1 Manhattan Training 72
5.7.2 Lifting the Derivative of the Activation Function . . . 73
5.7.3 Momentum Term 73
5.7.4 Self-Adaptive Error Backpropagation 74
5.7.5 Resilient Error Backpropagation 75
5.7.6 Quick-Propagation 75
5.7.7 Weight Decay 77
5.8 Examples for Some Variants 77
5.9 Number of Hidden Neurons 79
5.10 Deep Learning 82
5.11 Sensitivity Analysis 89
References 91

6 Radial Basis Function Networks 93
6.1 Definition and Examples 93
6.2 Function Approximation 98
6.3 Initializing the Parameters 101
6.4 Training the Parameters 107
6.5 Generalized Form 111
References 112

7 Self-organizing Maps 113
7.1 Definition and Examples 113
7.2 Learning Vector Quantization 116
7.3 Neighborhood of the Output Neurons 123
7.3 Neighborhood of the Output Neurons 123
References 128

8 Hopfield Networks 131
8.1 Definition and Examples 131
8.2 Convergence of the Computations 135
8.3 Associative Memory 139
8.4 Solving Optimization Problems 144
8.5 Simulated Annealing 150
8.6 Boltzmann Machines 151
References 156

9 Recurrent Networks 159
9.1 Simple Examples 159
9.2 Representing Differential Equations 164
9.3 Vectorial Neural Networks 166
9.4 Error Backpropagation in Time 169
References 171

10 Mathematical Remarks for Neural Networks 173
10.1 Equations for Straight Lines 173
10.2 Regression 175
10.3 Activation Transformation 179
Reference 180

Part II Evolutionary Algorithms

11 Introduction to Evolutionary Algorithms 183
11.1 Metaheuristics 183
11.2 Biological Evolution 184
11.3 Simulated Evolution 189
11.3.1 Optimization Problems 189
11.3.2 Basic Notions and Concepts 192
11.3.3 Building Blocks of an Evolutionary Algorithm 195
11.4 The n-Queens Problem 197
11.5 Related Optimization Techniques 202
11.5.1 Gradient Ascent or Descent 203
11.5.2 Hill Climbing 205
11.5.3 Simulated Annealing 206
11.5.4 Threshold Accepting 206
11.5.5 Great Deluge Algorithm 207
11.5.6 Record-to-Record Travel 207
11.6 The Traveling Salesman Problem 208
References 211

12 Elements of Evolutionary Algorithms 213
12.1 Encoding of Solution Candidates 213
12.1.1 Hamming Cliffs 214
12.1.2 Epistasis 216
12.1.3 Closedness of the Search Space 218
12.2 Fitness and Selection 220
12.2.1 Fitness Proportionate Selection 221
12.2.2 The Dominance Problem 222
12.2.3 Vanishing Selective Pressure 223
12.2.4 Adapting the Fitness Function 225
12.2.5 The Variance Problem 227
12.2.6 Rank-Based Selection 228
12.2.7 Tournament Selection 229
12.2.8 Elitism 230
12.2.9 Niche Techniques 231
12.2.10 Characterization of Selection Methods 231
12.3 Genetic Operators 232
12.3.1 Mutation Operators 233
12.3.2 Crossover Operators 236

12.3.3 Multi-parent Operators . . . 240
12.3.4 Characteristics of Recombination Operators . . . 241
12.3.5 Interpolating and Extrapolating Recombination . . . 242
References . . . 243

13 Fundamental Evolutionary Algorithms . . . 245
13.1 Genetic Algorithms . . . 245
13.1.1 The Schema Theorem . . . 247
13.1.2 The Two-Armed Bandit Argument . . . 254
13.1.3 The Principle of Minimal Alphabets . . . 256
13.2 Evolution Strategies . . . 257
13.2.1 Selection . . . 258
13.2.2 Global Variance Adaptation . . . 259
13.2.3 Local Variance Adaptation . . . 261
13.2.4 Covariances . . . 262
13.2.5 Recombination Operators . . . 267
13.3 Genetic Programming . . . 268
13.3.1 Initialization . . . 271
13.3.2 Genetic Operators . . . 273
13.3.3 Application Examples . . . 275
13.3.4 The Problem of Introns . . . 279
13.3.5 Extensions . . . 280
13.4 Multi-criteria Optimization . . . 280
13.4.1 Weighted Combination of Criteria . . . 281
13.4.2 Pareto-Optimal Solutions . . . 281
13.4.3 Finding Pareto-Frontiers with Evolutionary Algorithms . . . 283
13.5 Special Applications and Techniques . . . 287
13.5.1 Behavioral Simulation . . . 288
13.5.2 Parallelization . . . 294
References . . . 296

14 Computational Swarm Intelligence . . . 299
14.1 Introduction . . . 299
14.2 Basic Principles of Computational Swarm Intelligence . . . 300
14.2.1 Swarms in Known Environments . . . 303
14.2.2 Swarms in Unknown Environments . . . 304
14.3 Particle Swarm Optimization . . . 305
14.3.1 Influence of the Parameters . . . 307
14.3.2 Turbulence Factor . . . 308
14.3.3 Boundary Handling . . . 308

14.4 Multi-objective Particle Swarm Optimization 309
14.4.1 Leader Selection Mechanism 310
14.4.2 Archiving 312
14.5 Many-Objective Particle Swarm Optimization 316
14.5.1 Ranking Non-dominated Solutions 316
14.5.2 Distance Based Ranking 317
14.6 Ant Colony Optimization 317
References 324

Part III Fuzzy Systems

15 Introduction to Fuzzy Sets and Fuzzy Logic 329
15.1 Natural Languages and Formal Models 329
15.2 Fuzzy Sets 330
15.3 Interpretation of Fuzzy Sets 332
15.3.1 Gradual Membership is Different from Probability 332
15.3.2 Fuzzy Sets for Modeling Similarity 333
15.3.3 Fuzzy Sets for Modeling Preference 334
15.3.4 Fuzzy Sets for Modeling Possibility 334
15.3.5 Consistent Interpretations of Fuzzy Sets in Applications 334
15.4 Representation of Fuzzy Sets 335
15.4.1 Definition Based on Functions 336
15.4.2 Level Sets 338
15.5 Fuzzy Logic 340
15.5.1 Propositions and Truth Values 340
15.5.2 t-Norms and t-Conorms 343
15.5.3 Aggregation Functions 348
15.5.4 Basic Assumptions and Problems 349
15.6 Operations on Fuzzy Sets 350
15.6.1 Intersection 350
15.6.2 Union 352
15.6.3 Complement 353
15.6.4 Linguistic Modifiers 354
15.7 Extensions of Fuzzy Set Theory 355
References 358

16 The Extension Principle 361
16.1 Mappings of Fuzzy Sets 361
16.2 Mapping of Level Sets 363
16.3 Cartesian Product and Cylindrical Extension 364
16.4 Extension Principle for Multivariate Mappings 365
References 367

17 Fuzzy Relations 369
17.1 Crisp Relations 369
17.2 Application of Relations and Deduction 371
17.3 Chains of Deductions 373
17.4 Simple Fuzzy Relations 375
17.5 Composition of Fuzzy Relations 379
17.6 Fuzzy Relational Equations 381
References 382

18 Similarity Relations 383
18.1 Similarity 383
18.2 Fuzzy Sets and Extensional Hulls 384
18.3 Scaling Concepts 386
18.4 Fuzzy Sets and Similarity Relations 389
References 393

19 Fuzzy Control 395
19.1 Mamdani Controllers 395
19.1.1 Remarks on Fuzzy Controller Design 399
19.1.2 Defuzzification Methods 402
19.2 Takagi–Sugeno–Kang Controllers 405
19.3 Mamdani Controller and Similarity Relations 407
19.3.1 Interpretation of a Controller 407
19.3.2 Construction of a Controller 409
19.4 Logic-Based Controllers 410
19.5 Control Based on Fuzzy Relational Equations 412
19.6 Hybrid Systems to Tune Fuzzy Controllers 413
19.6.1 Neuro-Fuzzy Control 414
19.6.2 Evolutionary Fuzzy Control 423
References 428

20 Fuzzy Data Analysis 431
20.1 Fuzzy Methods in Data Analysis 431
20.2 Fuzzy Clustering 432
20.2.1 Clustering 433
20.2.2 Presuppositions and Notation 433
20.2.3 Classical c-Means Clustering 434
20.2.4 Fuzzification by Membership Transformation 436
20.2.5 Fuzzification by Membership Regularization 439
20.2.6 Comparison 444
20.3 Analysis of Imprecise Data Using Random Sets 445
20.4 Possibility Theory and Generalized Measures 447
20.5 Fuzzy Random Variables 450
References 453

Part IV Bayes and Markov Networks

21 Introduction to Bayes Networks 459

22 Elements of Probability and Graph Theory 465
22.1 Probability Theory 465
22.1.1 Random Variables and Random Vectors 468
22.1.2 Independences 472
22.2 Graph Theory 474
22.2.1 Background 474
22.2.2 Join Graphs 482
22.2.3 Separations 485
References 491

23 Decompositions 493
References 504

24 Evidence Propagation 507
24.1 Initialization 511
24.1.1 Message Passing 511
24.1.2 Update 512
24.1.3 Marginalization 512
24.1.4 Derivation 517
24.2 Other Propagation Algorithms 518
References 519

25 Learning Graphical Models 521
References 530

26 Belief Revision 531
26.1 Introduction 531
26.2 Revision Procedure 533
26.3 A Real-World Application 535
26.3.1 Knowledge Representation 536
References 538

27 Decision Graphs 541
27.1 Motivation 541
27.2 Definition 543
27.3 Policies and Strategies 546
27.4 Finding Optimal Strategies 546
27.5 Example Scenario 548
References 551

Index 553