

Contents

PREFACE xxi

ACKNOWLEDGMENTS xxiii

Overview 1

- O.1 Early Biomedical Systems 1
 - O.1.1 History 1
 - O.1.2 Medical Records 2
 - O.1.3 Drawbacks of Traditional Approaches 3
 - O.1.4 Numerical versus Symbolic Approaches 3
- O.2 Medical and Biological Data 3
 - O.2.1 Binary data 4
 - O.2.2 Categorical data 4
 - O.2.3 Integer Data 4
 - O.2.4 Continuous Data 4
 - O.2.5 Fuzzy Data 4
 - O.2.6 Temporal Data 5
 - O.2.7 Time Series Data 6
 - O.2.8 Image Data 8
- O.3 Organization of the Book 8
- References 9

PART I NEURAL NETWORKS

CHAPTER 1 Foundations of Neural Networks 13

- 1.1 Objectives of Neural Networks 13
 - 1.1.1 Modeling Biomedical Systems 13
 - 1.1.2 Establishment of Decision-Making Systems 14

1.2	Biological Foundations of Neural Networks	14
1.2.1	Structure of the Neuron	14
1.2.2	Structure of the Central Nervous System	16
1.3	Early Neural Models	16
1.3.1	McCulloch and Pitts Neuron	16
1.3.2	Hebbian Learning	17
1.3.3	ADALINE	17
1.3.4	Rosenblatt Perceptron	17
1.3.5	Problems with Early Systems	18
1.4	Precursor to Current Models: Pattern Classification	19
1.4.1	Feature Extraction	19
1.4.2	Supervised Learning	21
1.4.3	Unsupervised Learning	21
1.4.4	Learning Algorithms	22
1.5	Resurgence of the Neural Network Approach	24
1.6	Basic Concepts	25
1.6.1	Artificial Neurons	25
1.6.2	Selection of Input Nodes	25
1.6.3	Network Structure	25
1.6.3.1	Feed-Forward Networks	25
1.6.3.2	Feed-Backward Networks	25
1.6.4	Learning Mechanism	26
1.6.5	Output	26
1.7	Summary	26
	References	27

CHAPTER 2 Classes of Neural Networks 29

2.1	Basic Network Properties	29
2.1.1	Terminology	29
2.1.2	Structure of Networks	29
2.1.3	Computational Properties of Nodes	30
2.1.4	Algorithm Design	31
2.2	Classification Models	32
2.3	Association Models	32
2.3.1	Hopfield Nets	33
2.3.1.1	Theoretical Basis	33
2.3.2	Other Associative Memory Approaches	34
2.3.2.1	Theoretical Basis of Bidirectional Associative Memory (BAM)	34
2.3.3	Hamming Net	36
2.3.3.1	Theoretical Basis	36
2.3.4	Applications of Association Models	37
2.4	Optimization Models	38
2.4.1	Hopfield Net	38
2.4.2	Boltzmann Machines	39
2.4.2.1	Theoretical Basis	39
2.4.3	Applications of Optimization Models	40
2.5	Self-Organization Models	40

- 2.6 Radial Basis Functions (RBFs) 41
 - 2.6.1 Theoretical Basis 41
 - 2.6.2 Applications of Radial Basis Functions 42
- 2.7 Summary 43
- References 43

CHAPTER 3 Classification Networks and Learning 45

- 3.1 Network Structure 45
 - 3.1.1 Layer Definition 45
 - 3.1.2 Input Layer 45
 - 3.1.3 Hidden Layer 45
 - 3.1.4 Output Layer 45
- 3.2 Feature Selection 46
 - 3.2.1 Types of Variables 46
 - 3.2.2 Feature Vectors 46
 - 3.2.3 Image Data 47
 - 3.2.4 Time Series Data 47
 - 3.2.4.1 Chaotic Analysis of Time Series 48
 - 3.2.4.2 Graphical Measures of Chaos 49
 - 3.2.4.3 Numerical Measures of Chaos 49
 - 3.2.5 Issues of Dimensionality 50
- 3.3 Types of Learning 51
 - 3.3.1 Supervised Learning 51
 - 3.3.1.1 Selection of Training and Test Sets 51
 - 3.3.1.2 Selection of Learning Algorithm 52
 - 3.3.2 Unsupervised Learning 52
 - 3.3.3 Causal Models 55
- 3.4 Interpretation of Output 55
- 3.5 Summary 55
- References 56

CHAPTER 4 Supervised Learning 59

- 4.1 Decision Surfaces 59
- 4.2 Two-Category Separation, Linearly Separable Sets 60
 - 4.2.1 Fisher's Linear Discriminant 60
 - 4.2.2 Gradient Descent Procedures 61
 - 4.2.3 Perceptron Algorithm 62
 - 4.2.4 Relaxation Procedures 62
 - 4.2.5 Potential Functions 63
- 4.3 Nonlinearly Separable Sets 64
 - 4.3.1 Nonlinear Discriminant Functions 64
 - 4.3.2 Hypernet, A Nonlinear Potential Function Algorithm 64
 - 4.3.3 Categorization of Nonlinearly Separable Sets 65
 - 4.3.3.1 Minimum Squared Error Procedures (MSEs) 65
 - 4.3.3.2 Ho-Kashyap Procedure 66
- 4.4 Multiple Category Classification Problems 66
 - 4.4.1 Extension of Fisher Discriminant 66

- 4.4.2 Kesler Construction 67
- 4.4.3 Backpropagation 68
- 4.5 Relationship to Neural Network Models 69
- 4.6 Comparison of Methods 70
 - 4.6.1 Convergence and Stability 70
 - 4.6.2 Training Time 70
 - 4.6.3 Predictive Power 70
- 4.7 Applications 71
 - 4.7.1 Single-Category Classification 71
 - 4.7.2 Multicategory Classification 72
 - 4.7.3 Reduction of Nodes 74
- 4.8 Summary 74
- References 76

CHAPTER 5 Unsupervised Learning 79

- 5.1 Background 79
- 5.2 Clustering 79
 - 5.2.1 Basic Isodata 79
 - 5.2.2 Similarity Measures 80
 - 5.2.3 Criterion Functions 80
 - 5.2.3.1 Sum of Squared Error Criteria 80
 - 5.2.3.2 Minimum Error Criteria 81
 - 5.2.3.3 Scattering Criteria 81
 - 5.2.3.4 Iterative Optimization 81
 - 5.2.4 Hierarchical Clustering 82
 - 5.2.5 Metrics 82
- 5.3 Kohonen Networks and Competitive Learning 83
- 5.4 Hebbian Learning 85
- 5.5 Adaptive Resonance Theory (ART) 86
- 5.6 Applications 88
 - 5.6.1 Dimensionality Reduction 88
 - 5.6.1.1 Minimization of Criteria Functions 88
 - 5.6.1.2 Clustering and Dimensionality Reduction 89
 - 5.6.2 Biomedical Applications 89
 - 5.6.3 Diagnosis of CAD as a Clustering Problem 89
 - 5.6.4 Other Biomedical Applications 90
- 5.7 Summary 91
- References 92

CHAPTER 6 Design Issues 95

- 6.1 Introduction 95
 - 6.1.1 Objective of the Model 95
 - 6.1.2 Information Sources 95
- 6.2 Input Data Types 96
 - 6.2.1 Extracting Information from the Medical Record 96
 - 6.2.2 Using Information from Data Collection Sheets 97
 - 6.2.2.1 Coding Multiple Responses 98
 - 6.2.2.2 Ordering Categorical Data 99

- 6.2.2.3 Changing Categorical Data into Binary Data 99
- 6.2.2.4 Considering the Use of Fuzzy Input Data 99
- 6.2.2.5 Missing Data 100
- 6.2.3 Time Series Data 100
- 6.2.4 Image Data 101
- 6.3 Structure of Networks 101
 - 6.3.1 Number of Layers 101
 - 6.3.2 Connectivity 101
- 6.4 Implications of Network Structures 101
 - 6.4.1 Classification Potential 101
 - 6.4.2 Training 103
 - 6.4.2.1 Number of Cases Required 103
 - 6.4.3 Reduction in Number of Nodes 104
 - 6.4.3.1 Expert Intervention 104
 - 6.4.3.2 Statistical Significance 104
 - 6.4.3.3 Threshold Pruning 104
 - 6.4.3.4 Other Techniques 105
 - 6.4.4 Output 105
- 6.5 Choice of Learning Algorithm 105
- 6.6 Summary 106
- References 106

CHAPTER 7 Comparative Analysis 109

- 7.1 Introduction 109
- 7.2 Input Data Considerations 109
- 7.3 Supervised Learning Algorithms 110
 - 7.3.1 Gradient Descent Procedures 111
 - 7.3.2 Extensions to Nonlinear Decision Functions 111
 - 7.3.3 Extensions to Multiple Categories 113
- 7.4 Unsupervised Learning 114
 - 7.4.1 Clustering Methods 114
 - 7.4.1.1 Choice of Method 114
 - 7.4.1.2 Choice of Distance Measure 114
 - 7.4.1.3 Limitations 115
 - 7.4.2 Self-Organization Networks 115
 - 7.4.2.1 Kohonen Networks 115
 - 7.4.2.2 ART Networks 115
- 7.5 Network Structures 115
 - 7.5.1 Number of Categories 115
 - 7.5.2 Connectivity 115
- 7.6 Interpretation of Results 116
 - 7.6.1 Supervised Learning 116
 - 7.6.1.1 Training 116
 - 7.6.1.2 Evaluation 116
 - 7.6.1.3 Classification 117
 - 7.6.2 Unsupervised Learning 117
 - 7.6.2.1 Training 117
 - 7.6.2.2 Evaluation 118
 - 7.6.2.3 Classification 118

- 7.6.3 Data Scaling and Normalization 118
- 7.6.4 Dependence on Training Data 118
- 7.7 Summary 118
- References 119

CHAPTER 8 Validation and Evaluation 121

- 8.1 Introduction 121
- 8.2 Data Checking 121
 - 8.2.1 Verification of Accuracy of Data for Training 121
 - 8.2.1.1 Chart Review 121
 - 8.2.1.2 Databases 122
 - 8.2.1.3 Prospective Studies 122
 - 8.2.2 Appropriateness of Data for Training 122
 - 8.2.3 Use of Gold Standards in Supervised Learning 123
- 8.3 Validation of Learning Algorithm 123
 - 8.3.1 Technical Integrity of Algorithm 123
 - 8.3.2 Appropriateness of Algorithm for Given Application 123
 - 8.3.2.1 Theoretical Considerations 123
 - 8.3.2.2 Practical Considerations 123
 - 8.3.2.3 Comparison to Other Approaches 123
- 8.4 Evaluation of Performance 124
 - 8.4.1 Supervised Learning Algorithms 124
 - 8.4.1.1 Performance of Algorithm on Test Set 124
 - 8.4.1.2 Relevance of Contributing Parameters 124
 - 8.4.1.3 Comparison to Other Methods 124
 - 8.4.2 Unsupervised Learning 124
 - 8.4.2.1 Applicability to Other Data Sets 125
- 8.5 Summary 126
- References 127

PART II ARTIFICIAL INTELLIGENCE

CHAPTER 9 Foundations of Computer-Assisted Decision Making 131

- 9.1 Motivation for Computer-Assisted Decision Making 131
- 9.2 Databases and Medical Records 131
 - 9.2.1 The First Decade (1970–1980) 131
 - 9.2.2 The Second Decade (1980–1990) 134
 - 9.2.3 Current Approaches to Medical Databases 134
- 9.3 Mathematical Modeling and Simulation 135
- 9.4 Pattern Recognition 136
- 9.5 Bayesian Analysis 137
 - 9.5.1 Early Bayesian Systems 137
 - 9.5.2 Bayesian Belief Networks 138
- 9.6 Decision Theory 138
- 9.7 Symbolic Reasoning Techniques 139
 - 9.7.1 Early Expert Systems 139
 - 9.7.2 Second-Generation Expert Systems 142

- 9.7.2.1 Causal Systems 143
- 9.7.2.2 Reasoning with Uncertainty 143
- 9.7.2.3 Hybrid Systems 144

9.8 Summary 144

References 145

CHAPTER 10 Knowledge Representation 151

10.1 Production Rules 151

10.1.1 General Structure 151

10.1.2 Methods of Confirming Conditions 152

10.1.2.1 Matching 152

10.1.2.1.1 Natural Language Processing 152

10.1.2.1.2 Partial Matching 152

10.1.2.1.3 Data-Driven Approaches 153

10.1.2.2 Conflict Resolution 153

10.1.3 Rule Searching Strategies 153

10.1.4 Expanded Production Rule Systems 155

10.1.5 Certainty Factors 156

10.1.6 Advantages of Production Systems 158

10.1.7 Disadvantages of Production Systems 158

10.1.8 Areas of Applications of Production Rule Systems 160

10.2 Frames 160

10.2.1 General Structure 160

10.2.2 Inheritance 161

10.2.3 Example of a Frame-Based Decision-Support System 161

10.3 Databases 162

10.3.1 Relational Databases 163

10.3.2 Query Languages 165

10.3.3 Object-Oriented Databases 165

10.4 Predicate Calculus and Semantic Nets 166

10.4.1 Syntax 166

10.4.2 Method of Proof 167

10.4.3 Semantic Trees 167

10.4.4 Semantic Interpretation 167

10.4.5 Applications 167

10.5 Temporal Data Representations 168

10.5.1 Knowledge-Based Systems 168

10.5.2 Data-Based Systems 169

10.6 Summary 169

References 171

CHAPTER 11 Knowledge Acquisition 173

11.1 Introduction 173

11.2 Expert Input 173

11.2.1 Acquisition for a New System 173

11.2.1.1 Use of Existing Material 173

11.2.1.2 Techniques for Knowledge Elicitation 175

11.2.1.3 Dealing with Multiple Experts 176

11.2.1.4	Consistency	177
11.2.1.5	Completeness	177
11.2.2	Updating of Information	177
11.3	Learned Knowledge	178
11.3.1	Rote Learning	178
11.3.2	Learning by Being Told	178
11.3.3	Learning from Examples	178
11.3.3.1	Pattern Classification and Neural Networks	178
11.3.3.2	Learning Single Concepts	178
11.3.3.3	Learning Multiple Concepts	179
11.4	Meta-Knowledge	181
11.5	Knowledge Base Maintenance	182
11.5.1	Assuring Accuracy	182
11.5.1.1	Permission to Change Knowledge Base	182
11.5.1.2	Verifying Sources of Information	182
11.5.2	Maintaining Consistency	183
11.6	Summary	183
	References	183

CHAPTER 12 Reasoning Methodologies 185

12.1	Introduction	185
12.2	Problem Representations	185
12.2.1	Graphs and Trees	185
12.2.2	Binary Trees	187
12.2.3	State-Space Representations	188
12.2.4	Problem Reduction Representations	189
12.2.5	Game Trees	190
12.3	Blind Searching	190
12.3.1	Depth-First Search	190
12.3.2	Breadth-First Search	191
12.4	Ordered Search	191
12.4.1	Uniform Cost Method	192
12.4.2	Using Heuristic Information	192
12.5	AND/OR Trees	193
12.5.1	Breadth-First Search and Depth-First of AND/OR Tree	194
12.5.2	Costs of Solution Trees	194
12.5.3	Ordered Searching of AND/OR Trees	195
12.6	Searching Game Trees	196
12.6.1	Minimax	196
12.6.2	Alpha-Beta	196
12.7	Searching Graphs	196
12.7.1	Breadth-First Graph Searching	197
12.7.2	Uniform Cost Algorithm	197
12.7.3	AND/OR Graphs	197
12.8	Rule Base Searching	197
12.8.1	Backward-Chaining	197
12.8.2	Forward-Chaining	198
12.9	Higher-Level Reasoning Methodologies	198
12.9.1	Inference Engines	198

- 12.9.1.1 Binary Logic Engines 198
- 12.9.1.2 Approximate Reasoning Engines 199
- 12.9.1.3 Fuzzy Logic Engines 199
- 12.9.1.4 Probability-Based Engines 199
- 12.9.2 Cognitive Models 200
- 12.9.3 Automatic Deduction 200
- 12.9.4 Natural Language Processing 200
- 12.10 Examples in Biomedical Expert Systems 201
- 12.11 Summary 201
- References 203

CHAPTER 13 Validation and Evaluation 205

- 13.1 Introduction 205
- 13.2 Algorithmic Evaluation 205
 - 13.2.1 Searching Algorithm 205
 - 13.2.1.1 AND/OR Trees 205
 - 13.2.1.2 Control by Meta Rules 206
 - 13.2.1.3 Data-Driven Search 206
 - 13.2.1.4 Hierarchical Search 206
 - 13.2.2 Inference Engine 206
 - 13.2.2.1 Binary Engines 206
 - 13.2.2.2 Complex Engines 207
 - 13.2.3 Aggregation of Evidence 207
 - 13.2.4 Use of Meta Knowledge 207
- 13.3 Knowledge Base Evaluation 207
 - 13.3.1 Expert-Derived Information 207
 - 13.3.1.1 Individual Units of Knowledge 208
 - 13.3.1.2 Combination of Knowledge 208
 - 13.3.2 Learned Information 208
 - 13.3.3 Meta Knowledge 208
- 13.4 System Evaluation 208
 - 13.4.1 Evaluation with Original Knowledge Base 209
 - 13.4.2 Evaluation with Updated Knowledge Base 209
 - 13.4.3 Evaluation of User Interaction Parameters 209
 - 13.4.3.1 Interpretation of Input 209
 - 13.4.3.2 Explanation Capabilities 210
 - 13.4.4 Validation with Clinical Data 210
 - 13.4.4.1 Sources of Clinical Data 210
 - 13.4.4.1.1 Retrospective Studies 210
 - 13.4.4.2 Selection of Cases 210
 - 13.4.4.3 Actual Outcome 211
 - 13.4.4.4 Results from Clinical Decision-Support System 211
- 13.5 Summary 212
- References 213

PART III ALTERNATIVE APPROACHES

CHAPTER 14 Genetic Algorithms 217

- 14.1 Foundations 217
- 14.2 Representation Schemes 218

- 14.3 Evaluation Functions 218
- 14.4 Genetic Operators 218
 - 14.4.1 Mutation 218
 - 14.4.2 Crossover 218
- 14.5 Evolution Strategies 219
 - 14.5.1 Genetic Algorithms 219
 - 14.5.2 Optimization Strategies 219
 - 14.5.2.1 Hill Climbing 219
 - 14.5.2.2 Simulated Annealing 219
 - 14.5.3 Genetic Search 220
- 14.6 Biomedical Examples 221
 - 14.6.1 Literature References 221
- 14.7 Summary 222
- References 223

CHAPTER 15 Probabilistic Systems 225

- 15.1 Introduction 225
- 15.2 Bayesian Approaches 225
 - 15.2.1 Bayes' Rule 225
 - 15.2.2 Bayes' Decision Theory 226
 - 15.2.3 Risk Analysis 226
 - 15.2.4 Supervised Bayesian Learning 228
 - 15.2.5 Decision Trees 229
- 15.3 Parameter Estimation 231
 - 15.3.1 Maximum Likelihood Estimation 231
 - 15.3.2 Bayesian Estimation 232
- 15.4 Discriminant Analysis 233
- 15.5 Statistical Pattern Classification 234
- 15.6 Unsupervised Learning 235
 - 15.6.1 Parzen Windows 235
 - 15.6.2 Nearest Neighbor Algorithms 236
 - 15.6.3 Mixture Densities and Maximum Likelihood Estimates 236
 - 15.6.4 Unsupervised Bayesian Learning 237
- 15.7 Regression Analysis 238
- 15.8 Biomedical Applications 240
- 15.9 Summary 240
- References 241

CHAPTER 16 Fuzzy Systems 243

- 16.1 Introduction 243
- 16.2 Fuzzy Information 243
 - 16.2.1 Input Data 243
 - 16.2.2 Fuzzy Logic and Fuzzy Set Theory 244
 - 16.2.3 Representation of Fuzzy Variables 244
 - 16.2.4 Membership Functions 245

- 16.3 Fuzzy Neural Networks 245
- 16.4 Fuzzy Approaches for Supervised Learning Networks 246
 - 16.4.1 Pre-Processing of Fuzzy Input 246
 - 16.4.2 Propagation of Results 247
 - 16.4.2.1 Max–Min Networks 247
 - 16.4.2.2 Learning Algorithms for Interval Data 247
 - 16.4.2.3 Analogue Models 248
- 16.5 Fuzzy Generalizations of Unsupervised Learning Methods 248
 - 16.5.1 Fuzzy Associative Memories 248
 - 16.5.2 Fuzzy Clustering 248
- 16.6 Reasoning with Uncertain Information 249
 - 16.6.1 Uncertainty in Input Data 250
 - 16.6.1.1 Degree of Presence Input 250
 - 16.6.1.2 Linguistic Input 250
 - 16.6.2 Uncertainty in Knowledge Base 250
 - 16.6.3 Inference Engines for Uncertain Information 251
 - 16.6.3.1 Binary Logic Engines 251
 - 16.6.3.2 Fuzzy Logic Engines 252
 - 16.6.4 Evidential Reasoning 252
 - 16.6.4.1 Possibility Theory 252
 - 16.6.4.2 Probabilistic Approaches 253
 - 16.6.4.3 Dempster–Shafer Belief Theory 253
 - 16.6.5 Compatibility Indices 254
 - 16.6.6 Approximate Reasoning 255
- 16.7 Pre-Processing and Post-Processing Using Fuzzy Techniques 256
- 16.8 Applications in Biomedical Engineering 257
- 16.9 Summary 258
- References 259

CHAPTER 17 Hybrid Systems 261

- 17.1 Hybrid Systems Approaches 261
- 17.2 Components of Hybrid Systems 261
 - 17.2.1 Knowledge-Based Approaches 262
 - 17.2.1.1 Knowledge Base 262
 - 17.2.1.2 Input Data 263
 - 17.2.1.3 Decision-Making Algorithm 264
 - 17.2.1.4 Output Data 264
 - 17.2.2 Data-Based Approaches 264
 - 17.2.2.1 Neural Networks 265
 - 17.2.2.2 Genetic Algorithms 266
 - 17.2.3 General Methodologies 266
 - 17.2.3.1 Fuzzy Logic 266
 - 17.2.3.2 Statistical Approaches 267
- 17.3 Use of Complex Data Structures 267
 - 17.3.1 Time Series Data 267
 - 17.3.1.1 Automatic ECG Analyzers 267
 - 17.3.1.2 Summary Methods 268
 - 17.3.2 Image Data 268
- 17.4 Design Methodologies 268
 - 17.4.1 System Structure 268

- 17.4.2 User Interfaces 269
- 17.4.3 Pre-Processing 269
- 17.4.4 Post-Processing 269
- 17.4.5 Presentation of Results 270
- 17.5 Summary 270
- References 270

CHAPTER 18 HyperMerge, a Hybrid Expert System 273

- 18.1 Introduction 273
- 18.2 Knowledge-Based Component 273
 - 18.2.1 Crisp Implementation 273
 - 18.2.2 Partial Substantiation of Antecedents 274
 - 18.2.3 Weighted Antecedents and Partial Substantiation of Rules 275
 - 18.2.4 Handling of Temporal Data 276
- 18.3 Neural Network Component 276
 - 18.3.1 Learning Algorithm 276
 - 18.3.2 Special Data Types 277
 - 18.3.2.1 Temporal Data 277
 - 18.3.2.2 Crisp versus Fuzzy Temporal Data 277
 - 18.3.2.3 Time Series Data 278
- 18.4 Analysis of Time Series Data 278
 - 18.4.1 Chaos Theory 278
 - 18.4.2 Continuous versus Discrete Chaotic Modeling 279
 - 18.4.3 Difference Equations and Graphs 280
 - 18.4.4 Central Tendency Measure 281
- 18.5 Combined System 282
 - 18.5.1 Weighting of Antecedents 282
 - 18.5.2 Determination of Thresholds 282
 - 18.5.3 Neural Network with Symbolic Layer 283
- 18.6 Application: Diagnosis of Heart Disease 284
 - 18.6.1 Categories of Heart Disease 284
 - 18.6.2 Knowledge-Based Information 285
 - 18.6.3 Data-Based Information 285
 - 18.6.4 Chaotic Data 285
 - 18.6.5 Sample System 288
- 18.7 Summary 289
- References 289

CHAPTER 19 Future Perspectives 291

- 19.1 Introduction 291
- 19.2 Effects of Hardware Advances 291
 - 19.2.1 Faster Computing Speeds 291
 - 19.2.2 Increased Memory 292
 - 19.2.3 Parallel Machines 292
 - 19.2.4 Miniaturization 292
 - 19.2.5 Organic Semiconductors 292
- 19.3 Effects of Increase in Knowledge 293
 - 19.3.1 Information Explosion 293
 - 19.3.2 Human Genome Project 293

Contents

19.3.3	Proliferation of Databases	293
19.3.4	Communication of Information	294
19.4	The Future of Software	294
19.4.1	Hybrid Systems	294
19.4.2	Parallel Systems	294
19.4.3	Nontextual Data	295
19.4.4	Neural Network Models	295
19.4.5	Artificial Intelligence Approaches	295
	References	295

INDEX 297

ABOUT THE AUTHORS 305