Andreas Geyer-Schulz

Fuzzy Rule-Based Expert Systems and Genetic Machine Learning

Second, Revised and Enlarged Edition

With 84 Figures

Physica-Verlag
A Springer-Verlag Company

Contents

I Fuzzy Rule-Based Expert Systems 1

1 Fuzzy Technologies 7

2 Introduction to Fuzzy Sets 17

2.1 Fuzzy Sets 18

2.2 Basic Operations on Fuzzy Sets 24

2.3 Triangular Norms and Conorms 26

2.4 Aggregation Operations 33

2.5 The Extension Principle 35

2.6 Properties of Fuzzy Sets 37

2.7 A (Simple) Lookup Table 40

2.7.1 An Empty Lookup Table 40

2.7.2 The Generator of the Lookup Table 41

2.7.3 The Access Functions 41

3 Natural Language Computation 43

3.1 Overview 43

3.2 Approximate Reasoning 44

3.2.1 Adjectives 48

3.2.2 Adverbs 49

3.2.3 Connectives 52

3.2.4 Inference 53

3.3 Linguistic Approximation 56
3.3.1 The Best Fit Method 56
3.3.2 The Successive Approximation Method 60
3.3.3 The Piecewise Decomposition Method 61
3.4 Defuzzification 63

4 A Little but Extendible Language **65**
4.1 The Boston Consulting Group (BCG) Approach 67
4.2 Model Prototyping 74
4.3 Gouldner's Patterns of Industrial Bureaucracy 76
4.4 The MIT Beer Distribution Game 78

5 Hybrid Reasoning **87**
5.1 An Object-Oriented System in a Nutshell 88
5.1.1 Objects, Closures and Contexts 88
5.1.2 Inheritance and the Construction of Contexts . . 97
5.1.3 Dynamic Reinterpretation 104
5.2 The Creditworthiness of Consumers 108

6 A Fuzzy Backtrack Algorithm **117**
6.1 Introduction 117
6.2 An Object-Oriented Framework for Time Series Analysis 121
6.2.1 Overview 121
6.2.2 The Model Specification Language 122
6.2.3 The Time Series Data Base 125
6.2.4 Tools for Model Identification 126
6.2.5 Transformations of Time Series 127
6.2.6 Estimation of ARMA-Model Parameters 129
6.2.7 Diagnostic Checking and Forecasting 129
6.2.8 Generating Synthetic Time Series 130

6.2.9 The User Interface *Time Series Analyst* 132
6.3 Fuzzy Time Series Analysis 133
6.3.1 The Fuzzy Rule Language 135
6.3.2 The Fuzzy Rule Compiler 136
6.3.3 The Fuzzy Rule Interpreter 138
6.3.4 The Backtrack Algorithm 139
6.3.5 The Interface Between Numerical Routines and the Rule Interpreter 141
6.4 Example 144

II Fuzzy Classifier Systems 147

7 Genetic Algorithms 153
7.1 The Natural Evolution Metaphor 153
7.2 A Simple Genetic Algorithm 156
7.3 Optimizing an Order Heuristic for The MIT Beer Game 167
7.4 Mathematical Foundations of Genetic Algorithms 170
7.4.1 The 2–Armed Bandit 174
7.4.2 The k–Armed Bandit 182
7.4.3 The Simple Genetic Algorithm Revisited 185
7.4.4 Comparing the Loss Functions 192
7.5 Variants of Genetic Algorithms 199
7.5.1 The Structures Undergoing Adaptation 200
7.5.2 The Initial Structures 203
7.5.3 Fitness 204
7.5.4 The Genetic Operators 207
7.5.5 The System State 216
7.5.6 Control Parameters of the Algorithm 217
7.5.7 Termination of a Genetic Algorithm 218

7.5.8 Choosing the Result of a Genetic Algorithm . . . 219
7.6 Hybrid Genetic Algorithms . . . 219
7.7 Parameterization Techniques . . . 220
7.8 Fuzzy Genetic Algorithms . . . 227

8 The Genetic Machinery over Context-Free Languages 233
8.1 The Genetic Programming Paradigm . . . 233
8.2 The Components of the Machinery . . . 237
8.3 A Simple Genetic Algorithm for Context–Free Languages 239
8.3.1 Problem Specification for Genetic Programming . 239
8.3.2 On Grammars, Words and Derivation Trees . . . 242
8.3.3 The Main Routine . . . 254
8.3.4 Generating Random Populations . . . 255
8.3.5 Evaluating the Fitness Function . . . 257
8.3.6 Calculating the Next Generation . . . 259
8.3.7 A Comparison with Koza's Genetic Programming Approach . . . 263
8.4 The Probability of Generating Words . . . 264
8.4.1 Counting Derivation Trees . . . 264
8.4.2 MEMO Functions . . . 272
8.4.3 Improving Crossover and Mutation . . . 272
8.4.4 An Exact Uniform Initializing Algorithm . . . 275
8.4.5 Experimental Results . . . 279
8.5 The (Functional) Abstraction Operator . . . 280
8.5.1 Abstraction . . . 280
8.5.2 The "Genetic" Operator Abstraction . . . 284
8.5.3 Abstraction and Intermediate Goals . . . 285
8.5.4 The Effect of Abstraction . . . 286
8.5.5 Breeding Programs with Subprograms . . . 288

8.6 Compound Derivations 290
8.6.1 Initializing a Population 292
8.6.2 Specifying a Priori Information 293
8.6.3 The Genetic Operator Compound 293
8.7 Discovering a Heuristic by Genetic Programming 295
8.8 Deriving a Fuzzy Rule Base by Fuzzy Genetic Programming 300

9 Fuzzy Classifier Systems 305
9.1 The Components of a (Holland) Classifier System 305
9.1.1 The Task Environment 307
9.1.2 The Production System 311
9.1.3 The Bucket Brigade Algorithm 318
9.1.4 The Genetic Algorithm 323
9.1.5 Cover Detector, Cover Effector and Triggered Chaining Operator 325
9.1.6 The Interpreter 326
9.2 Fuzzy Classifier Systems 328

10 The Monte Carlo Selection Rule 331
10.1 Motivation 331
10.2 The Basic Idea 332
10.3 The Monte Carlo Selection Rule 333
10.4 Global Convergence 334
10.5 Summary 337

11 The Search Space Size of Fuzzy Classifier Systems 339
11.1 Counting and Formal Languages 341
11.2 An Outline of the Proof Technique 347
11.3 A Fuzzy Control Rule Language 351
11.4 The BCG's Rule Language 359

11.5 Related Work 375
11.6 Summary 377

Bibliography **379**

List of Symbols **411**

Index **416**