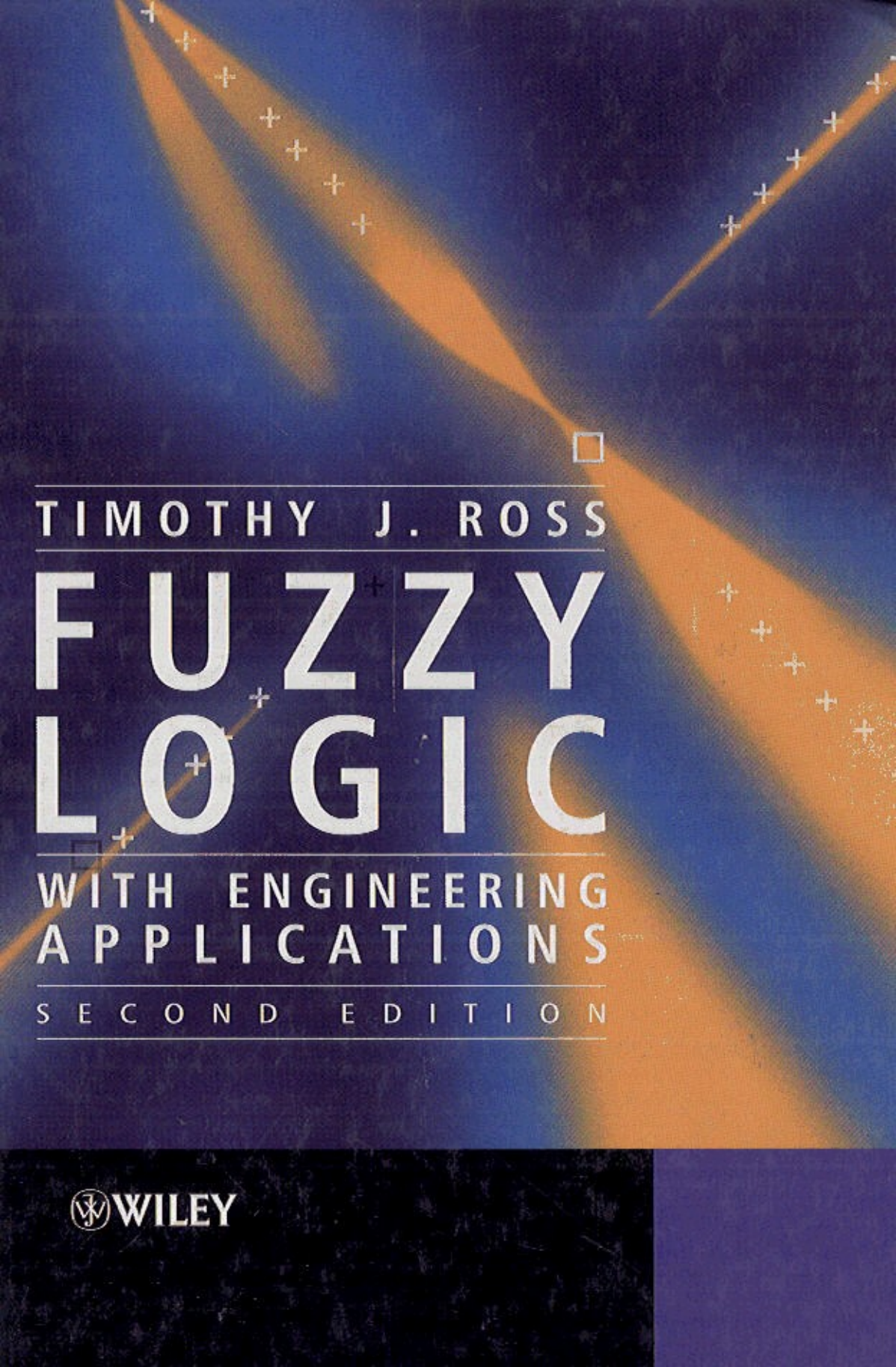

TIMOTHY J. ROSS

FUZZY LOGIC

WITH ENGINEERING APPLICATIONS

SECOND EDITION

WILEY

CONTENTS

About the Author xiii

Preface to the Second Edition xv

1 Introduction 1
The Case for Imprecision 2
An Historical Perspective 3
The Utility of Fuzzy Systems 6
Limitations of Fuzzy Systems 8
The Allusion: Statistics and Random Processes 10
Uncertainty and Information 12
Fuzzy Sets and Membership 13
Chance versus Fuzziness 15
Sets as Points in Hypercubes 17
Summary 19
References 19
Problems 20

2 Classical Sets and Fuzzy Sets 24
Classical Sets 25
Operations on Classical Sets 27
Properties of Classical (Crisp) Sets 28
Mapping of Classical Sets to Functions 32
Fuzzy Sets 34
Fuzzy Set Operations 35
Properties of Fuzzy Sets 36
Noninteractive Fuzzy Sets 41
Alternative Fuzzy Set Operations 42
Summary 43
References 43
Problems 44

3 Classical Relations and Fuzzy Relations 52
Cartesian Product 53
Crisp Relations 53
Cardinality of Crisp Relations 55
Operations on Crisp Relations 56
Properties of Crisp Relations 56
Composition 57
Fuzzy Relations 58
Cardinality of Fuzzy Relations 59
Operations on Fuzzy Relations 59
Properties of Fuzzy Relations 59
Fuzzy Cartesian Product and Composition 59
Tolerance and Equivalence Relations 66
Crisp Equivalence Relation 66
Crisp Tolerance Relation 67
Fuzzy Tolerance and Equivalence Relations 68
Value Assignments 71
Cosine Amplitude 72
Max–Min Method 74
Other Similarity Methods 74
Other Forms of the Composition Operation 74
Summary 75
References 75
Problems 76
General Relations 76
Value Assignments and Similarity 85
Equivalence Relations 88
Other Composition Operations 88

4 Properties of Membership Functions, Fuzzification, and Defuzzification 90
Features of the Membership Function 91
Various Forms 93
Fuzzification 94
Defuzzification to Crisp Sets 96
λ-cuts for Fuzzy Relations 98
Defuzzification to Scalars 99
Summary 112
References 113
Problems 114

5 Logic and Fuzzy Systems 120
Part I Logic 120
Classical Logic 121
Tautologies 126
Contradictions 128
Equivalence 128

Exclusive Or and Exclusive Nor 129
Logical Proofs 130
Deductive Inferences 132
Fuzzy Logic 134
Approximate Reasoning 137
Other Forms of the Implication Operation 141
Part II Fuzzy Systems 142
Natural Language 143
Linguistic Hedges 145
Fuzzy (Rule-Based) Systems 148
Graphical Techniques of Inference 151
Summary 162
References 163
Problems 165

6 Development of Membership Functions 178
Membership Value Assignments 179
Intuition 179
Inference 180
Rank Ordering 181
Neural Networks 182
Genetic Algorithms 193
Inductive Reasoning 200
Summary 206
References 208
Problems 209

7 Automated Methods for Fuzzy Systems 212
Definitions 213
Batch Least Squares Algorithm 216
Recursive Least Squares Algorithm 220
Gradient Method 223
Clustering Method 228
Learning From Example 231
Modified Learning From Example 234
Summary 242
References 243
Problems 243

8 Fuzzy Systems Simulation 245
Fuzzy Relational Equations 250
Nonlinear Simulation Using Fuzzy Systems 251
Fuzzy Associative Memories (FAMs) 254
Summary 264
References 265
Problems 265

9 Rule-base Reduction Methods 274
Fuzzy Systems Theory and Rule Reduction 275
New Methods 275
Singular Value Decomposition 276
Combs Method 282
SVD and Combs Method Examples 284
Summary 303
References 304
Problems 304
Singular Value Decomposition 304
Combs Method for Rapid Inference 306

10 Decision Making with Fuzzy Information 308
Fuzzy Synthetic Evaluation 310
Fuzzy Ordering 312
Nontransitive Ranking 315
Preference and Consensus 317
Multiobjective Decision Making 320
Fuzzy Bayesian Decision Method 326
Decision Making under Fuzzy States and Fuzzy Actions 335
Summary 349
References 350
Problems 350
Ordering and Synthetic Evaluation 350
Nontransitive Ranking 352
Fuzzy Preference and Consensus 353
Multiobjective Decision Making 355
Bayesian Decision Making 357

11 Fuzzy Classification and Pattern Recognition 362
Part I Classification 362
Classification by Equivalence Relations 363
Crisp Relations 363
Fuzzy Relations 365
Cluster Analysis 369
Cluster Validity 370
c-Means Clustering 370
Hard c-Means (HCM) 371
Fuzzy c-Means (FCM) 379
Fuzzy c-Means Algorithm 382
Classification Metric 387
Hardening the Fuzzy c-Partition 389
Similarity Relations from Clustering 391
Part II Pattern Recognition 392
Feature Analysis 393
Partitions of the Feature Space 393

Single-Sample Identification 394
Multifeature Pattern Recognition 400
Image Processing 412
Syntactic Recognition 420
Formal Grammar 422
Fuzzy Grammar and Syntactic Recognition 424
Summary 429
References 429
Problems 430
Exercises for Equivalence Classification 430
Exercises for Fuzzy *c*-Means 431
Exercises for Classification Metric and Similarity 434
Exercises for Fuzzy Vectors 435
Exercises for Multifeature Pattern Recognition 436
Exercises for Syntactic Pattern Recognition 444
Exercises for Image Processing 444

12 Fuzzy Arithmetic and the Extension Principle 445
Extension Principle 445
Crisp Functions, Mapping, and Relations 446
Functions of Fuzzy Sets – Extension Principle 447
Fuzzy Transform (Mapping) 448
Practical Considerations 450
Fuzzy Arithmetic 455
Interval Analysis in Arithmetic 457
Approximate Methods of Extension 459
Vertex Method 459
DSW Algorithm 462
Restricted DSW Algorithm 465
Comparisons 466
Summary 469
References 469
Problems 470

13 Fuzzy Control Systems 476
Control System Design Problem 478
Control (Decision) Surface 479
Assumptions in a Fuzzy Control System Design 480
Simple Fuzzy Logic Controllers 480
Examples of Fuzzy Control System Design 481
Aircraft Landing Control Problem 485
Fuzzy Engineering Process Control [Parkinson, 2001] 492
Classical Feedback Control 492
Classical PID Control 494
Fuzzy Control 496
Multi-input, Multi-output (MIMO) Control Systems 500
Fuzzy Statistical Process Control 504

Measurement Data – Traditional SPC 505
Attribute Data – Traditional SPC 510
Industrial Applications 517
Summary 518
References 519
Problems 521

14 Miscellaneous Topics 537
Fuzzy Optimization 537
One-dimensional Optimization 538
Fuzzy Cognitive Mapping 544
Fuzzy Cognitive Maps 545
System Identification 550
Fuzzy Linear Regression 555
The Case of Nonfuzzy Data 557
The Case of Fuzzy Data 558
Summary 567
References 567
Problems 568
Fuzzy Optimization 568
System Identification 569
Regression 570
Cognitive Mapping 571

15 Monotone Measures: Belief, Plausibility, Probability, and Possibility 572
Monotone Measures 573
Belief and Plausibility 574
Evidence Theory 578
Probability Measures 582
Possibility and Necessity Measures 583
Possibility Distributions as Fuzzy Sets 590
Possibility Distributions Derived from Empirical Intervals 592
Deriving Possibility Distributions from Overlapping Intervals 593
Redistributing Weight from Nonconsonant to Consonant Intervals 595
Comparison of Possibility Theory and Probability Theory 600
Summary 601
References 603
Problems 603

Appendix A Axiomatic Differences between Fuzzy Set Theory and Probability Theory 610

Appendix B Answers to Selected Problems 614

Index of Examples and Problems by Discipline 621

Index 623