

Foreword	xiii
Preface	xxv
Introduction	xxi
I FUNDAMENTALS OF FUZZY SETS	1
1 Basic Notions and Concepts of Fuzzy Sets	3
1.1 Set Membership and Fuzzy Sets	3
1.2 Basic Definition of a Fuzzy Set	5
1.3 Types of Membership Functions	8
1.4 Characteristics of a Fuzzy Set	10
1.5 Basic Relationships between Fuzzy Sets: Equality and Inclusion	16
1.6 Fuzzy Sets and Sets: The Representation Theorem	16
1.7 The Extension Principle	18
1.8 Membership Function Determination	19
1.9 Generalizations of Fuzzy Sets	26
1.10 Chapter Summary	28
1.11 Problems	29
References	30
2 Fuzzy Set Operations	31
2.1 Set Theory Operations and Their Properties	31
2.2 Triangular Norms	32
2.3 Aggregation Operations on Fuzzy Sets	40
2.4 Sensitivity of Fuzzy Sets Operators	45
2.5 Negations	47
2.6 Comparison Operations on Fuzzy Sets	48
2.7 Chapter Summary	56
2.8 Problems	56
References	57
3 Information-Based Characterization of Fuzzy Sets	59
3.1 Entropy Measures of Fuzziness	59
3.2 Energy Measures of Fuzziness	63
3.3 Specificity of a Fuzzy Set	65
3.4 Frames of Cognition	66
3.5 Information Encoding and Decoding Using Linguistic Landmarks	69
3.6 Decoding Mechanisms for Pointwise Data	72

3.7	Decoding Using Membership Functions of the Linguistic Terms of the Codebook	74
3.8	General Possibility-Necessity Decoding	75
3.9	Distance between Fuzzy sets Based on Their Internal, Linguistic Representation	78
3.10	Chapter Summary	80
3.11	Problems	81
	References	84
4	Fuzzy Relations and Their Calculus	85
4.1	Relations and Fuzzy Relations	85
4.2	Operations on Fuzzy Relations	89
4.3	Compositions of Fuzzy Relations	90
4.4	Projections and Cylindric Extensions of Fuzzy Relations	92
4.5	Binary Fuzzy Relations	95
4.6	Some Classes of Fuzzy Relations	97
4.7	Fuzzy-Relational Equations	100
4.8	Estimation and Inverse Problem in Fuzzy Relational Equations	103
4.9	Solving Fuzzy-Relational Equations with the sup-t Composition	104
4.10	Solutions to Dual Fuzzy-Relational Equations	114
4.11	Adjoint Fuzzy-Relational Equations	115
4.12	Generalizations of Fuzzy Relational Equations	116
4.13	Approximate Solutions to Fuzzy-Relational Equations	118
4.14	Chapter Summary	123
4.15	Problems	124
	References	126
5	Fuzzy Numbers	129
5.1	Defining Fuzzy Numbers	129
5.2	Interval Analysis and Fuzzy Numbers	130
5.3	Computing with Fuzzy Numbers	133
5.4	Triangular Fuzzy Numbers and Basic Operations	135
5.5	General Formulas for LR Fuzzy Numbers	143
5.6	Accumulation of Fuzziness in Computing with Fuzzy Numbers	144
5.7	Inverse Problem in Computation with Fuzzy Numbers	145
5.8	Fuzzy Numbers and Approximate Operations	146
5.9	Chapter Summary	147
5.10	Problems	148
	References	150

6	Fuzzy Sets and Probability	151
6.1	Introduction	151
6.2	Probability and Fuzzy Sets	151
6.3	Hybrid Fuzzy-Probabilistic Models of Uncertainty	152
6.4	Probability-Possibility Transformations	158
6.5	Probabilistic Sets and Fuzzy Random Variables	159
6.6	Chapter Summary	162
6.7	Problems	162
	References	164
7	Linguistic Variables	165
7.1	Introduction	165
7.2	Linguistic Variables: Formalization	166
7.3	Computing with Linguistic Variables: Hedges, Connectives and Negation	169
7.4	Linguistic Approximation	172
7.5	Linguistic Quantifiers	175
7.6	Applications of Linguistic Variables	178
7.7	Chapter Summary	179
7.8	Problems	179
	References	180
8	Fuzzy Logic	181
8.1	Introduction	181
8.2	Propositional Calculus	182
8.3	Predicate Logic	186
8.4	Many-Valued Logic	188
8.5	Fuzzy Logic	190
8.6	Computing with Fuzzy Logic	190
8.7	Some Remarks about Inference Methods	202
8.8	Chapter Summary	202
8.9	Problems	203
	References	204
9	Fuzzy Measures and Fuzzy Integrals	205
9.1	Fuzzy Measures	205
9.2	Fuzzy Integrals	210
9.3	Chapter Summary	215
9.4	Problems	216
	References	217

II	COMPUTATIONAL MODELS	219
10	Rule-Based Computations	221
	10.1 Rules in Knowledge Representation	221
	10.2 Syntax of Fuzzy Rules	224
	10.3 Semantics of Fuzzy Rules and Inference	230
	10.4 Computing with Fuzzy Rules	241
	10.5 Some Properties of Fuzzy Rule-Based Systems	251
	10.6 Rule Consistency and Completeness	252
	10.7 Chapter Summary	261
	10.8 Problems	261
	References	263
11	Fuzzy Neurocomputation	265
	11.1 Neural Networks: Basic Notions, Architectures, and Learning	265
	11.2 Logic-Based Neurons	267
	11.3 Logic Neurons and Fuzzy Neural Networks with Feedback	275
	11.4 Referential Logic-Based Neurons	279
	11.5 Fuzzy Threshold Neurons	282
	11.6 Classes of Fuzzy Neural Networks	282
	11.7 Referential Processor	288
	11.8 Fuzzy Cellular Automata	290
	11.9 Learning	291
	11.10 Selected Aspects of Knowledge Representation in Fuzzy Neural Networks	296
	11.11 Chapter Summary	299
	11.12 Problems	300
	References	302
12	Fuzzy Evolutionary Computation	303
	12.1 Introduction	303
	12.2 Genetic Algorithms	304
	12.3 Design of Fuzzy Rule-Based Systems with Genetic Algorithms	309
	12.4 Learning in Fuzzy Neural Networks with Genetic Algorithms	317
	12.5 Evolution Strategies	319
	12.6 Hybrid and Cooperating Approaches	322
	12.7 Chapter Summary	323

	12.8 Problems	323
	References	325
13	Fuzzy Modeling	327
	13.1 Fuzzy Models: Beyond Numerical Computations	327
	13.2 Main Phases of System Modeling	328
	13.3 Fundamental Design Objectives in System Modeling	329
	13.4 General Topology of Fuzzy Models	330
	13.5 Compatibility of Encoding and Decoding Modules	332
	13.6 Classes of Fuzzy Models	334
	13.7 Verification and Validation of Fuzzy Models	348
	13.8 Chapter Summary	353
	13.9 Problems	354
	References	357
III	PROBLEM SOLVING WITH FUZZY SETS	359
14	Methodology	361
	14.1 Analysis and Design	361
	14.2 Fuzzy Controllers and Fuzzy Control	364
	14.3 Mathematical Programming and Fuzzy Optimization	384
	14.4 Chapter Summary	395
	14.5 Problems	395
	References	397
15	Case Studies	399
	15.1 Traffic Intersection Control	399
	15.2 Distributed Traffic Control	411
	15.3 Elevator Group Control	426
	15.4 Induction Motor Control	431
	15.5 Communication Network Planning	441
	15.6 Neurocomputation in Fault Diagnosis of Dynamic Systems	444
	15.7 Multicommodity Transportation Planning in Railways	453
	References	460
	Index	463