

Table of Contents

1.	Introduction	1
1.1	Goal	1
1.2	Relation to Other Scientific Fields	4
1.3	Plan of the Monograph	7
2.	A Quantitative Description of Nature	11
2.1	Synergetics of Natural Phenomena	11
2.2	A Description of Nature	17
2.3	Fundamentals of Quantitative Description	21
2.4	Fundamentals of Physical Laws	27
2.5	The Random Character of Physical Variables	30
2.6	Expression of Natural Laws by Differential Equations	31
2.7	Methods of Empirical Modeling	33
2.7.1	The Role of Models	33
2.7.2	Piecewise Linear Models of Empirical Natural Laws	35
2.8	Introduction to Modeling by Neural Networks	41
2.8.1	Functional Properties of a Neuron	44
2.8.2	Empirical Modeling by a Perceptron	48
3.	Transducers	51
3.1	The Role of Sensors and Actuators	51
3.2	Sensors and Actuators of Biological Systems	53
3.2.1	Performance Characteristics of Biological Sensors	54
3.2.2	Structure of Biological Sensors	55
3.2.3	Transduction Characteristics of Biological Sensors	57
3.3	Operational Characteristics of Transducers	60
3.3.1	Transducer Classification	60
3.3.2	Transduction Characteristics	62
3.3.3	Sensor Loading Effects	77
3.3.4	Transducer Field Characteristics	81
3.4	Fabricated Transducers	86
3.4.1	Microsensors and Integrated Sensors	87
3.4.2	Synthetic Bio-sensors and Neurobiology	92
3.5	Transducers in Intelligent Measurement Systems	94
3.6	Future Directions in Transducer Evolution	95

XII Table of Contents

4. Probability Densities	99
4.1 Estimation of Probability Density	99
4.1.1 Parzen Window Approach	99
4.1.2 An Optimal Selection of the Window Function	103
4.1.3 Nearest Neighbor and Maximal Self-Consistency Approach.....	110
4.1.4 The Self-Consistent Method in the Multivariate Case .	117
4.1.5 Numerical Examples	118
4.1.6 Conclusions About Filtering of the Empirical PDF ...	123
5. Information.....	125
5.1 Some Basic Ideas	125
5.2 Entropy of Information	127
5.3 Properties of Information Entropy	128
5.4 Relative Information	129
5.4.1 Information of Continuous Distributions.....	130
5.4.2 Information Gain from Experiments	131
5.5 Information Measure of Distance Between Distributions	133
6. Maximum Entropy Principles.....	137
6.1 Gibbs Maximum Entropy Principle	137
6.2 The Absolute Maximum Entropy Principle	141
6.3 Quantization of Continuous Probability Distributions	145
6.3.1 Quadratic Measure of Discrepancy Between Distributions	146
6.3.2 Information Divergence as a Measure of Discrepancy	152
6.3.3 Vector Quantization and Reconstruction Measure of Discrepancy	156
7. Adaptive Modeling of Natural Laws	167
7.1 Probabilistic Modeler of Natural Laws	167
7.2 Optimization of Adaptive Modeler Performance	169
7.3 Stochastic Approach to Adaptation Laws	172
7.4 Stochastic Adaptation of a Vector Quantizer	175
7.5 Perturbation Method of Adaptation	176
7.6 Evolution of an Optimal Modeler and Perturbation Method ..	179
7.7 Parametric Versus Non-Parametric Modeling	183
8. Self-Organization and Formal Neurons	185
8.1 Optimal Storage of Empirical Information in Discrete Systems	185
8.2 Adaptive Vector Quantization and Topological Mappings	186
8.3 Self-Organization Based on the Absolute Maximum-Entropy Principle	188

8.4	Derivation of a Generalized Self-Organization Rule	189
8.5	Numerical Examples of Self-Organized Adaptation.....	193
8.6	Formal Neurons and the Self-Organization Process.....	195
9.	Modeling by Non-Parametric Regression	203
9.1	The Problem of an Optimal Prediction	203
9.2	Parzen's Window Approach to General Regression	206
9.3	General Regression Modeler, Feedback and Recognition	209
9.4	Application of the General Regression Modeler	217
9.4.1	Empirical Modeling of Acoustic Phenomena	217
9.4.2	Prediction of the Seismic Capacity of Walls	233
9.4.3	Modeling of a Periodontal Disease Healing Process ...	237
10.	Linear Modeling and Invariances	243
10.1	Relation Between Parametric Modeling and Invariances	243
10.2	Generalized Linear Regression Model	244
10.2.1	An Example of Iterative Determination of a Linear Regression Model	252
10.3	Sequential Adaptation of Linear Regression Model	255
10.4	Transition from the Cross- to Auto-Associator	258
10.4.1	Application of the Auto-Associator to Analysis of Ultrasonic Signals	264
11.	Modeling and Forecasting of Chaotic Processes	277
11.1	Modeling of Chaotic Processes	277
11.2	Examples of Chaotic Process Forecasting	282
11.3	Forecasting of Chaotic Acoustic Emission Signals	292
11.4	Empirical Modeling of Non-Autonomous Chaotic Systems ...	298
11.4.1	Example of Economic Time-Series Forecasting	300
11.5	Cascade Modeling of Chaos Generators.....	302
11.5.1	Numerical Experiments	305
11.5.2	Concluding Remarks	308
12.	Modeling by Neural Networks	309
12.1	From Biological to Artificial Neural Networks	309
12.1.1	Basic Blocks of Neural Networks and Their Dynamics .	312
12.2	A Linear Associator	317
12.3	Multi-layer Perceptrons and Back-Propagation Learning	322
12.4	Radial Basis Function Neural Networks	326
12.5	Equivalence of a Radial Basis Function NN and Perceptrons .	328
13.	Fundamentals of Intelligent Control	333
13.1	Introduction	333
13.2	Basic Tasks of Intelligent Control	339
13.2.1	Empirical Description of a Controlled System	339

XIV Table of Contents

13.2.2 General Identification by Non-Parametric Modeling ..	342
13.3 The Tracking Problem	346
13.4 Cloning	353
13.5 An Empirical Approach to Optimal Control.....	358
13.5.1 The Theoretical Problem of Optimal Control	358
13.5.2 Experimental Description of Plant Performance and Optimal Control.....	359
13.5.3 Design of an Intelligent Optimal Controller	361
13.5.4 The Influence of the Environment on Optimal Control	370
13.5.5 The Problem of Phase Space Exploration	373
13.5.6 Numerical Simulations of Optimal Control	378
13.5.7 Summary and Conclusions.....	388
14. Self-Control and Biological Evolution	391
14.1 Modeling of Natural Phenomena by Biological Systems	391
14.2 Joint Modeling of Organism and Environment.....	393
14.3 An Operational Description of Consciousness	395
14.4 The Fundamental Problem of Evolution	397
A. Fundamentals of Probability and Statistics	401
A.1 Sample Points, Sample Space, Events and Relations	401
A.2 Probability	403
A.3 Random Variables and Probability Distributions	405
A.4 Averages and Moments.....	409
A.5 Random Processes	410
A.6 Sampling, Estimation and Statistics	413
B. Fundamentals of Deterministic Chaos	417
B.1 Instability of Chaotic Systems.....	417
B.2 Characterization of Strange Attractors	421
B.3 Experimental Characterization of Chaotic Phenomena	426
References	429
Index	447

