

Contents

1. Introduction	1
1.1 What This Book Is About	1
1.2 Statement of the Problem	3
1.3 Some Preliminary Definitions of Complexity and Organization	7
1.3.1 Complexity	7
1.3.2 Organization	7
2. Preliminaries from Nonlinear Dynamics and Statistical Physics	9
2.1 Symmetries and Conservation Principles	9
2.2 Instabilities at the Root of Broken Symmetries, Dissipation, and Irreversibility for Low-Dimensional (Not Statistical) Dynamical Systems	11
2.2.1 The Role of Gravitation	11
2.2.2 Comments on the Role of Coupling Among the Four Basic Interactions in Evolution	15
2.2.3 The Overdamped Nonlinear Oscillator: A Case of Spontaneously Breaking Symmetry	17
2.2.4 The Laser: A Case of Broken Symmetry	18
2.2.5 The Rotating Pendulum: A Case of Bifurcation Leading to Spontaneous Symmetry Breaking	25
2.2.6 Broken Symmetry Through a Hysteresis-Like Process	27
2.2.7 Essentials of Stability Theory	29
a) General Criterion	29
b) Specific Analyses	33
2.2.8 Behavior of a Two-Dimensional Dynamical System in the Vicinity of Singular Points (Steady States)	34
2.2.9 First Encounter with Nontrivial Dissipative Systems: The Concept of the Attractor in Two Dimensions (Limit Cycle) ...	37
2.3 Elements of Statistical Physics and Their Relevance to Evolutionary Phenomena	42
2.3.1 Some Characteristics of Stochastic Systems	42
2.3.2 Informational Entropy, Physical Entropy, Thermodynamic Entropy	46
	XI

2.3.3	Entropy of a Perfect Gas at Thermodynamic Equilibrium	59
2.3.4	Entropy of a Photon Gas at Thermodynamic Equilibrium	60
2.3.5	Elements of Newtonian Big Bang Cosmology	62
2.3.6	Expansion of a Mixture of Matter and Radiation. Differential Cooling and Entropy Production	67
2.3.7	The Concept of Complexity	72
	a) Structural Complexity and Its Relationship to the Stability of a System	72
	b) Algorithmic Complexity	74
2.4	Concluding Remarks	76
3.	The Role of Spherical Electromagnetic Waves as Information Carriers	77
3.1	Radiation from Accelerated Charge in Vacuo. The Concept of "Self"-Force. Thermodynamics of Electromagnetic Radiation	77
3.1.1	Radiation in Vacuum	77
3.1.2	The Concept of Self-Force	83
3.1.3	Thermodynamics of Electromagnetic Radiation	86
3.2	Electromagnetic Wave Propagation in Dispersive Media and Lossy Media	90
3.3	Analysis of a Spherical Wave in Terms of Elemental "Rays". The Mode Theory of Wave Propagation. Excitable Modes (Degrees of Freedom) in a Closed Cavity	98
3.3.1	Spectral Decomposition of a Spherical Wave	98
3.3.2	The Wave-Guide Mode Theory of Wave Propagation	103
3.3.3	A Cavity Resonator	107
3.4	The Entropy of Electromagnetic Radiation. Information Received by an Electromagnetic Wave Impinging on a Finite Aperture. Ambiguity of Perception	112
4.	Elements of Information and Coding Theory, with Applications	121
4.1	Information Transfer and the Concept of Channel Capacity for Discrete and Continuous Memoryless Signals	121
4.2	Some Ideas from Coding Theory Instrumental in Minimizing Reception Error	133
4.3	Some Efficient Coding Algorithms for Source-Channel Matching and Single-Error Detection and Correction	140
4.3.1	Coding for Source-Channel Matching	140
4.3.2	Coding for Error Detection and Correction	144
4.4	Information Sources with Memory. Markov Chains	147
4.5	Specific Examples of Some Useful Channels and Calculations of Their Capacities	151

4.5.1	Capacity of a Homogeneously Turbulent Channel	151
4.5.2	The Lossless Channel	153
4.5.3	The Deterministic Channel	154
4.5.4	The Uniform Channel	155
4.5.5	The Binary Symmetrical Channel	156
4.5.6	The Binary "Erasure" Channel	157
4.5.7	Capacity of an Optical Channel	157
4.5.8	Role of Quantum Noise in an Optical Channel	159
4.5.9	An Introduction to the "Genetic Channel" and the Genetic Code	161
4.5.10	The Phase-Locked Loop in the Absence and Presence of Noise	167
4.6	Modeling of Stochastic Time Series	178
4.7	Communication Between Two Hierarchical Systems Modeled by Controlled Markov Chains	181
4.7.1	Introduction: Elaboration of the Nature of Hierarchical Systems	182
4.7.2	Dynamics at the Base Levels Q , Q' and the Underlying Game ..	185
4.7.3	A Semi-Markov Chain Model for the Hierarchical Levels W and W'	191
4.7.4	The Control Problem	197
	a) Biological Rhythms Underlying the Games	197
	b) Description of the Communication and Control Processes	197
	c) Selection of Control Mechanisms	199
4.7.5	Computer Simulation	200
4.7.6	Biological Relevance of the Model	202
4.8	Emergence of New Hierarchical Levels in a Self-Organizing System ..	207
4.8.1	Formulation of the Problem	207
4.8.2	Creation of a New Hierarchical Level	211
4.8.3	A Comment on Typical Cases of "Psychosomatic Disturbances" .	215
5.	Elements of Game Theory, with Applications	217
5.1	Constant-Sum Games	218
5.1.1	Both Players Have a Dominant Strategy	218
5.1.2	Only One Player Has a Dominant Strategy	219
5.1.3	Neither Player Has a Dominant Strategy	219
5.1.4	Mixed Strategies	221
5.2	Non-Constant-Sum Games	222
5.2.1	Non-Constant-Sum "Negotiable" Games	223
5.2.2	Non-Constant-Sum, Nonnegotiable "Paradoxical" Games	229

5.3	Competing Species	237
5.4	Survival and Extinction	240
5.5	Some Elementary Knowledge from Genetics: Selection and Fitness	242
5.6	Games Between Animals Adopting Specific Modes of Behavior (Roles). Concepts of Evolutionarily Stable Strategy	248
5.7	The Game of Competitive-Cooperative Production and Exchange. The Concept of "Parasite" at a Symbolic Level	252
5.8	Epidemiology of Rumors	257
6.	Stochasticity Due to Deterministic Dynamics in Three- or Higher- Dimensional Space: Chaos and Strange Attractors	262
6.1	A Reappraisal of Classical Statistical Mechanics. The Kolmogorov- Arnold-Moser Theorem	262
6.2	Dynamics in Three-Dimensional State Space (Three Degrees of Freedom). Steady States, Limit Cycles, Attracting Tori	270
6.3	Strange Attractors	276
6.3.1	One-Dimensional Maps on the Interval. The "Logistic" Model .	276
6.3.2	Fractal Dimensionality. The Cantor Set	284
6.3.3	The Concept of the Lyapounov Exponents for the Period- Doubling and Chaotic Regimes	287
6.3.4	A Typical Three-Dimensional Strange Attractor. The Lorenz Model	291
6.3.5	The Rate of Information Production by the Lorenz Attractor .	297
6.4	Parameters Characterizing the Average Behavior of Strange Attractors: Dimensions, Entropies, and Lyapounov Exponents	299
6.4.1	The Concept of Information Dimension	301
6.4.2	The Concept of Characteristic Lyapounov Exponents and Their Relation to Information Dimension	308
6.4.3	The Concept of Metric (Kolmogorov-Sinai) Entropy and Its Relation to Information Dimension	316
6.5	A Possible Role for Chaos in Reliable Information Processing	321
6.5.1	Theoretical Considerations and General Discussion	322
6.5.2	Application: The Electrical Activity of the Brain - Should It Be Chaotic?	330
6.5.3	Experimental Data from EEG Research	331
6.5.4	The Model	333
6.5.5	The Dual Role of Intermittency in Information Processing ...	336
6.5.6	The Origin of Conflict in Communicating Hierarchical Systems	337
6.6	Comments on the Effects of Internal Fluctuations and External Noise on the Stability Properties of Dynamical Systems	340

7. Epilogue: Relevance of Chaos to Biology and Related Fields	342
7.1 Computational Complexity	342
7.2 Towards a Dynamic Theory of Language	344
7.2.1 The Nature of the Problem	344
7.2.2 Structural and Functional Hierarchical Levels	346
7.2.3 An Evolutionary Linguistic Model: Digits and Patterns	348
a) Total Entrainment	351
b) Part Entrainment, Part "Jittery" Phase Locking	352
c) Chaos	352
7.2.4 Unresolved Problems: Communication Between Two Hierarchical Systems	354
7.3 Concluding Remarks	359
Appendix	363
A. A View of the Role of External Noise at a Neuronal Hierarchical Level	363
A.1 Introduction to the Problem	363
A.2 Organization Through Weak Stationary-Amplitude Noise	369
A.3 Relevance of the Model to Neuronal and Cognitive Organization	372
B. On the Difficulty of Treating the Transaction Between Two Hierarchical Levels with Continuous Nonlinear Dynamics	377
B.1 The Level Q of Partner I	377
B.2 Homeostasis and Cross-Correlations	378
B.3 The Level W of Partner I	379
B.4 The Controller	379
C. Noisy Entrainment of a Slightly Nonlinear Relaxation Oscillator by an External Harmonic Excitation	380
C.1 General Description of the Model	380
C.2 A Method for the Study of Entrainment	381
C.2.1 Strict Entrainment	381
C.2.2 Loose or "Jittery" Entrainment	381
C.2.3 Pure "Free-Running" Oscillation	382
C.2.4 Free-Running Oscillation	382
C.3 Mathematical Treatment and Computer Simulation	382
C.4 Behavior of the Oscillator Under an Applied Harmonic Excitation (Entrainment)	384
References	389
Subject Index	395