

Contents

Part I Overview 1

1. Introduction: Fractals Really Are Everywhere 3
 - 1.1. Fractals Are Everywhere 3
 - 1.2. Structures in Space 3
 - 1.3. Processes in Time 4
 - 1.4. The Meaning of Fractals 7

Part III Properties of Fractals and Chaos 9

2. Properties of Fractal Phenomena in Space and Time 11
 - 2.1. Introduction 11
 - 2.2. Self-Similarity: Parts That Look Like the Whole 12
 - 2.3. Scaling: The Measure Depends on the Resolution 16
 - 2.4. Fractal Dimension: A Quantitative Measure of Self-Similarity and Scaling 21
 - 2.5. The Surprising Statistical Properties of Fractals 33
 - 2.6. Summary 42
3. The Fractal Dimension: Self-Similar and Self-Affine Scaling 45
 - 3.1. Introduction 45
 - 3.2. Branching in the Lung: Power Law Scaling 49
 - 3.3. A More Complex Scaling Relationship: Weierstrass Scaling 52
 - 3.4. Branching in the Lung: Weierstrass Scaling 55
 - 3.5. Other Examples 60
 - 3.6. Summary 62
4. Fractal Measures of Heterogeneity and Correlation 63
 - 4.1. Introduction 63
 - 4.2. Dispersional Analysis 67
 - 4.3. Rescaled Range Analysis: The Hurst Exponent, H 78
 - 4.4. Correlation versus Distance 90
 - 4.5. History of Fractal Correlation Analysis 105
 - 4.6. Summary 106
5. Generating Fractals 108
 - 5.1. Introduction 108
 - 5.2. Mandelbrot Set 110
 - 5.3. Line Replacement Rules 112
 - 5.4. Area and Volume Replacement Rules 116
 - 5.5. The Logistic Equation 120
 - 5.6. Iterated Function Systems 122
 - 5.7. The Collage Theorem 126
 - 5.8. Lindenmayer Systems 127
 - 5.9. Cellular Automata 130
 - 5.10. Cellular Growth Processes 132

5.11.	Generating One-Dimensional Fractal Time Series	132
5.12.	Summary	135
6.	Properties of Chaotic Phenomena	136
6.1.	Introduction	136
6.2.	Fractals and Chaos Share Ideas and Methods but They Are Not the Same Thing	138
6.3.	The Defining Properties of Chaos	139
6.4.	Additional Features of Chaos	141
6.5.	A Change in Perspective	144
6.6.	Summary	145
7.	From Time to Topology: Is a Process Driven by Chance or Necessity?	147
7.1.	Introduction	147
7.2.	Distinguishing Chaos from Randomness	148
7.3.	Methods Suggestive of Underlying Chaos	149
7.4.	Phase Space and Pseudo-Phase Space	150
7.5.	Additional Types of Deterministic Relationships	158
	Capacity, Correlation, and Information Dimensions	160
7.7.	Good News and Bad News About This Analysis	170
7.8.	Summary	173
Part III Physiological Applications		175
8.	Ion Channel Kinetics: A Fractal Time Sequence of Conformational States	177
8.1.	Introduction	177
8.2.	The Patch Clamp	178
8.3.	Models of Ion Channel Kinetics	182
8.4.	Comparison of Markov and Fractal Models	197
8.5.	Uncovering Mechanisms Giving Fractal Channel Kinetics	204
8.6.	Summary	207
9.	Fractals in Nerve and Muscle	210
9.1.	Spread of Excitation	210
9.2.	The Fractal Heart	210
9.3.	Fractal Neurons	214
9.4.	Spatiotemporal Organization	229
9.5.	Summary	234
10.	Intraorgan Flow Heterogeneities	236
10.1.	Introduction	236
10.2.	Methods of Measuring Regional Flows	237
10.3.	Estimating the Fractal D for Flow Heterogeneity	238
10.4.	Fractal Vascular Anatomy	246
10.5.	Dichotomous Branching Fractal Network Models for Flow Heterogeneity	248
10.6.	Scaling Relationships within an Organ	252
10.7.	Scaling Relationships from Animal to Animal	255
10.8.	Do Fractal Rules Extend to Microvascular Units?	256

10.9.	Fractal Flows and Fractal Washout	259	
10.10.	Summary	261	
11.	Fractal Growth	263	
11.1.	Introduction	263	
11.2.	Primitive Growth Patterns	265	
11.3.	Influences of Matrix Structure on the Form	268	
11.4.	More General Types of Aggregation Processes	270	
11.5.	Neuronal Growth Patterns	273	
11.6.	Algorithms for Vascular Growth	273	
11.7.	Patterns of Vascular Branching	279	
11.8.	Phylogeny versus Ontogeny	283	
11.9.	Summary	283	
11.10.	Some Fractal Growth Programs	284	
12.	Mechanisms That Produce Fractals	285	
12.1.	Fractals Describe Phenomena and Give Hints about Their Causes	285	
12.2.	A Single Process or Many Processes?	286	
12.3.	Single Causes That Spread Across Many Scales	287	
12.4.	Different Causes That Become Linked Across Many Scales	298	
12.5.	Summary	299	
13.	Chaos? in Physiological Systems	300	
13.1.	Introduction	300	
13.2.	Cardiovascular Chaos	302	
13.3.	Metabolism	317	
13.4.	The Chaotic Brain	320	†
13.5.	Physiological Advantages of Chaos	325	
13.6.	Special Situations	326	
13.7.	Summary	327	
Works Cited		328	
Index		355	