## DATA SCIENCE FOR COMPLEX SYSTEMS

ANINDYA S. CHAKRABARTI Indian Institute of Management Ahmedabad

> K. SHUVO BAKAR University of Sydney

ANIRBAN CHAKRABORTI BML Munjal University



## Contents

	Prefe	<i>page</i> vii	
	Ackn	owledgments	X
Pa	ırt I	Introduction	
1	Facets of Complex Systems		3
	1.1	Features of Complex Systems	6
	1.2	A Data-Driven View of Complexity	8
	1.3	A World of Simulations	9
Part II Het		Heterogeneity and Dependence	
2	Quantifying Heterogeneity: Classical and Bayesian Statistics		15
	2.1	Data Characteristics	16
	2.2	Probability Distributions	22
	2.3	Classical Statistical Inference	41
	2.4	Bayesian Statistics and Inference	70
	2.5	Multivariate Statistics	81
	2.6	Taking Stock and Further Reading	86
3	Statistical Analyses of Time-Varying Phenomena		88
	3.1	Some Basic Definitions and Constructions	90
	3.2	Stationary Time Series	94
	3.3	Analyses of Non-stationary Time Series	114
	3.4	Modeling Fluctuations	118
	3.5	Scaling and Long Memory	122
	3.6	Taking Stock and Further Reading	129

## Part III Patterns and Interlinkages

4	Pattern Recognition in Complex Systems: Machine Learning		
	4.1	Patterns in the Data	133
	4.2	Types of Learning Models	134
	4.3	Modeling Dependence via Regression	136
	4.4	Low-Dimensional Projection	142
	4.5	Finding Similarity in Data	152
	4.6	Classifying Observations	159
	4.7	Model Validation and Performance	172
	4.8	Taking Stock and Further Reading	177
5	Interlinkages and Heterogeneity: Network Theory		179
	5.1	Understanding Linkages	179
	5.2	Parts of a Network	182
	5.3	Node- and Network-Level Characteristics	186
	5.4	Information Content and Filtered Networks	204
	5.5	Influence of Nodes and Edges	208
	5.6	Multiple Layers of Connectivity	214
	5.7	Communities and How to Detect Them	216
	5.8	Network Architectures	222
	5.9	Taking Stock and Further Reading	232

## Part IV Emergence: From Micro to Macro

6	Intera	action and Emergence: Agent-Based Models	237	
	6.1	Social Segregation: Interactions on Grids	238	
	6.2	Ripples on Sand-Piles: Self-Organized Criticality	239	
	6.3	Size of Cities: Scaling Behavior	242	
	6.4	Inequality and Heterogeneity: Kinetic Exchange Models	248	
	6.5	Dynamics of Languages: Competition and Dominance	253	
	6.6	Emergence of Coordination and Anti-coordination: Bounded		
		Rationality and Repeated Interactions	257	
	6.7	Realism vs. Generalizability	263	
	Epilogue			
	Refer	ences	271	
	292			