

Contents

Preface	XIII
1. Self-Organized Criticality Phenomena	1
1.1 The Concept of Self-Organized Criticality	1
1.2 SOC Laboratory Experiments	5
1.3 SOC in Human Activities	7
1.4 SOC in Biophysics	12
1.5 SOC in Geophysics	14
1.6 SOC in Magnetospheric Physics	19
1.7 SOC in Planetary Physics	22
1.8 SOC in Solar Physics	23
1.9 SOC in Stellar Physics	28
1.10 SOC in Galaxies and Cosmology	32
1.11 Summary	34
1.12 Problems	35
2. Numerical SOC Models	37
2.1 SOC Simulations of Laboratory Experiments	38
2.1.1 Coupled Pendulums	38
2.1.2 The Bak-Tang-Wiesenfeld 1-D Sandpile Model	39
2.1.3 The Bak-Tang-Wiesenfeld 2-D Sandpile Model	41
2.1.4 The Lattice-Gas Model	44
2.2 SOC Simulations of Human Activities	46
2.2.1 Conway's Game of Life Model	46
2.2.2 Traffic Jam Simulations	47
2.2.3 Financial Market Simulations	50
2.3 SOC Simulations in Biophysics	51
2.3.1 The Punctuated Equilibrium (Bak-Sneppen Model)	51
2.4 SOC Simulations in Geophysics	53
2.4.1 Slider-Block Spring Model	53
2.4.2 The Forest-Fire Model	54

2.5	SOC Simulations in Magnetospheric Physics	57
2.5.1	SOC Model with Finite System Size	57
2.5.2	Cellular Automaton Model with Discretized MHD	58
2.6	SOC Simulations in Solar Physics	63
2.6.1	Isotropic Cellular Automaton Models	63
2.6.2	Anisotropic Cellular Automaton Models	67
2.6.3	Discretized MHD Cellular Automaton Models	70
2.6.4	Divergence-Free Field Braiding Models	73
2.6.5	Branching Process Models	77
2.7	SOC Simulations in Astrophysics	77
2.7.1	Cellular Automaton Model of Accretion Disk Fluctuations	78
2.8	Summary	81
2.9	Problems	81
3.	Analytical SOC Models	83
3.1	The Exponential-Growth Model	84
3.2	The Powerlaw-Growth Model	89
3.3	The Logistic-Growth Model	94
3.4	Analytical Fit to Numerical SOC Simulations	98
3.5	Inertial Range, Lower and Upper Cutoff	102
3.6	Continuum Limit of Cellular Automaton Model	105
3.7	Summary	109
3.8	Problems	109
4.	Statistics of Random Processes	111
4.1	Binomial Distribution	112
4.2	Gaussian Distribution	115
4.3	Poisson Distribution	117
4.4	Exponential Distribution	119
4.5	Count Rate Statistics	122
4.6	White Noise	122
4.7	$1/f$ Power Spectra Nomenclature	126
4.8	Shot Noise or Flicker Noise	129
4.8.1	Derivation of Schottky's Theorem	129
4.8.2	Shot Noise Spectrum for Rectangular Pulses	131
4.8.3	Shot Noise Spectrum for Exponential-Decay Pulses	132
4.8.4	Shot Noise Spectrum and Distribution of Pulse Durations	133
4.9	Log-Normal Distribution	135
4.10	Summary	137
4.11	Problems	137
5.	Waiting-Time Distributions	139
5.1	Waiting Times	140
5.2	Nonstationary Waiting-Time Statistics	142
5.3	Measurement of Waiting Times	146

5.4	Waiting-Time Statistics in Geophysics	149
5.5	Waiting-Time Statistics in Magnetospheric Physics	151
5.6	Waiting-Time Statistics in Solar Physics	153
5.6.1	Solar Flare Hard X-Rays	154
5.6.2	Solar Flare Soft X-Rays	159
5.6.3	Coronal Mass Ejections	162
5.6.4	Solar Radio Bursts	163
5.6.5	Solar Wind	163
5.7	Waiting-Time Statistics in Astrophysics	165
5.7.1	Flare Stars	165
5.7.2	Black Hole Accretion Disks	167
5.8	Summary	169
5.9	Problems	170
6.	Event Detection Methods	171
6.1	Test Data for Event Detection	172
6.2	Threshold-Based Event Detection	174
6.3	Highpass-Filtered Event Detection	180
6.4	Peak-Based Event Detection	182
6.5	Fourier-Filtered Event Detection	182
6.6	Time Scale Statistics from Power Spectra	184
6.7	Wavelet-Based Time Scale Statistics	187
6.8	Principal Component Analysis	191
6.9	Image-Based Event Detection	193
6.10	Summary	198
6.11	Problems	200
7.	Occurrence Frequency Distributions	201
7.1	Basics of Frequency Distribution Functions	202
7.1.1	Differential Frequency Distributions	202
7.1.2	Cumulative Frequency Distributions	203
7.1.3	Rank-Order Plots	206
7.1.4	Numerical Generation of Frequency Distributions	208
7.1.5	Integrals of Powerlaw Distributions	210
7.1.6	Powerlaw Scaling Laws and Correlations	211
7.1.7	Accuracy of Powerlaw Fits	212
7.2	Frequency Distributions in Magnetospheric Physics	214
7.3	Frequency Distributions in Solar Physics	217
7.3.1	Solar Flare Hard X-rays	217
7.3.2	Solar Flare Soft X-rays	224
7.3.3	Solar Flare Extreme Ultraviolet Emission	229
7.3.4	Solar Radio Emission	233
7.3.5	Solar Energetic Particle (SEP) Events	237
7.4	Frequency Distributions in Astrophysics	238
7.4.1	Stellar Flares	239

7.4.2	Pulsar Glitches	242
7.4.3	Soft Gamma-Ray Repeaters	244
7.4.4	Black Hole Objects	245
7.4.5	Blazars	246
7.5	Summary	247
7.6	Problems	248
8.	Fractal Geometry	249
8.1	1-D Fractals	250
8.1.1	The Cantor Set and Koch Curve	250
8.1.2	Irregularity of Time Series.....	251
8.1.3	Variability of Solar Radio Emission	253
8.2	2-D Fractals	256
8.2.1	Hausdorff Dimension and Box-Counting Method	257
8.2.2	Solar Photosphere and Chromosphere	259
8.2.3	Solar Flares	262
8.3	3-D Fractals	267
8.3.1	Cellular Automaton Simulations.....	268
8.3.2	Solar Flares	270
8.4	Multifractal Analysis	273
8.5	Spatial Power Spectrum Analysis	275
8.6	Statistics of Spatial Scales	277
8.6.1	Solar Photosphere and Chromosphere	277
8.6.2	Solar Flares	279
8.6.3	Lunar Craters	280
8.6.4	Asteroid Belt	282
8.6.5	Saturn Ring	283
8.7	Summary	285
8.8	Problems	285
9.	Physical SOC Models	287
9.1	A General (Physics-Free) Definition of SOC	288
9.2	Astrophysics	289
9.2.1	Galaxy Formation	289
9.2.2	Star Formation	290
9.2.3	Blazars	291
9.2.4	Neutron Star Physics	293
9.2.5	Blackhole Objects and Accretion Disks	295
9.2.6	Cosmic Rays	296
9.3	Solar and Stellar Physics	298
9.3.1	Maxwell's Electrodynamics	298
9.3.2	The Solar Dynamo	299
9.3.3	Magnetic Field Braiding	301
9.3.4	Magnetic Reconnection in Solar/Stellar Flares	304
9.3.5	Thermal Energy of Flare Plasma	306

9.3.6	Nonthermal Energy of Flares	308
9.3.7	Particle Acceleration	311
9.3.8	Coherent Radio Emission	313
9.3.9	Master Equation	314
9.4	Magnetospheric Physics	315
9.4.1	Coronal Mass Ejections and Magnetospheric Storms	315
9.4.2	Heliospheric Field and Magnetospheric Substorms	316
9.5	Summary	319
9.6	Problems	320
10.	SOC-Like Models	321
10.1	Hierarchical SOC Systems	322
10.2	Self-Organization without Criticality	324
10.3	Brownian Motion and Diffusion	326
10.4	MHD Turbulence	329
10.4.1	Solar Corona	329
10.4.2	Solar Wind	332
10.4.3	Magnetospheric Substorms	334
10.4.4	Interstellar Medium	335
10.5	Forced Criticality Models	337
10.5.1	Magnetospheric Physics	337
10.6	Percolation Models	338
10.6.1	Solar Active Regions	339
10.7	Nonlinear Chaotic Systems	340
10.7.1	Astrophysics	341
10.7.2	Solar Physics	342
10.8	Summary	344
10.9	Problems	345
Appendices		347
Appendix A:	Physical Constants	347
Appendix B:	Plasma Parameters	348
Notation		349
Physical Units	Symbols	349
Latin Symbols		349
Greek Symbols		351
Acronyms		353
Image Credit: Public Websites		357
References		359
Index		391