Contents

List of Contributors XVII

1	Introduction 1
	Dietmar Plenz and Ernst Niebur
1.1	Criticality in Neural Systems 1
2	Criticality in Cortex: Neuronal Avalanches and Coherence Potentials Dietmar Plenz
2.1	The Late Arrival of Critical Dynamics to the Study of Cortex Function 5
2.1.1	Studying Critical Dynamics through Local Perturbations 7
2.1.2	Principles in Cortex Design that Support Critical Neuronal Cascades 8
2.2	Cortical Resting Activity Organizes as Neuronal Avalanches 11
2.2.1	Unbiased Concatenation of Neuronal Activity into Spatiotemporal Patterns 11
2.2.2	The Power Law in Avalanche Sizes with Slope of $-3/2$ 15
2.2.3	Neuronal Avalanches are Specific to Superficial Layers of Cortex 17
2.2.4	The Linking of Avalanche Size to Critical Branching 17
2.3	Neuronal Avalanches: Cascades of Cascades 20
2.4	The Statistics of Neuronal Avalanches and Earthquakes 23
2.5	Neuronal Avalanches and Cortical Oscillations 23
2.6	Neuronal Avalanches Optimize Numerous Network Functions 28
2.7	The Coherence Potential: Threshold-Dependent Spread of Synchrony with High Fidelity 30
2.8	The Functional Architecture of Neuronal Avalanches and Coherence Potentials 33 Acknowledgement 36 References 36

۷I	Contents

3	Critical Brain Dynamics at Large Scale 43
	Dante R. Chialvo
3.1	Introduction 43
3.1.1	If Criticality is the Solution, What is the Problem? 43
3.2	What is Criticality Good for? 45
3.2.1	Emergence 46
3.2.2	Spontaneous Brain Activity is Complex 46
3.2.3	Emergent Complexity is Always Critical 47
3.3	Statistical Signatures of Critical Dynamics 47
3.3.1	Hunting for Power Laws in Densities Functions 48
3.3.2	Beyond Fitting: Variance and Correlation Scaling of BrainNoise 50
3.3.2.1	Anomalous Scaling 51
3.3.2.2	Correlation Length 52
3.4	Beyond Averages: Spatiotemporal Brain Dynamics at Criticality 55
3.4.1	fMRI as a Point Process 56
3.4.2	A Phase Transition 57
3.4.3	Variability and Criticality 59
3.5	Consequences 60
3.5.1	Connectivity versus Functional Collectivity 60
3.5.2	Networks, Yet Another Circuit? 62
3.5.3	River Beds, Floods, and Fuzzy Paths 62
3.6	Summary and Outlook 63
	References 64
4	The Dynamic Brain in Action: Coordinative Structures, Criticality,
	and Coordination Dynamics 67
	J. A. Scott Kelso
4.1	Introduction 67
4.2	The Organization of Matter 68
4.3	Setting the Context: A Window into Biological Coordination 72
4.4	Beyond Analogy 74
4.5	An Elementary Coordinative Structure: Bimanual Coordination 75
4.6	Theoretical Modeling: Symmetry and Phase Transitions 76
4.7	Predicted Signatures of Critical Phenomena in Biological
	Coordination 80
4.7.1	Critical Slowing Down 80
4.7.2	Enhancement of Fluctuations 81
4.7.3	Critical Fluctuations 81
4.8	Some Comments on Criticality, Timescales, and Related Aspects 82
4.8 4.9	Symmetry Breaking and Metastability 84
4.9	Symmetry Breaking and Metastability 84
4.9	Symmetry Breaking and Metastability 84 Nonequilibrium Phase Transitions in the Human Brain: MEG, EEG,

Transitions, Transients, Chimera, and Spatiotemporal Metastability 89
The Middle Way: Mesoscopic Protectorates 92
Concluding Remarks 94
Acknowledgments 95
References 96
The Correlation of the Neuronal Long-Range Temporal Correlations,
Avalanche Dynamics with the Behavioral Scaling Laws and
Interindividual Variability 105
Jaakko Matias Palva and Satu Palva
Introduction 105
Criticality in the Nervous System: Behavioral and Physiological
Evidence 106
Human Task Performance Fluctuations Suggest Critical
Dynamics 106
Two Lines of Empirical Evidence for Critical-State Dynamics in
Neuronal Systems 108
Magneto- and Electroencephalography (M/EEG) as a Tool for
Noninvasive Reconstruction of Human Cortical Dynamics 109
Slow Neuronal Fluctuations: The Physiological Substrates of
LRTC 111
Infra-Slow Potential Fluctuations Reflect Endogenous Dynamics of
Cortical Excitability 111
Slow Fluctuations in Oscillation Amplitudes and Scalp Potentials are
Correlated with Behavioral Dynamics 113
Slow BOLD Signal Fluctuations in Resting-State Networks 114
Neuronal Scaling Laws are Correlated with Interindividual Variability
in Behavioral Dynamics 115
Neuronal Avalanches, LRTC, and Oscillations: Enigmatic
Coexistence? 117
The Mechanistic Insights from Interindividual Variability in Scaling
Laws 118
Conclusions 119
Acknowledgment 120
References 120
The Turbulent Human Brain: An MHD Approach to the MEG 127
Arnold J. Mandell, Stephen E. Robinson, Karen A. Selz,
Constance Schrader, Tom Holroyd, and Richard Coppola
Introduction 127
Autonomous, Intermittent, Hierarchical Motions, from Brain Proteins
Fluctuations to Emergent Magnetic Fields 129
Magnetic Field Induction and Turbulence; Its Maintenance, Decay,
and Modulation 130

VIII	Contents	
	6.4	Localizing a Time-Varying Entropy Measure of Turbulence, Rank Vector Entropy (RVE) [35, 107], Using a Linearly Constrained Minimum Variance (LCMV) Beamformer Such as Synthetic Aperture Magnetometry (SAM) [25, 34], Yields State and Function-Related Localized Increases and Decreases in the RVE Estimate 139
	6.5	Potential Implications of the MHD Approach to MEG Magnetic Fields for Understanding the Mechanisms of Action and Clinical Applications of the Family of TMS (Transcranial Magnetic Stimulation) Human Brain Therapies 142
	6.6	Brief Summary of Findings 145 References 145
	7	Thermodynamic Model of Criticality in the Cortex Based on EEG/ECoG Data 153 Polant Korma Marko Pulita and Walter L. Fraguegy
	7.1	Robert Kozma, Marko Puljic, and Walter J. Freeman Introduction 153
	7.1	
	7.2.1	Principles of Hierarchical Brain Models 154 Freeman K-Models: Structure and Functions 154
	7.2.1	Basic Building Blocks of Neurodynamics 155
	7.2.2	Motivation of Neuropercolation Approach to Neurodynamics 157
	7.2.3	Mathematical Formulation of Neuropercolation 158
	7.3.1	Random Cellular Automata on a Lattice 158
	7.3.2	Update Rules 159
	7.3.3	Two-Dimensional Lattice with Rewiring 160
	7.3.4	Double-Layered Lattice 161
	7.3.5	Coupling Two Double-Layered Lattices 162
	7.3.6	Statistical Characterization of Critical Dynamics of Cellular Automata 163
	7.4	Critical Regimes of Coupled Hierarchical Lattices 164
	7.4.1	Dynamical Behavior of 2D Lattices with Rewiring 164
	7.4.2	Narrow Band Oscillations in Coupled Excitatory—Inhibitory Lattices 165
	7.5	BroadBand Chaotic Oscillations 167
	7.5.1	Dynamics of Two Double Arrays 167
	7.5.2	Intermittent Synchronization of Oscillations in Three Coupled Double Arrays 170
	7.5.3	Hebbian Learning Effects 170
	7.6	Conclusions 173 References 174
	8	Neuronal Avalanches in the Human Brain 177 Oren Shriki and Dietmar Plenz
	8.1	Introduction 177
	8.2	Data and Cascade-Size Analysis 178
	8.3	Cascade-Size Distributions are Power Laws 181

8.4	The Data are Captured by a Critical Branching Process 181
8.5	Discussion 186
8.6	Summary 188
	Acknowledgements 188
	References 188
9	Critical Slowing and Perception 191
	Karl Friston, Michael Breakspear, and Gustavo Deco
9.1	Introduction 191
9.1.1	Perception and Neuronal Dynamics 191
9.1.2	Overview 192
9.2	Itinerant Dynamics 193
9.2.1	Chaotic Itinerancy 193
9.2.2	Heteroclinic Cycling 194
9.2.3	Multistability and Switching 194
9.2.4	Itinerancy, Stability, and Critical Slowing 195
9.3	The Free Energy Principle 196
9.3.1	Action and Perception 197
9.3.2	The Maximum Entropy Principle and the Laplace Assumption 198
9.3.3	Summary 199
9.4	Neurobiological Implementation of Active Inference 199
9.4.1	Perception and Predictive Coding 202
9.4.2	Action 204
9.4.3	Summary 204
9.5	Self-Organized Instability 205
9.5.1	Conditional Lyapunov Exponents and Generalized Synchrony 205
9.5.2	Critical Slowing and Conditional Lyapunov Exponents 207
9.5.3	Summary 210
9.6	Birdsong, Attractors, and Critical Slowing 211
9.6.1	A Synthetic Avian Brain 212
9.6.2	Stimulus Generation and the Generative Model 213
9.6.3	Perceptual Categorization 214
9.6.4	Perceptual Instability and Switching 216
9.6.5	Perception and Critical Slowing 219
9.6.6	Summary 221
9.7	Conclusion 223
	References 224
10	Self-Organized Criticality in Neural Network Models 227
	Matthias Rybarsch and Stefan Bornholdt
10.1	Introduction 227
10.2	Avalanche Dynamics in Neuronal Systems 228
10.2.1	Experimental Results 228
10.2.2	Existing Models 229

х	Contents	
	10.3	Simple Models for Self-Organized Critical Adaptive Neural Networks 231
	10.3.1	A First Approach: Node Activity Locally Regulates Connectivity 231
	10.3.2	Correlation as a Criterion for Rewiring: Self-Organization on a Spin Lattice Neural Network Model 235
	10.3.3	Simplicity versus Biological Plausibility – and Possible Improvements 238
	10.3.3.1	Transition from Spins to Boolean Node States 238
	10.3.3.2	Model Definitions 239
	10.3.3.3	Exploration of Critical Properties – Activity-Dependent Criticality 240
	10.3.3.4	Extension of the Model: Thermal Noise 242
	10.3.4	Self-Organization on the Boolean State Model 243
	10.3.4.1	Model Definitions 244
	10.3.4.2	Rewiring Algorithm 245
	10.3.4.3	Observations 247
	10.3.5	Response to External Perturbations 249
	10.4	Conclusion 252
		Acknowledgments 252
		References 252
		References 232
	11	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255
		Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom
	11.1	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255
		Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257
	11.1 11.2 11.3	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261
	11.1 11.2	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263
	11.1 11.2 11.3 11.4	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263
	11.1 11.2 11.3 11.4	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265
	11.1 11.2 11.3 11.4 11.5	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273
	11.1 11.2 11.3 11.4 11.5	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273 Lucilla de Arcangelis and Hans J. Herrmann
	11.1 11.2 11.3 11.4 11.5	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273 Lucilla de Arcangelis and Hans J. Herrmann The Model 274
	11.1 11.2 11.3 11.4 11.5 12	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273 Lucilla de Arcangelis and Hans J. Herrmann The Model 274 Plastic Adaptation 276
	11.1 11.2 11.3 11.4 11.5 12 12.1 12.1.1 12.2	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273 Lucilla de Arcangelis and Hans J. Herrmann The Model 274 Plastic Adaptation 276 Neuronal Avalanches in Spontaneous Activity 277
	11.1 11.2 11.3 11.4 11.5 12 12.1 12.1.1 12.2 12.2.1	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273 Lucilla de Arcangelis and Hans J. Herrmann The Model 274 Plastic Adaptation 276 Neuronal Avalanches in Spontaneous Activity 277 Power Spectra 278
	11.1 11.2 11.3 11.4 11.5 12 12.1 12.1.1 12.2 12.2.1 12.3	Single Neuron Response Fluctuations: A Self-Organized Criticality Point of View 255 Asaf Gal and Shimon Marom Neuronal Excitability 255 Experimental Observations on Excitability Dynamics 257 Self-Organized Criticality Interpretation 261 Adaptive Rates and Contact Processes 263 Concluding Remarks 265 References 269 Activity Dependent Model for Neuronal Avalanches 273 Lucilla de Arcangelis and Hans J. Herrmann The Model 274 Plastic Adaptation 276 Neuronal Avalanches in Spontaneous Activity 277 Power Spectra 278 Learning 280

and Klaus Linkenkaer-Hansen 13.1 Introduction 293 13.2 Properties of Scale-Free Time Series 294 13.2.1 Self-Affinity 294 13.2.2 Stationary and Nonstationary Processes 298 13.2.3 Scaling of an Uncorrelated Stationary Process 298 13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305 13.4.3 Extract the Amplitude Envelope and Perform DFA 305
13.2 Properties of Scale-Free Time Series 294 13.2.1 Self-Affinity 294 13.2.2 Stationary and Nonstationary Processes 298 13.2.3 Scaling of an Uncorrelated Stationary Process 298 13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.2.1 Self-Affinity 294 13.2.2 Stationary and Nonstationary Processes 298 13.2.3 Scaling of an Uncorrelated Stationary Process 298 13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.2.2 Stationary and Nonstationary Processes 298 13.2.3 Scaling of an Uncorrelated Stationary Process 298 13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.2.3 Scaling of an Uncorrelated Stationary Process 298 13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.2.3 Scaling of an Uncorrelated Stationary Process 298 13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.2.4 Scaling of Correlated and Anticorrelated Signals 300 13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.3 The Detrended Fluctuation Analysis (DFA) 302 13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.4 DFA Applied to Neuronal Oscillations 304 13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.4.1 Preprocessing of Signals 304 13.4.2 Filter Design 305
13.4.2 Filter Design 305
<u>e</u>
13.4.3 Extract the Amplitude Envelope and Perform DFA 305
13.4.4 Determining the Temporal Integration Effect of the Filter 305
13.5 Insights from the Application of DFA to Neuronal Oscillations 305
13.5.1 DFA as a Biomarker of Neurophysiological Disorder 309
13.6 Scaling Behavior of Oscillations: a Sign of Criticality? 310
13.6.1 CRitical OScillations Model (CROS) 310
13.6.2 CROS Produces Neuronal Avalanches with Balanced Ex/In
Connectivity 311
13.6.3 CROS Produces Oscillations with LRTC When there are Neuronal
Avalanches 313
13.6.4 Multilevel Criticality: A New Class of Dynamical Systems? 315
Acknowledgment 316
References 316
14 Critical Exponents, Universality Class, and Thermodynamic
"Temperature" of the Brain 319
Shan Yu, Hongdian Yang, Oren Shriki, and Dietmar Plenz
14.1 Introduction 319
14.2 Thermodynamic Quantities at the Critical Point and Their Neuronal
Interpretations 320
14.3 Finite-Size Scaling 324
14.4 Studying the Thermodynamics Properties of Neuronal Avalanches at
Different Scales 325
14.5 What Could be the "Temperature" for the Brain? 330
Acknowledgment 331
References 331
15 Peak Variability and Optimal Performance in Cortical Networks at
Criticality 335
Hongdian Yang, Woodrow L. Shew, Rajarshy Roy, and Dietmar Plenz
15.1 Introduction 335
15.2 Fluctuations Are Highest Near Criticality 336

XII	Contents	
	15.3	Variability of Spatial Activity Patterns 338
	15.4	Variability of Phase Synchrony 339
	15.5	High Variability, but Not Random 342
	15.6	Functional Implications of High Entropy of Ongoing Cortex
		Dynamics 343
		References 344
	16	Criticality at Work: How Do Critical Networks Respond to Stimuli? 347
		Mauro Copelli
	16.1	Introduction 347
	16.1.1	Phase Transition in a Simple Model 347
	16.1.2	What is the Connection with Neuronal Avalanches? 350
	16.1.3	What if Separation of Time Scales is Absent? 351
	16.2	Responding to Stimuli 351
	16.2.1	What Theory Predicts 352
	16.2.1.1	Self-Regulated Amplification via Excitable Waves 352
	16.2.1.2	Enhancement of Dynamic Range 354
	16.2.1.3	Nonlinear Collective Response and Maximal Dynamic Range at
	4600	Criticality 355
	16.2.2	What Data Reveals 356
	16.2.2.1	Nonlinear Response Functions in Sensory Systems 356
	16.2.2.2	Enhanced Dynamic Range 356
	16.2.2.3	Scaling In Brain Dynamics 357
	16.3	Concluding Remarks 359
		Acknowledgements 361
		References 361
	17	Critical Dynamics in Complex Networks 365
		Daniel B. Larremore, Woodrow L. Shew, and Juan G. Restrepo
	17.1	Introduction: Critical Branching Processes 365
	17.2	Description and Properties of Networks 367
	17.2.1	Network Representation by an Adjacency Matrix 368
	17.2.2	Node Degrees 368
	17.2.3	Degree Distribution 369
	17.2.4	Degree Correlations 370
	17.2.5	Largest Eigenvalue and the Corresponding Eigenvector 372
	17.3	Branching Processes in Complex Networks 373
	17.3.1	Subcritical Regime 378
	17.3.2	Supercritical Regime 381
	17.3.3	Critical Regime 383
	17.4	Discussion 387
		References 390

18	Mechanisms of Self-Organized Criticality in Adaptive Networks 393 Thilo Gross, Anne-Ly Do, Felix Droste, and Christian Meisel
18.1	Introduction 393
18.2	Basic Considerations 393
18.3	A Toy Model 395
18.4	Mechanisms of Self-Organization 397
18.5	Implications for Information Processing 399
18.6	Discussion 400 References 401
19	Cortical Networks with Lognormal Synaptic Connectivity and Their Implications in Neuronal Avalanches 403 Tomoki Fukai, Vladimir Klinshov, and Jun-nosuke Teramae
19.1	Introduction 403
19.2	Critical Dynamics in Neuronal Wiring Development 404
19.3	Stochastic Resonance by Highly Inhomogeneous Synaptic Weights on Spike Neurons 405
19.4	SSWD Recurrent Networks Generate Optimal Intrinsic Noise 409
19.5	Incorporation of Local Clustering Structure 410
19.6	Emergence of Bistable States in the Clustered Network 412
19.7	Possible Implications of SSWD Networks for Neuronal Avalanches 413
19.8	Summary 414
	Acknowledgment 414
	References 415
20	Theoretical Neuroscience of Self-Organized Criticality: From Formal
	Approaches to Realistic Models 417
	Anna Levina, J. Michael Herrmann, and Theo Geisel
20.1	Introduction 417
20.2	The Eurich Model of Criticality in Neural Networks 417
20.2.1	Model Description 418
20.2.2	Simulations and Analysis 419
20.3	LHG Model: Dynamic Synapses Control Criticality 420
20.3.1	Model Description 420
20.3.2	Mean-Field Approximation 423
20.3.3	Toward a Realistic Model: Network Structure, Leakage, and
	Inhibition 424
20.3.4	Synaptic Facilitation 427
20.4	Criticality by Homeostatic Plasticity 429
20.4.1	Branching Processes 429
20.4.2	Self-Organization by Long-Term Plasticity 430
20.4.3	Effects of Spike-Time-Dependent Plasticity and Network Structure 431
20.5	Conclusion 433

Acknowledgment 434

	References 434
21	Nonconservative Neuronal Networks During Up-States Self-Organize Near Critical Points 437
	Stefan Mihalas, Daniel Millman, Ramakrishnan Iyer, Alfredo Kirkwood,
	and Ernst Niebur
21.1	Introduction 437
21.2	Model 439
21.2.1	Analytical Solution 440
21.2.2	Numerical Evolution of the Fokker–Planck Equation 441
21.2.3	Fixed-Point Analysis 442
21.3	Simulations 444
21.3.1	Up- and Down-States 444
21.3.1.1	Up-/Down-State Transitions 446
21.3.2	Up-States are Critical; Down-States are Subcritical 448
21.3.3	More Biologically Realistic Networks 449
21.3.3.1	Small-World Connectivity 449
21.3.3.2	NMDA and Inhibition 450
21.3.4	Robustness of Results 452
21.4	Heterogeneous Synapses 454
21.4.1	Influence of Synaptic Weight Distributions 454
21.4.2	Voltage Distributions for Heterogeneous Synaptic Input 455
21.4.3	Results for Realistic Synaptic Distributions in the Absence of
	Recurrence and STSD 456
21.4.4	Heterogeneous Synaptic Distributions in the Presence of Synaptic
	Depression 458
21.5	Conclusion 460
	Acknowledgment 460
	References 460
22	Self-Organized Criticality and Near-Criticality in Neural Networks 465
	Jack D. Cowan, Jeremy Neuman, and Wim van Drongelen
22.1	Introduction 465
22.1.1	Neural Network Dynamics 466
22.1.2	Stochastic Effects Near a Critical Point 468
22.2	A Neural Network Exhibiting Self-Organized Criticality 468
22.2.1	A Simulation of the Combined Mean-Field Equations 470
22.2.2	A Simulation of the Combined Markov Processes 471
22.3	Excitatory and Inhibitory Neural Network Dynamics 472
22.3.1	Equilibria of the Mean-Field Wilson–Cowan Equations 473
22.4	An E–I Neural Network Exhibiting Self-Organized
	Near-Criticality 475
22.4.1	Modifiable Synapses 475
22.4.2	A Simulation of the Combined Mean-Field E/I equations 477

22.4.3 22.4.4 22.5	Balanced Amplification in E/I Patches 477 Analysis and Simulation of the Combined E/I Markov Processes 479 Discussion 481 Acknowledgements 482 References 482
23	Neural Dynamics: Criticality, Cooperation, Avalanches, and
	Entrainment between Complex Networks 485
23.1	Paolo Grigolini, Marzieh Zare, Adam Svenkeson, and Bruce J. West Introduction 485
23.2	Decision-Making Model (DMM) at Criticality 487
23.2.1	Intermittency 489
23.2.1	Response to Perturbation 492
23.2.2	Neural Dynamics 493
23.3.1	Mittag-Leffler Function Model Cooperation 494
23.3.2	Cooperation Effort in a Fire-and-Integrate Neural Model 496
23.4	Avalanches and Entrainment 501
23.5	Concluding Remarks 504
	References 505
24	Complex Networks: From Social Crises to Neuronal Avalanches 509 Bruce J. West, Malgorzata Turalska, and Paolo Grigolini
24.1	Introduction 509
24.2	The Decision-Making Model (DMM) 510
24.3	Topological Complexity 514
24.4	Temporal Complexity 517
24.5	Inflexible Minorities 518
24.6	Conclusions 521
	References 522
25	The Dynamics of Neuromodulation 525 Gerhard Werner [†] and Bernhard J. Mitterauer
25.1	Introduction 525
25.2	Background 525
25.2.1	Gap Junctions and Neuroglia 525
25.2.2	Brain Cell Microenvironment (Extracellular Fluid) 527
25.2.3	Neuromodulatory Processes 528
25.3	Discussion and Conclusions 529
25.4	A Final Thought 532
25.5	Summary 532
	References 532
	Color Plates 539

Index 559



Participants of the 'Criticality in Neural Systems' conference held April 30 - May, 1st, 2012, at the National Institutes of Health, Bethesda, MD, USA. The conference was organized to increase the coherence of the volume at hand.