

Contents

1. Introduction	1
1.1 Goal	1
1.2 Physiological Motivation	3
1.2.1 Resetting Cerebral Rhythms	3
1.2.2 Deep Brain Stimulation	5
1.3 Stochastic Approach	6
1.4 Synergetics	9
2. Resetting an Ensemble of Oscillators	11
2.1 Introductory Remarks	11
2.2 Deterministic Models	11
2.2.1 Macroscopic Level	12
2.2.2 Cluster of Oscillators	19
2.3 Stochastic Model	21
2.4 Fokker–Planck Equation	22
2.4.1 Stationary Solution	23
2.4.2 Fourier Transformation	24
2.5 Spontaneous Behavior	25
2.6 Black Holes Without Noise	26
2.7 Ensemble Dynamics During Stimulation	28
2.7.1 Black Holes in the Presence of Noise	28
2.7.2 Stimulation Induced Frequency Shift	35
2.7.3 Stimulation Mechanism with Higher Harmonics	39
2.8 Firing Patterns	46
2.9 Summary and Discussion	51
3. Synchronization Patterns	57
3.1 Introductory Remarks	57
3.2 Pattern Recognition	57
3.3 Clustering	59
3.4 Populations of Neurons	60
3.4.1 Model Neuron	61
3.4.2 Neuronal Interactions	62
3.5 Populations of Phase Oscillators	63

3.6	Slaving Principle and Center Manifold	66
3.6.1	Center Manifold Theorem	68
3.6.2	Strategy	71
3.7	n -Cluster States	71
3.7.1	Configuration of Cluster States	71
3.7.2	One Cluster	73
3.7.3	Two Clusters	77
3.7.4	Three Clusters	79
3.7.5	Four Clusters	80
3.8	Complexity of Synchronized States	81
3.8.1	Hierarchy of Frequency Levels	81
3.8.2	Phase and Frequency Shifts	84
3.8.3	Cluster Variables	87
3.8.4	Frozen States	89
3.8.5	Transient Behavior	91
3.8.6	Coupling Mechanism	92
3.9	Neural Coding	95
3.9.1	Information Compression	95
3.9.2	Coding by Clusters	95
3.10	Summary	98
4.	Stochastic Model	101
4.1	Introductory Remarks	101
4.2	Derivation of the Model Equation	102
4.3	Fourier Transformation	107
4.4	Summary and Discussion	108
5.	Clustering in the Presence of Noise	109
5.1	Introductory Remarks	109
5.2	Modelling Emerging Synchronization	109
5.3	Comparison with the Ensemble's Dynamics	110
5.4	Noisy Cluster States	111
5.4.1	Linear Problem	112
5.4.2	First-Mode Instability	113
5.4.3	Second-Mode Instability	119
5.4.4	Third-Mode Instability	120
5.4.5	Fourth-Mode Instability	121
5.4.6	Two-Mode Instability	122
5.5	Scaling of Noisy Cluster States	127
5.6	The Experimentalist's Inverse Problem	129
5.6.1	Travelling Waves	130
5.6.2	Firing Patterns	134
5.7	Neural Coding Revisited	137
5.8	Summary and Discussion	139

6. Single Pulse Stimulation	147
6.1 Introductory Remarks	147
6.2 How Stimulation Affects Order Parameters	149
6.2.1 Cluster Variables and Order Parameters	150
6.2.2 Uniform and Partial Desynchronization	151
6.2.3 Stimulating a One-Cluster State	152
6.2.4 Stimulating a Two-Cluster State	161
6.3 Transient Mode Excitation and Early Response	165
6.3.1 Excitation of Higher Order	167
6.3.2 Excitation of Lower Order	171
6.4 Couplings Determine Reaction to Stimulation	174
6.4.1 Rapid Recovery	175
6.4.2 Harmonic Early Response	176
6.5 Vulnerability and Recovery	178
6.5.1 Phase Errors Versus Duration Errors	179
6.5.2 Protective Effect of Couplings	183
6.5.3 Partial Desynchronization and Transient Phenomena ..	185
6.6 Black Hole and Recovery	187
6.7 Subcritical Long Pulses	189
6.7.1 Spiraling Towards the Desynchronized State	191
6.7.2 Excitation of Higher Order	193
6.7.3 Excitation of Lower Order	197
6.8 Summary and Discussion	197
7. Periodic Stimulation	205
7.1 Introductory Remarks	205
7.2 Smooth Periodic Stimulation	206
7.2.1 1:1 Phase Locking	207
7.2.2 1:2 Phase Locking	209
7.2.3 Changes of the Synchronization Pattern	212
7.3 Pulsatile Periodic Stimulation	214
7.4 Annihilation of Rhythms	216
7.5 Summary and Discussion	217
8. Data Analysis	221
8.1 Introductory Remarks	221
8.2 Phases and Amplitudes	222
8.2.1 Marker Events	223
8.2.2 Reconstruction of the Modes' Dynamics	224
8.2.3 Slaving Principle and Transients	226
8.3 Tracking Down the Black Holes	227
8.4 MEG and EEG Analysis	228
8.4.1 Triggered Averaging	229
8.4.2 Phase Dependent Triggered Averaging	229
8.4.3 Stimulus Locked $n : m$ Transients	231

8.4.4	Stimulus Locked $n : m$ Transients with Delay	238
8.4.5	Multiple Stimulus Locked $n : m$ Transients	240
8.4.6	Detection of Multiple Stimulus Locked $n : m$ Transients	242
8.4.7	Multiple Stimulus Locked $n : m$ Transients with Delay	244
8.4.8	$n : m$ Phase Synchronization	246
8.4.9	Self-Synchronization Versus Transients	250
8.4.10	The Flow of Synchronized Cerebral Activity	251
8.4.11	Inverse Problems	252
8.5	Summary and Discussion	253
9.	Modelling Perspectives	259
9.1	Neural Oscillators	259
9.1.1	Time-Delayed Interactions	260
9.1.2	Anatomy of Interacting Clusters	262
9.2	Limit Cycle Oscillators	262
9.3	Chaotic Oscillators	263
9.4	Macroscopic Versus Microscopic	264
10.	Neurological Perspectives	267
10.1	Therapeutic Stimulation Techniques	267
10.2	Parkinsonian Resting Tremor	268
10.2.1	Disease Mechanism	268
10.2.2	Stereotactic Treatment	272
10.2.3	Resetting the Tremor Rhythm	274
11.	Epilogue	277
11.1	Natural Sensory Stimulation	277
11.2	Experimental Electrical and Magnetic Stimulation	281
11.3	Therapeutic Stimulation	282
	Appendices	284
A.	Numerical Analysis of the Partial Differential Equations	287
B.	Phase and Frequency Shifts Occurring in Chap. 3	289
B.1	Two Clusters	289
B.2	Three Clusters	290
B.3	Four Clusters	290
C.	Single-Mode Instability	293
C.1	First-Mode Instability	293
C.2	Second-Mode Instability	293
C.3	Third-Mode Instability	294
C.4	Fourth-Mode Instability	294

D. Two-Mode Instability 295

 D.1 Center Manifold 295

 D.2 Order Parameter Equation 295

 D.3 Linear Problem (Type I) 296

 D.4 Linear Problem (Type II) 296

 D.5 Singularities 297

References 299

Author Index 323

Subject Index 327