Contents

List of Figures ix
Preface xi

1 Modeling Single Neurons 1
1.1 The Leaky Integrator Model 1
1.2 The EIF Model 5
1.3 Modeling Synapses 10

2 Measuring and Modeling Neural Variability 15
2.1 Spike Train Variability, Firing Rates, and Tuning 15
2.2 Modeling Spike Train Variability with Poisson Processes 21
2.3 Modeling a Neuron with Noisy Synaptic Input 25

3 Modeling Networks of Neurons 33
3.1 Feedforward Spiking Networks and Their Mean-Field Approximation 33
3.2 Recurrent Spiking Networks and Their Mean-Field Approximation 37
3.3 Modeling Surround Suppression with Rate Network Models 43

4 Modeling Plasticity and Learning 49
4.1 Synaptic Plasticity 49
4.2 Feedforward Artificial Neural Networks 54

Appendix A: Mathematical Background 61
A.1 Introduction to ODEs 61
A.2 Exponential Decay as a Linear, Autonomous ODE 63
A.3 Convolutions 65
A.4 One-Dimensional Linear ODEs with Time-Dependent Forcing 69
A.5 The Forward Euler Method 71
A.6 Fixed Points, Stability, and Bifurcations in One-Dimensional ODEs 74
A.7 Dirac Delta Functions 78
A.8 Fixed Points, Stability, and Bifurcations in Systems of ODEs 81

Appendix B: Additional Models and Concepts 89
B.1 Ion Channel Currents and the HH Model 89
B.2 Other Simplified Models of Single Neurons 97
B.3 Conductance-Based Synapse Models 113

B.4 Neural Coding 115
B.5 Derivations and Alternative Formulations of Rate Network Models 124
B.6 Hopfield Networks 127
B.7 Training Readouts from Chaotic RNNs 131
B.8 DNNs and Backpropagation 136

References 141
Index 147