PREFACE

Neuroscience is an inherently interdisciplinary field that strives to understand the functioning of neural systems at levels ranging from molecules and cells to behaviour and cognition. Theoretical neuroscience has flourished over the past three decades, becoming an indelible part of neuroscience, and has arguably entered its maturity. It encompasses a vast array of approaches stemming from theoretical physics, computer science, and applied mathematics.

Historically, the application of theoretical techniques to unravelling the operating principles of neurons started with the seminal work of Hodgkin and Huxley, who explained the generation of action potentials and their propagation. A decade later, Rall introduced an appropriate formal framework for investigating synaptic integration. Theoretical physics inspired new theories of network behaviour and organization, following the early work by Wilson and Cowan. The seminal work of Hopfield and of Amit, Gutfreund, and Sompolinsky demonstrated that statistical mechanics provided a powerful framework to analyse memory and learning. Progressively, mathematicians and physicists have elaborated a theoretical framework for analysing neural systems, creating a subfield one may term "neurophysics". At the same time, the emphasis has moved beyond models loosely inspired by biology to ones that directly reflect organisational and biological principles of neural systems.

Methods from statistical mechanics, dynamical systems theory, singular perturbation theory, theory of stochastic processes, theory of signal processing and information theory have enriched neurophysics over the years. For example, geometrical methods for nonlinear differential equations considerably improved our understanding of the dynamics of individual neurons and small circuits. Concepts from oscillation theory, such as averaging, phase reductions and discrete maps have elucidated how cell and synaptic properties determine the dynamical states of systems of interacting neurons. Mean field theories have been successfully used to describe and analyse collective dynamics of large scale networks. Recently, non-trivial extensions of mean field theory have arisen together with the use of symmetric bifurcation theory and group theoretic approaches to study pattern formation in cortical areas. Information theory is now commonly employed to analyse spike trains, to uncover neural coding strategies and to examine their optimality.

This volume comes out of the five weeks course of the Summer School in Physics that took place at Les Houches in July–August 2003. The course was composed of a series of theoretical lectures on neurophysics. These lectures comprise this volume. To provide a functional counterpart to some of the theoretical issues addressed, there were three workshops dedicated to selected issues in experimental neuroscience on the topics of: 1) The neuron in the network, 2) The dynamics of the somatosensory system, and 3) Learning and Memory. There were also special seminars by Philippe Ascher and Idan Segev.

A number of excellent textbooks in computational and theoretical neuroscience are now available. However, many of these books lack detailed coverage of the approaches originating from mathematics and physics. This book fills this need by providing complete derivations of the theoretical techniques now used in neurophysics. The lecturers have strived to present in their contributions coherent frameworks that include the important theorems and axioms upon which the methods are based and to delineate the limitations of the formalism. We hope this volume will provide the reader with the necessary tools and background to master theoretical neuroscience and to explore new tracks.

We address this volume to an audience of advanced graduate students and post-doctoral fellows in mathematics and physics, practicing researchers who are moving into theoretical neuroscience, and to neuroscientists who would like to gain deeper understanding of theory. We expect the book to be both a desktop reference as well as a textbook used in advanced courses and seminars on neurophysics.

We would like to thank the faculty for their invaluable contributions to the summer school and for the contents of this volume. We express our gratitude to all the experimentalists who invigorated the topical workshops through their inspired talks. We are indebted to Professor Philippe Ascher for his public lecture intended for a general audience. We would like to acknowledge CNRS, IBRO, NATO, and NSF for their generous support as well as the Les Houches Physics School, and its administrative team. Last but not least we would like to thank the attendees of the course who were instrumental in enlivening the school for five weeks.

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