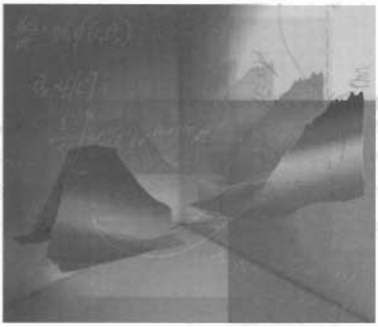
THEORY OF CORTICAL PLASTICITY



Leon N Cooper
Brown University, USA

Nathan Intrator
Tel-Aviv University, Israel & Brown University, USA

Brian S Blais
Bryant College & Brown University, USA

Harel Z Shouval
The University of Texas Medical School at Houston
& Brown University, USA

World Scientific

NEW JERSEY • LONDON • SINGAPORE • BEIJING • SHANGHAI • HONG KONG • TAIPEI • CHENNAI

Preface

Is theory possible in neuroscience? Not only possible, in our opinion, necessary. For a system as complex as the brain it is obvious that we cannot just make observations. (The number of possible observations is substantially larger than the available number of scientist-hours, even projecting several centuries into the future.) Without a theoretical structure to connect diverse observations with one another, the result would be a listing of facts of little use in understanding what the brain is about.

The eminent biochemist Edmond Fischer has said* "Biochemistry provides us with words – what is missing is language." It is theory that provides us with language-language that shapes the direction of analysis, that guides us toward significant experiments; language that provides a framework within which questions become relevant and leads us from assumptions to conclusions.

But what kind of language or theory is necessary? If one or two steps is all that is required to make connections between assumptions and conclusions, little mathematics is needed. However, if what is required is a long chain of reasoning with a quantitative dependence on parameters, mathematics, while possibly not required, helps. (It is important to distinguish such mathematical structures from computer simulations, where connections between assumptions and conclusions are often lost in mountains of printouts.) In this respect experiments that are theory driven may be regarded as extensions of hypothesis driven experiments in situations in which the path between hypothesis and experiment is too long or too complex to be followed without a mathematical structure. Examples of such theory driven experiments will be given later in this book.

A "correct" theory is not necessarily a good or a useful theory. It is presumably correct to say that the brain, is one consequence of the Schrödinger

*Private Communication

equation (the basic equation of quantum physics) applied to some very large number of electrons and nuclei. In analyzing a system as complicated as the brain, we must avoid the trap of trying to include everything too soon. Theories involving vast numbers of neurons in all their complexity can lead to systems of equations that defy analysis. Their fault is not that what they contain is incorrect, but that they contain too much. A theory that predicts everything predicts nothing.

The usefulness of a theoretical framework lies in its concreteness and in the precision with which questions can be formulated. The more precise the questions, the easier it is to compare theoretical consequences with experience. An approach that has been successful is to find the minimum number of assumptions that imply as logical consequences the qualitative features of the system that we are trying to describe. If we pose the question this way, it means that we agree to simplify. As Albert Einstein once said, "Make things as simple as possible, but no simpler." Once the major qualitative features are understood, complexity can be added as indicated by experiment.

The task, then, is first to limit the domain of our investigation, to introduce a set of assumptions concrete enough to give consequences that can be compared with observation. We must be able to see our way from assumptions to conclusions. The next step is experimental: to assess the validity of the underlying assumptions, if possible, and test their predicted consequences.

In the work that follows, we present the Bienenstock, Cooper and Munro (BCM) theory of synaptic plasticity. The theory is sufficiently concrete so that it can be and, as is discussed below, has been compared with experiment. The theory has suggested experiments that have uncovered new phenomena such as Long Term Depression (LTD), bi-directional synaptic modification dependent on the depolarization of the post-synaptic cell and the sliding modification threshold. These are in agreement with BCM synaptic modification function and provide experimental verification of the postulates of the BCM theory. Theory has suggested experiments to test various subtle and counter-intuitive consequences such as the noise dependence of the loss of response of the closed eye in monocular deprivation and has clarified connections between seemingly unrelated observations in different brain regions such as LTD and Long Term Potentiation (LTP) in hippocampus to reverse suture results in visual cortex. In addition, as is shown in Chapter 3 (Objective Function Formulation), there is a connection between the BCM unsupervised learning algorithm and the statistical method of projection pursuit – a procedure that seeks interesting projections in high dimensional spaces of data points. This suggests the possibility that the biological neuron has evolved in such a way as to perform a sophisticated statistical procedure.

The BCM theory should be regarded as a phenomenological theory in the sense that its basic variables and assumptions are expected to be defined and refined when it becomes possible to construct them from underlying cellular and molecular mechanisms. (This is analogous to the ideal gas equation PV=nRT with its variables defined from underlying kinetic theory or statistical mechanics and the equation itself modified for real gases by additions such as the van der Waals forces and the sizes of real molecules.)

Most of the connections between the BCM theory and experiments that we discuss in this book require complex simulations. A special feature of this work is the accompanying software package (built by one of our authors, Brian Blais) that will allow the reader to repeat these simulations varying both parameters and assumptions, with many different learning algorithms. Thus through mathematical analysis as well as the ability to repeat and change the simulations, we hope readers will be able to obtain hands-on knowledge of the structure of this theory and the connections between assumptions and consequences as well as the possibility of creating variations of their own.