Chapter XXXII
Investigating the Collective Behavior of Neural Networks:
A Review of Signal Processing Approaches

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ABSTRACT

In this chapter, authors review main methods, approaches, and models for the analysis of neuronal network data. In particular, the analysis concerns data from neurons cultivated on Micro Electrode Arrays (MEA), a technology that allows the analysis of a large ensemble of cells for long period recordings. The goal is to introduce the reader to the MEA technology and its significance in both theoretical and practical aspects of neurophysiology. The chapter analyzes two different approaches to the MEA data analysis: the statistical methods, mainly addressed to the network activity description, and the system theory methods, more dedicated to the network modeling. Finally, authors present two original methods, introduced by their selves. The first method involves innovative techniques in order to globally quantify the degree of synchronization and inter-dependence on the entire neural network. The second method is a new geometrical transformation, performing very fast whole-network analysis; this method is useful for singling out collective-network behaviours with a low-cost computational effort. The chapter provides an overview of methods dedicated to the quantitative analysis of neural network activity measured through MEA technology. Until now many efforts were devoted to biological aspects of this problem without taking in to account the computational and methodological signal processing questions. This is precisely what the authors try to do with their contribution, hoping that it could be a starting point in an interdisciplinary cooperative research approach.

INTRODUCTION

In last years Neuroscience has been greatly enriched by engineering techniques and methods, and this scientific exchange supports specific applications of micro- or nano-technology in neurobiology and molecular biology. This new high-technological approach is called "Neuroengineering". Engineering contribution is not simply restricted to instrumentation, but it also supplies various approaches to analyze neuronal activity, studying mathematical models and computer aided simulation of neurobiological phenomena present in "in vitro" and "in vivo" cultivations.

The widespread instrumentation is the, so-called, Micro Electrode Array (MEA) technology complementing traditional electrophysiological techniques in neuroscience research (e.g., how the brain stores and process information), prosthesis development (using living neurons as components of an integrated circuit or directly connecting a computer to them), and bio-analytics and information technology. MEA technology is very helpful to understand the dynamics of a functioning neuronal network, because it allows understanding of which different processes or components are acting together at the same time, going beyond the traditional single-neuron approach.

Engineering contribution is not however restricted to instrumentation design, and the related utilization, but it supplies advanced approaches for the neuronal activity investigation; among others, we recall data recording and elaboration, mathematical modelling and computer aided simulations of neurobiological phenomena, with virtual simulations of the behavior of a single neuron and cluster of neurons both "in vitro" and "in vivo" cultivations.

At this aim, neuroengineering gives extremely valid tools to get all information coming from neurons in an extremely wide scale, from system behavior down to single neuron. MEA data can be elaborated with custom methods of signal processing and pattern recognition or machine learning.

Specific and very promising long-term applications of MEA technologies are chemicals and pharmaceuticals set-ups, where new drugs are tested on "in vitro" neuron ensemble. At this aim, a tool able to implement a method for the evaluation of neuronal network behavior, as a consequence of different stimuli, would be is very useful by making such tests smarter and cheaper.

MEA instrumentation, summing up, complements traditional electrophysiological techniques for:

- Fundamental neuroscience research
- in-vitro drug assays
- Bio-analytics (biosensors)
- Prosthesis development
- Information technology

and allows:

- Long-term cultures
- Multi-site extra-cellular recordings/stimulations
- Combination with micro-fluidic systems and bio-patterning techniques

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