ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol Exp 2005, 65: 421-423

The need of neuroinformatic approach in functional neurophysiology

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Introduction

Abstract. Despite the enormous growth in the number of facts and regularities observed in neuroscience, the current state of the field does not allow their integration in coherent theoretical frameworks. Neuroinformatics is a new research field devoted to development of neuroscience data bases together with computational models and analytical tools for sharing, integration and analysis of experimental data and the advancement of theories of nervous system function. From 1996 the OECD countries promote fostering neuroinformatics by eliminating the barriers that prevent cooperation and by providing incentives to potential participants. This activity was formulated in the Report on Neuroinformatics from The Global Science Forum Neuroinformatics Working Group of the OECD (2002) as well as in several printed publications by the Neuroinformatics group (Amari et al. 2002, Eckersley et al. 2003). This article summarizes the ideas presented in the Report and stresses the importance of analytical and modeling approach to functional neurophysiology.

Key words: neuroinformatics, analytical methods for electrophysiological data, theoretical models

Human brain contains roughly 10^{11} nerve cells, and about 10^{14} connecting synapses forming an extremely complex and dynamic network. In order to understand its functional properties, we must bridge many levels of description from molecule, cell and synapse to perception, cognition and behavior. The nervous system contains circuits which solve specific tasks–whether detecting particular features in the environment, coordinating a group of muscles to produce a given type of movement, or storing different types of information. Some of these circuits mature as the nervous system develops, and become modified by experience – learning. The sensory, mental, and behavioral repertoire of each individual, whether mouse or man, is represented in the nervous system by the total number of neural circuits available at any given instant, and their potential for interaction.

Over the last century, neuroscience has matured as an empirical science. Facts about different aspects of the vast area of neuroscience accumulate at an increasing pace, but the insights gained about the actual principles underlying the operation of the nervous system have accumulated much more slowly. One reason for this is that a great number of parallel, dynamic and interactive processes occur at the single nerve cell level, as well as on the circuit and systems' level. The sum of these processes will result in some fragment of behavior. It is therefore difficult, often impossible, to deduce intuitively the net result of the different observations made experimentally. This problem is presently a central challenge of neuroscience and might be solved only when efficient methods of dissemination of experimental results and their integration into coherent theoretical frameworks will be elaborated.

Neuroinformatics is a new research field devoted to development of neuroscience data and knowledge bases together with computational models and analytical tools for the sharing, integration and analysis of experimental data and the advancement of theories of nervous system function. Neuroinformatics research is uniquely placed at the intersections of medical and behavioral sciences, biology, physical and mathematical sciences, computer science, and engineering. There is a strong synergy in these interactions, including a positive feedback loop from the interactions between informatics and neuroscience. This synergy can lead to a rapid acceleration of scientific and technological progress, which in turn will have major medical, social, and economic impacts.

The growing interest in the new field results in organization of specialized meetings, many of them on the occasion of conferences devoted to basic research areas. Papers presented in this issue of ANE contain a selection of lectures delivered on the Neuroinformatic Workshop held in Toruń (Poland), on September 15th, 2005, a satellite event to the International Conference on Artificial Neural Networks (ICANN 2005). The Workshop was focused on understanding dynamics in neuronal systems. It gathered presentations on new analytical methods for electrophysiological data recorded from non-anaesthetized animals and human subjects, theoretical models of network functions and internet tools supporting international cooperation in the area of neuroinformatics.

The field potentials, whether recorded locally from the brain (LFP), intracranially (ECoG) or from the skull (EEG) are commonly used for the analysis of the brain functioning. In fact, the EEG analysis might be a more efficient approach for understanding the information processing in neural network than elaboration of spike activity of single neurons. First, the field potential consist of on-line activation of many cells averaged at a given moment of the dynamic brain state in contrary to post-stimulus histograms obtained by summing spikes from unitary responses in many trials over a longer time period, possibly during different functional states of the nervous network. Second, stable field potentials can be monitored by means of gross chronic electrodes during long behavioral experiments, which is very difficult to achieve with the precise requirements needed for single neuron recordings (Munk et al. 1996, Wróbel et al. 1998). Since more than a century a pivotal problem, however, remains: how to decompose the complex field signals into underlying active components of known cell populations.

This problem has been addressed by Jakuczun and coauthors (2005) in the study presented in this issue of ANE. These authors studied the way in which information is processed in local neural networks of rat's barrel cortex. They used a new method of local classifiers for reliable and meaningful classification of single evoked potentials (EP) and consequently showed that the resulting classes may be attributed to different functional states of the cortical column. Similarly, Matysiak and coauthors (2005) developed a hybrid method for localization of oscillatory EEG activity. It consists of two steps: multichannel matching pursuit with complex Gabor dictionary, and LORETA inverse solution. Again, the proposed algorithm was successfully applied to the localization of epileptogenic sources in ECoG. These new methods incorporate into a growing wave of neuroinformatic tools for understanding the complex nature of field potentials.

It is widely agreed that analysis of multichannel data may give a better insight into the dynamics of activated neuronal network. However, it may be challenging to extract the desired information from such datasets. Multichannel datasets require adequate handling in order to get proper results. For instance, the popular mapping technique uses values calculated for each channel separately, neglecting inter-dependencies between signals which may lead to misinterpretation of the results. Kamiński and coauthors (2005) discuss basic aspects of multichannel data processing. They show how the autoregressive model of directed transfer function (DTF) can be used to evaluate the dynamics of transmissions in EEG during motor activity. Indeed, in the preliminary results this group has already found general systematic patterns of ECoG signal transmissions accompanying the muscle contraction of a fist or tongue. One particular advantage of the proposed algorithm is the fact that it may be fitted to short data segments, much shorter than the length required for Fourier analysis.

The paper by Rychwalska and coauthors (2005) proposes theoretical novelty measures in artificial neural networks that enable the net to dynamically control its information processing. These measures could be applied early in the recognition process and therefore they would allow for fast and reliable novelty check. Moreover, both are robust and work even for very overloaded networks. Though the physiological interpretation of the proposed measures is currently not possible, the model formulates some new hypotheses which might be applicable to experimental findings. For example, it provides a possible explanation for observation that distinguishing between novel/familiar stimuli is faster than recognition itself (Skarda and Freeman, 1987).

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Received 30 September 2005, accepted 31 October 2005.