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Editorial

Analysis and modeling of massively parallel neural signals—2010 Special Issue

1. Introduction

Uncovering how the brain processes information requires large-scale observations of neuronal activity. Recent progresses in experimental techniques provide novel methods to achieve massively parallel recordings of neuronal activity. For instance, multi-channel electrodes and fluorescent molecular sensors are now commonly used to simultaneously record the spiking activity of hundreds or thousands of neurons and to monitor intracellular signaling molecules, such as calcium, cAMP, and a variety of enzymes, with high spatiotemporal resolution.

With the unprecedented rate at which data are being collected and electronically archived today, efficient extraction of information and insight from this flood of data becomes an increasing technical and scientific challenge. This process requires the application of high-level data mining methods including parallel and distributed strategies, finding associations and sequences, visualization by clustering, classification, and graph theory.

While mathematical models and computer simulations have played essential roles in analyzing neuronal recordings, the flood of highly detailed data generated by these advanced techniques prompt us to develop new modeling strategies for formulating and validating new hypotheses and quantitative models in a data-driven manner. The assessment of large-scale neural network simulations poses the same challenge as experimental data does.

This special issue has thus focused on the following topics: (a) Mathematical methods for analyzing data from massively parallel neural recordings and large-scale neural network simulations; (b) Frameworks for constructing quantitative or conceptual models from large-scale observations of neural activity, morphology, and development; (c) Novel neuroscientific perspectives gained by these methods.

2. Papers in this special issue

As described above, this special issue is intended to survey the state of the art in the young and dynamic field of parallel and distributed data mining and large-scale model building and simulations. Now effort has to be made on a multidisciplinary project in which neuroscientists, physicists, mathematicians, and computer scientists work together to arrive at a unifying picture of the complex networks of the brain. Below, each paper contained in the special issue is briefly explained.

To know how a single neuron embedded in a neural network behaves is a key to understand functions of neuronal networks. Targeted patch-clamp recordings are a promising technique to directly address the physiological properties of such a neuron. Ishikawa et al. introduce a novel method to target not only neurons but also their neurites without suffering from chromatic aberration or mechanical complication in optics. The novel technique will be wildly available for pipette micromanipulation under online visual control.

Recording large-scale neuronal data *in vivo* is an expanding field and requires many technically challenging analysis tools. Traditionally used analysis methods, however, do not account for the data properties inherent in multi-electrode recordings. For instance, data are often not best modeled by normal distribution and the variables of interest may not be linearly related. Reed et al. reviewed expansions of the Generalized Linear Model designed to address such data properties and tested some methods on data from 100-electrode arrays implanted in the somatosensory cortex of owl monkeys.

Despite the fact that multichannel acquisition from neuronal networks, either *in vivo* or *in vitro*, is becoming a standard in modern neuroscience, researchers often find it difficult to manage the huge quantity of data routinely recorded during the experimental sessions. Chiappalone et al. reviewed their open-source toolbox called "SPYCODE", which provides a rich repertoire of algorithms for multichannel data processing with the capability of autonomously repeating the same set of computational operations on a huge data set.

Synchronized neural activity is ubiquitous in normal or pathological states of the brain. Li et al. proposed a novel method to estimate genuine and random synchronization indexes in multivariate neural signals by means of the correlation matrix analysis and surrogate technique. The authors demonstrated how the proposed method was successfully applied to the analysis of 21-channel scalp electroencephalographic recordings of a patient suffering from medial temporal lobe epilepsy.

An analysis of higher-order synchronization in massively parallel data is of great importance in understanding computational processes in the cortex. Gruen et al. devised an efficient method to reliably extract the size and temporal precision of groups of synchronously firing neurons in the presence of strong rate covariations. The authors introduced population measures to overcome the combinatorial explosion of different spike patterns taking place as the number of neurons increases.

Information theory is a powerful tool to find out a relationship between uncertain phenomena and observations. Ince et al. reviewed an information-theoretic approach to population coding, which is the quantitative study of algorithms or representations used by the brain for evaluating the messages from different

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neurons. They discussed the methods to compute the information carried by neural populations and to reduce the limited sampling bias. The focus of their formalism is to quantify the contribution of individual neurons to the information encoded by the whole population, and the formalism was applied to numerically simulated and experimentally recorded multiple spike trains.

Recent advances in multi-electrode recording and imaging techniques have made it possible to observe the activity of large populations of neurons. To achieve the full potential of these techniques, Hofer et al. derived an algorithm for optimizing population decoding with distance metrics, in which responses evoked by the same stimulus should be ‘close’ to each other and responses evoked by different stimuli should be ‘far’ from each other. The authors demonstrated the utility of their algorithm under experimental conditions by decoding both population spike trains and calcium signals with different correlation structures.

Aiming at applications to real-time prosthetic controls engineering, Kaneko et al. studied the abilities of two vectorizing procedures (multineuronal and time-segmental) to extract information from spike trains during the same total neuron-seconds. They found that the multineuronal vectorizing method extracts more information from neuronal signals than the time-segmental vectorizing method as the dimensions of the response vector increase.

Chronically implanted arrays of microelectrodes provide a popular method to record activities of an enormous number, typically more than 100, of neurons from behaving animals. However, it is difficult to visualize activity patterns across many neurons to gain an insight into their implications in functions such as perceptual categorization. Matsumoto et al. used a variational Bayes algorithm to simultaneously perform clustering and dimension reduction of multineuronal activity.

The brain often displays rhythmic activity of various frequencies during sleep or cognitive tasks. Phase response curves characterize the response properties of oscillatory neurons and are computationally useful for studying the synchronization dynamics of neuronal networks. Nakae et al. proposed a novel Bayesian method for estimating phase response curves from noisy experimental data. The method solved common weak points of previous methods for a similar purpose. The authors tested the validity of the new method on data recorded from the pyramidal cells in rat motor cortex.

Cortical neurons in vivo typically show irregular spike firing, presumably reflecting a stochastic nature of synaptic inputs. Shinomoto proposed a multi-timescale adaptive threshold model of neuronal spiking that is capable of accurately predicting spike times of various biological neurons for given fluctuating input current. He showed plausible computational methods to find parameter values that achieve an optimal coincidence of spike times between the model and experimental data.

Classification of 2-dimensional array patterns is an important category of analysis of experimental data or engineering applications of neural networks. Chen et al. used an assembly of many small neural networks for such a classification to reduce the training complexity. They verified their network model by experiments involving gender classification and human face recognition, and proved that the assembly of small networks gives better performance than a single large neural network in highly noisy environment.

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