Special Session on Information Theory and Neuroscience At ISIT 2011

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***Abstract*—This represents a special session on information theory and neuroscience at ISIT 2011.**

I. INTRODUCTION

Recently, there has been an increased interest in the intersection in information theory and neuroscience, as evidenced by

- a special issue on Information Theory in Molecular Biology and Neuroscience, *IEEE Transactions on Information Theory*, February 2010
- a special issue on Methods of Information Theory in Neuroscience Research, *Journal of Computational Neuroscience*, February 2011
- 5 years of special sessions on "Methods of Information Theory in Computational Neuroscience" at the *Computational Neuroscience Annual Meeting (CNS)*

This fact, along with *CNS* and *ISIT* taking place one after another, in Stockholm, Sweden and St. Petersburg, Russia, has led to the *ISIT* workshop holding a special session pertaining to neuroscience in information theory. Each researcher in computational/experimental neuroscience will give an overview of their work and will speak to the potential synergies with information theory. The hope is that intrigued researchers on both sides of the disciplines might be able to use the same trip to Europe to attend both conferences and further identify the interplay between both.

II. PRESENTATION ABSTRACTS

A. Dendritic Decoding of Visual Stimuli Encoded with Hodgkin-Huxley Neurons

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We investigate architectures for time encoding and time decoding of visual stimuli such as natural and synthetic video streams (movies, animation). The architecture for time encoding is akin to models of the early visual system. It consists of a bank of filters in cascade with single-input multi-output neural circuits. Neuron firing is either based on a threshold-and-fire or an integrate-and-fire spiking mechanism with feedback. We show that analog information is represented by the neural circuits as projections on a set of bandlimited functions determined by the spike sequence. Under Nyquist-type and frame conditions, the encoded signal can be recovered from these projections with arbitrary precision. For the video time encoding machine architecture, we demonstrate that bandlimited video streams of finite energy can be faithfully recovered from the spike trains and provide a stable algorithm for perfect recovery. The key condition for recovery calls for the number of neurons in the population to be above a threshold value. Although the encoding mechanism can be efficiently implemented with neural circuits, the reconstruction algorithms call for the pseudo-inversion of a large scale matrix. Several real-time reconstruction algorithms have been demonstrated in the past. We shall present a solution to the reconstruction of time encoded signals using only neural hardware components. Finally, we extend the above results to neural encoding circuits built with Hodgkin-Huxley neurons.

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B. Understanding How Information is Conveyed in Dynamic Interacting Networks of Neural Activity

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We develop a generalization to Granger's notion of causality to infer the statistical dynamics underlying interacting neural circuits. Our approach is inspired from an information-theoretic sequential prediction methodology. Under the log loss, we demonstrate that this mathematization is precisely the causally conditioned directed information. We develop an estimation approach and demonstrate how the network causal dynamics represent information processing in the brain. In the primary visual cortex of an awake-behaving monkey, we analyze simultaneous spiking and field potential recordings and demonstrate a consistent change in causal interactions between cells depending upon the type of stimulus displayed. In primary motor cortex of an awake behaving monkey, our procedure identifies strong structure in the estimated causal relationships, the directionality and speed of which is consistent with predictions made from the wave propagation of simultaneously recorded local field potentials. We conclude with a discussion of new mathematical techniques going beyond the lens of causality that might be useful to elucidate the network dynamical aspects of brain function.

C. Information coding by recurrently connected networks

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Neurons code variety of perceptual and motor signals by their activity. The accuracy of information representation is subject to specific network connectivity. In this talk, using quantitative measures developed in information theory and statistics, I characterize how parameters of synaptic connections influence the accuracy of information coding. More specifically, simple analytical expressions of signal-to-noise ratio are derived to demonstrate the following: (1) With dynamical interactions between neurons, spike timing could add to spike counts significantly more information about static stimulus (2) Network connectivity and the resulting background activity of neurons determine neural responses to static and dynamic stimuli. In particular, when randomly connected networks are operating near the edge of chaos, external input can be more efficiently amplified and buffered with chaotic than non-chaotic background activity.

D. Estimating source space cross-frequency coupling from MEG event-related data -– a cross-term deprived covariance (CTDC) approach

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Synchronization of activity between distinct cortical regions underlies the mechanism of functional integration that forms a foundation of all our actions. Recently, the role of non-linear interactions manifested in cross-frequency(across scale) synchronization has been emphasized as facilitating the exchange of information between cell assemblies. Such synchronization has been found in many experimental paradigms and is currently under active study. Unfortunately spatially and temporally precise analysis available only in a limited number of cases corresponding to neurological patients with implanted cortical grids. In order to provide the flexibility in experimental designs and allow for more specific studies, tools for analysis of such non-linear synchronizations are to be developed. Instrumentally, MEG is a unique technology that allows for mapping of cortical activations and provides high temporal resolution. The use of beamformers supported by sufficiently accurate forward models allows for reasonable (0.5 cm) spatial resolution. The time frequency representation of MEG signals is natural and captures the nature of MEG observed cortical activity as consisting of short time narrow-band bursts.

In this work our goal was to combine the above and develop a signal processing method for identification of the cortical spatial structure of cross-frequency coupling between the oscillations in the two non-overlapping time-frequency windows. Our method is a statistical test contrasting the results of adaptive beamformer based inverse mapping obtained using the original and cross-term deprived time-frequency domain data covariance matrices by calculating the ratio of the two inverse values. We use multiple comparison corrected randomization statistical tests for identification of significant source space coupling.

Application of the method to an event-related MEG dataset from a single subject (imagined hand rotation) yielded plausible results with interacting pairs falling into physiologically plausible cortical sites. We observed beta-gamma coupling between frontal and parietal-occipital regions, consistent with published signal space analysis. We also observed beta-gamma prefrontal/frontal and alpha-gamma temporal/frontal couplings.