

# **Workshop on Innovation in Computational Approaches for Brain-Machine Interfaces IJCNN 2007 Orlando, Florida**

## **Organizers:**

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## **Session 1: New signal processing methodologies to electrophysiological data collection and preprocessing of spikes, LFP, ECoG, EEG, and EMG.**

**8:30-9:30 Introduction Sanchez/Principe**

**9:30-10:30 Emery Brown,**

### **Signal processing algorithms to decipher brain function**

Neural systems encode representations of biological signals in the firing patterns of their electrical activity, termed spike trains. The advent in the last 10 years of the capability to record with multiple electrode arrays the simultaneous spiking activity of many neurons (>100) has made it possible to study information encoding by ensembles rather than by simply single neurons. In particular, it makes it possible to study how groups of neurons act in concert to define the function of a given brain region. Spike trains are point process time-series and their codes are both dynamic and stochastic. Even though the signal is often continuous, its representation in the nervous systems is as a high-dimensional point process time-series. Because neural spike trains are point processes, standard signal processing techniques for continuous-valued data will have limited utility in the analysis of neural systems. Therefore, accurate analysis of neural signals requires the development of quantitative techniques to characterize correctly the point process nature of neural encoding. In this presentation, we discuss the application of the state-space paradigm in neural spike train signal processing. We use the Bayes' rule, Chapman-Kolmogorov equations to derive algorithms useful for neural spike train decoding, dynamic analysis of neural encoding (neural plasticity) and adaptive-decoding. We show how this approach leads to a natural definition of signal-to-noise ratio for a point process representation of a neural system. We illustrate the methods in three examples: Decoding position from the ensemble activity hippocampal pyramidal neurons and tracking the temporal evolution in hippocampal place receptive fields, and decoding motor cortex representations of movement velocity.

**10:30-11:30 Dong Song**

### **Multiple-Input Multiple-Output Nonlinear Dynamic Modeling of Spike Train Transformations for Hippocampal-Cortical Prostheses**

**\*Dong Song**, Rosa H. M. Chan, Vasilis Z. Marmarelis, Robert E. Hampson, Sam A. Deadwyler, Theodore W. Berger

One of the fundamental principles of cortical brain regions, including the hippocampus, is that information is represented in the ensemble firing of populations of neurons, i.e., spatio-temporal patterns of electrophysiological activity. The hippocampus has long been known to be responsible for the formation of declarative, or fact-based, memories. Damage to the hippocampus disrupts the propagation of spatio-temporal patterns of activity through hippocampal internal circuitry, resulting in a severe anterograde amnesia. Developing a neural prosthesis for the damaged hippocampus requires restoring this multiple-input, multiple-output transformation of spatio-temporal patterns of activity. Because the mechanisms underlying synaptic transmission and generation of electrical activity in neurons are inherently nonlinear, any such prosthesis must be based on a nonlinear multiple-input, multiple-output model. In this paper, we have formulated the transformational process of multi-site propagation of spike activity between two subregions of the hippocampus (CA3 and CA1) as the identification of a multiple-input, multiple-output (MIMO) system, and proposed that it can be decomposed into a series of multiple-input, single-output (MISO) systems. Each MISO system is modeled as a physiologically plausible structure that consists of (1) linear/nonlinear feedforward Volterra kernels modeling synaptic transmission and dendritic integration, (2) a linear feedback Volterra kernel modeling spike-triggered after-potentials, (3) a threshold for spike generation, (4) a summation process for somatic integration, and (5) a noise term representing intrinsic neuronal noise and the contributions of unobserved inputs. Input and output spike trains were recorded from hippocampal CA3 and CA1 regions of rats performing a spatial delayed-nonmatch-to-sample memory task that requires normal hippocampal function. Kernels were expanded with Laguerre basis functions and estimated using a maximum-likelihood method. Complexity of the feedforward kernel was progressively increased using a statistical model selection method to capture higher-order system nonlinear dynamics. Results showed higher prediction accuracies as kernel complexity increased. Self-kernels describe the nonlinearities within each input. Cross-kernels capture the nonlinear interaction between inputs. Second and third order nonlinear models were found to successfully predict the CA1 output spike distribution based on CA3 input spike trains. First order, linear models were shown to be insufficient.

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**11:30-12:30 Kevin Otto**

### **Where should I stimulate and what about the reactive tissue response?**

It is likely that the quality of the device-tissue interface will affect the amount of information available via chronically implanted neural prostheses. Previously, we have used lumped-circuit element models fit to impedance spectroscopy data in order to estimate several of the parameters of the device-tissue interface. Further, we have utilized brief DC voltage pulses to affect these parameters for a period on the order of hours. Here we extend these previous studies by exploring the relationship between the device-tissue interface parameters, the signal-to-noise ratio of electrophysiological recordings and the behavioral threshold for cortical microstimulation of the auditory cortex. We chronically implanted multi-channel silicon microelectrode arrays into the primary auditory cortex of Long-Evans rats. Utilizing cyclic voltammetry and impedance

spectroscopy as well as electrophysiology we quantified both the quality of the electrode-tissue interface and the physiologic location of the stimulation. We subsequently measured the cortical microstimulation behavioral thresholds and evaluated these data with-respect-to the interfacial quality data and location within cortex.

## **12:30-2:30 – Break/Lunch/Posters/Student Demos**

### **Session 2: Challenges in modeling for Brain-Machine Interfaces.**

**2:30-3:30 Paul Sajda**

#### **Spatio-temporal linear filters for decoding brain state: Application to performance augmentation in high-throughput tasks**

The conventional goal for a brain-computer interface has been to restore, for paralyzed individuals, a seamless interaction with the world. The shared vision in BCI research is that one-day patients will control a prosthetic device with signals originating directly from their brain. The topic addressed in this talk provides a new perspective on BCI, by asking instead "how can BCI be used to assist neurologically healthy individuals in specific demanding tasks?"

The limited signal-to-noise ratio (SNR) of non-invasive brain signals suggests that one must tailor the application of BCI to tasks where a small increment in information can make a large difference. High throughput tasks may provide such a scenario, as will be exemplified in this review for one such task: rapid visual target detection. BCI can assist in this task by prioritizing perceived target images.

Due to the speeded nature of this and relate tasks, it is essential to use fast and effective signal processing. Effective performance is achieved by extracting spatio-temporal discriminant brain activity in high dimensions (typically  $\geq 64$  electrodes distributed across the skull surface, with sampling rates of 1000Hz). Fast processing speed is achieved by constraining the methods to linear analysis of these data. In fact, considering the low SNR of scalp electroencephalography (scalp EEG) even linear features require careful regularization. This talk summarizes linear spatio-temporal signal analysis methods that derive their power from careful consideration of spatial and temporal features of skull surface potentials.

**3:30-4:30 Jennie Si**

#### **Asynchronous control for Brain-Machine Interfaces**

Jennie Si, Byron Olson, James Dankert

Direct brain machine interfaces have developed from humble beginnings into impressive laboratory systems capable of generating elaborate robotic movements. However useful systems will require not only the ability to create such outputs, but also retain command and control between active use and non-use. Such asynchronous systems are being actively developed at ASU. In the current discrete directional control system neural firing patterns are continuously

discriminated into one of four classes (Left, Right, Start, and Idle) using a support vector machine (SVM). Neural signals classified as task related are output to real-world devices. Such a system is functional but, results can be improved when the transitions between states were filtered using a state transition model. This hybrid method combines evidence from the SVM model predictions and the probability of a state transition from the current to the next. Other methods for asynchronous brain machine interfaces will also be examined.

**4:30-5:30 Sung-Phil Kim**

**Cortical Control of a 2D Cursor by a Human with Tetraplegia using a Direct Intracortical Neural Interface System**

S. P. Kim, J. D. Simeral, L. R. Hochberg, J. P. Donoghue, M. J. Black

A neural interface system (NIS) directly connecting intracortical activity to external actuators aims to restore the lost function to humans with paralysis. Initial evidence from an ongoing pilot study (Hochberg et al., 2006) demonstrated that a person with tetraplegia could volitionally control a 2D computer cursor using motor cortical signals. However, improvement upon the quality of cursor control from this study was desired to obtain more stable cursor movement, the ability to hold a cursor and the ability to click on the area of interest. To develop an NIS satisfying these requirements, we addressed the following issues: 1) representation of cursor kinematics that is most represented in the neural population; 2) the choice of decoding algorithm; 3) design of a training paradigm for both the decoding algorithm and a human with the absence of true movement; 4) real-time decoding of both continuous and discrete movement states from a single neural population for point-and-click. We designed an NIS in which the *Kalman filtering* algorithm was used to decode continuous cursor *velocity* and combined with a *linear classifier* for decoding discrete states (i.e. movement versus click). Also, new paradigms for *training* these algorithms and the participant were developed. Here we demonstrate the initial results from multiple recording sessions where a human with tetraplegia was able to achieve more precise cursor control for point-and-click using this NIS. Quantitative metrics that have been defined in human computer interaction (HCI) were leveraged to assess neural cursor control performance.

**5:30 Summary Sanchez/Principe**