Computational Intelligence for Decoding Brain's Motor Cortical Functions

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The goal of the proposed tutorial:

- Introduction of the brain decoding problem especially for motor cortical functions using a rat model
- Introduction of extracellular electrophysiology technique and the need for computational intelligence algorithms for neural information processing
- Introduction of challenges and opportunities for computational intelligence approaches to decoding neural signals in relations to behavior

This tutorial is intended for a period of 2 hours.

Tutorial significance:

On April 2, 2013, President Obama announced the BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies). The Initiative aims to accelerate the invention of new technologies that help researchers to map the brain by providing vivid pictures of complex neural circuits and the rapidly firing neuron cells. The ultimate goal is to understand how brain functions in relation to behavior, learning, as well as means to concur brain diseases.

Once large sets of neural activity data become available, there is going to be a great demand for computationally intelligent algorithms to decipher the data. With the possibility of analyzing neural data at ultra-high spatiotemporal resolution (single neuron resolution, at millisecond time scale), major progress toward understanding the brain will become a reality. New ways to treat and prevent brain disorders will then become possible. The outcome from analyzing neural events in relation to behavior will certainly fill major gaps in our current knowledge. The computational tools are critical for researchers to explore exactly how the brain enables the human to perceive, decide and act.

Background

A neuron is considered the basic computing unit in the brain. The sequence of ones and zeros respectively corresponding to firing or not firing of a neuron is used by spiking neurons to communicate and to compute. The sequence is believed to represent a compact code. However, this code has not yet been cracked. In recent years, it has become possible to measure *in vivo* sequences of neural spikes using advanced multichannel single unit recording technologies. The decoding problem discussed in this tutorial aims at discovering detailed neural mechanisms of the frontal cortical brain function. To make the problem tractable, I will use a rat model to elucidate how cortical neural activities in the rat's motor cortical areas lead to conscious, goal-directed action. It is important to realize that a good understanding of the experimental procedure and the neurophysiological background is necessary when any computational approaches are tested on the large scale, convoluted, and often noise-corrupted neural signals.

The overall objective for neural decoding is to discover how interacting neurons give rise to meaningful behavior, which is an ultimate challenge to experimental and computational neuroscientists. This tutorial will focus on using multi-channel simultaneous single unit recordings from rat's frontal areas to carry out the discussion. The tutorial will review a number of analytical and computational techniques that have been used in the neural computation community, and then introduce more advanced techniques that can provide additional insight that simple coding techniques fail to provide.

Outline of the proposed tutorial

- Introduction to the frontal cortical functions using a rat model, the frontal cortex, especially the primary and secondary motor cortices

- Introduction to chronic, multi-channel, single unit neural recording using behaving animals
    - Behavioral experiment considerations
    - Neural recording setup
    - Neural signal pre-processing – spike sorting

- Statistical approaches to analyzing neural activities
    - PETHs (peristimulus time histograms)
    - Significance testing
    - Detection theory and applications of ROC in neural computation

- Spatiotemporal neural computation
    - Rate based computation
    - Neural synchrony and timing based computation
    - Spatiotemporal based computation, functional connectivity model, generalized linear model, etc.

- Opportunities and challenges of deciphering the neural code

In the talk, I'll discuss findings based on the single unit recordings from rat's frontal areas, or specifically medial and lateral agranular areas of rats, while they perform an action selection task. In the task the rat is required to follow "traffic lights" to move a robot platform accordingly. Similar to our everyday driving experience, left arrow indicates a left turn and right arrow a right turn. I will discuss the neural activities recorded from the rat's cortical regions, how we have developed and utilized analytical techniques to uncover the basic computations taking place in a cortical neural network at different time scales. Hopefully the findings provide interesting neural substrate to rat's executive control behavior. During the discussion of the experiment, I'll cover results entailing both high level statistical snapshots of the neural data and more detailed dynamic modeling. The goal for performing the analyses is aiming at providing mechanistic account of how brains generate meaningful behaviors under our designed experimental condition using biologically plausible computational models.

Presenter Bio:

Dr. Jennie Si received her B.S. and M.S. degrees from Tsinghua University, Beijing, China, and her Ph.D. from the University of Notre Dame. She has been on the faculty in the Department of Electrical Engineering at Arizona State University since 1991. Dr. Si's research focuses on dynamic optimization or specifically approximate dynamic programming approaches to optimal control. She started learning electrophysiology a couple years ago to conduct animal behavioral and neural experiments. She is interested in discovering the fundamental neural representations in the frontal cortical area in relation to conscious, goal-directed behavior. Dr. Si received the NSF/White House Presidential Faculty Fellow Award in 1995, and Motorola Engineering Excellence Award the same year. She has been listed in several Marquis Who's Who publications. She is a Fellow of the IEEE. She is past Associate Editor of the *IEEE Trans. on Semiconductor Manufacturing*; *IEEE Trans. on Automatic Control*, and *IEEE Trans. on Neural Networks*. She is current Action Editor of *Neural Networks*, a publication of the International Neural Networks Society. Professor Si has served on several professional organizations' executive boards and international conference committees. She was the general chair of the 2007 International Joint Conference on Neural Networks on the occasion of its 20^{th} anniversary. She was the Vice President for Education in the IEEE Computation Intelligence Society (2009-2012). Dr. Si was an advisor to the NSF Social Behavioral and Economical directory, and served on several proposal review panels. In addition to her many research and service commitments, Dr. Si consulted for Intel, Arizona Public Service, and Medtronic.