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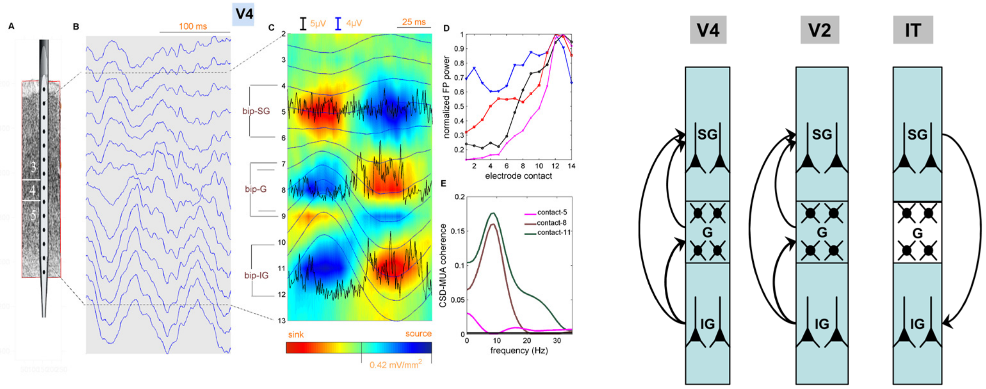
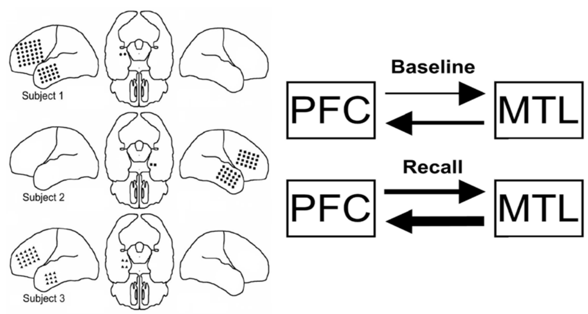
Neural engineering
Cognitive neuroscience
Signal processing
Dynamical systems and neural modeling

Our long-term research objective is to understand the neural basis of higher brain functions and their impairments by neurological and psychiatric disorders. In particular, applying quantitative engineering approaches to multimodal neural data, including single unit spike train, multiunit activity, local field potential, electroencephalogram, electrocorticogram, and fMRI data, we address fundamental questions in the dynamic organization of brain networks and its disruption in disease. A theoretical framework, which integrates human physiology, monkey physiology, and computational modeling, is formulated to interpret the findings. Some specific areas of interest are as follows.

Analyzing information flow in neuronal networks: Multi-electrode neurophysiological recording and functional brain imaging produce massive quantities of data. Multivariate time series analysis provides the foundation for analyzing the patterns of neural interactions in the data. Neural interactions, being mediated by the synaptic transmission of action potentials, are directional. Our ability to assess the directionality of neural interactions and information flow in brain networks holds the key to understanding the cooperative nature of neural computation. Research over the last few years has proven that Granger causality is a statistical technique furnishing this capability. Our lab has pioneered the application of Granger causality to neuroscience. Recently completed projects using the technique include: (1) laminar organization of alpha oscillations in primate visual cortex, (2) functional characterization of beta oscillations in a large-scale network in sensorimotor cortex, (3) top-down control of visual and somatosensory processing by the frontal-parietal attention network, and (4) memory-modulated directional interaction between frontal and medial-temporal lobes.



Network organizations of alpha oscillations in visual cortex revealed by current source density analysis (left) and Granger causality (right). Arrows represent directions of information flow.



Electrode arrays implanted over the cortex of three epilepsy patients undergoing evaluation for surgical therapy (left). Information flow patterns between prefrontal cortex (PFC) and medial temporal lobe (MTL) during recall of memory and during baseline .

Single trial analysis of event-related signals: Neural data following the onset of a stimulus is comprised of an event-related component that is relatively time-locked to stimulus onset and ongoing brain activity. These two types of signals, generated by possibly different neural mechanisms, may reflect different aspects of cognitive information processing. In collaboration with colleagues in the College of Engineering and from other institutions, we have developed methods capable of separating the two signals on a trial-by-trial basis. These methods are being used to answer questions in areas ranging from network basis of decision-making to improved target detection in cognitive brain machine interface to determination of the time course of emotional conditioning.

Cognitive brain machine interface: Brain machine interface (BMI) enables direct communication between the brain and an external device. While BMI research has been mainly focused on improving sensory-motor functions of paralyzed individuals, the same concept can be exploited to augment human cognition. Based on our recent physiological and methodological advances, a closed-loop cognitive brain machine interface (cBMI) is being designed and implemented, in which the stimulus presentation is conditioned on the occurrence of optimal brain states and the stimulus evoked response, separated from ongoing neural activity, is classified by machine learning methods.

Studies of translational relevance: New discoveries are being made constantly in basic science labs around the world. How to translate our growing knowledge into improved healthcare is a critical issue facing today's biomedical researchers. We are working with physicians and clinical scientists to address problems in the following areas: (1) effect of anticonvulsant drugs on language production and executive control of brain function, (2) disruption of cortical and subcortical network dynamics in depression and obsessive compulsive disorder, and (3) cognitive fatigue in Parkinson's disease.