

Topic 1: Autonomous task learning for Motor Brain Machine Interfaces

Brain-Machine Interfaces (BMIs) are rich systems inspired by the need to restore motor function for the disabled. Micro-electrode arrays are implanted into brain tissue to record spiking activity of single neurons with a time resolution on the order of milliseconds. A decoder finds the functional mapping between neural activity and motor behavior, using signal processing and machine learning techniques, to predict, control, and command external devices. Previous experiments have demonstrated the feasibility of brain control on neuroprosthesis without actual limb action, where subjects need to adjust brain activity to learn the operation on a BMI system based on visual feedback. However, current systems are still far from being ready for routine clinical use due to the limits of the actions, extensive training, frequent recalibration, and no generalization over new tasks. The ideal BMI is supposed to accomplish complex movement tasks with fast training, high accuracy, and stability over time. More importantly, we expect BMIs to have the smart learning ability to adapt and develop new movements autonomously.

We develop a series of kernel reinforcement learning (KRL) methods implemented in Reproducing Kernel Hilbert Space (RKHS) to go beyond just performance compensation, and establish an online dialogue between the cortical activity and the prosthesis controller that allows efficient optimization and targets movement learning. We further extend KRL from merely providing BMIs with robust adaptation over time on known tasks, to enabling them to learn new tasks, by using medial prefrontal cortex (mPFC) activity as an internal critic. Our study opens the door to the design of an autonomous decoder that adapts to and executes high-level goals provided by subjects. The translational impact is to empower clinical BMI devices with learning, where the subject starts with simple training at the lab and learns how to execute complex movements through daily interactions.

Topic 2: Tracking Neural Plasticity for Motor Brain Machine Interfaces

A fundamental aspect of biological behavior is the ability to learn and adapt to the environment. The brain has developed a remarkable mechanism to achieve this ability, neuroplasticity. Brain activity changes during behavior, ranging from cellular changes to large-scale cortical remapping. How do these changes ranging from single neural spiking to the re-wiring of the connectivity among neurons, finally result in behavioral learning? As part of the overall effort to permit the brain to control neuroprosthetic devices via brain-machine interfaces (BMI), it is critical to go beyond observation, to understand, harness, and recreate the mechanisms of adaptive phenomena.

Neuroplasticity has been observed in BMI as the alteration of the preferred direction or modulation depth in cortical neurons, and as changes of the connectivity among neurons. This helps BMI subjects to better control the system over time. However, there has been no high-resolution computational description of how neuroplasticity changes, how it can be modeled, or if it can be predicted. I will introduce a series of computational approaches to model and shape the plasticity of individual neural tuning and neural population dynamics using multi-neuronal recordings both during and after task learning. This study will shed light on the essence of neuroplasticity and learning for neuroscience.