Presentations (Session E)

8:00 - 8:30 (E1) Neural correlate of rapid decisions in macaque frontal cortex
Terrence Stanford (Wake Forest School of Medicine), and Emilio Salinas

The task of returning a 130 mph tennis serve or hitting a 95 mph fastball is each exemplary of a neural computational problem that is poorly understood from a mechanistic point of view. Common to these, and likely all such rapid decisions, is the requirement to modify an initially uninformed motor plan on the basis of newly arriving perceptual information. Using a novel task, and aided by the intuition derived from a model that simulates the dynamic interaction between perceptual decision formation and motor response selection, we have examined the neural correlate of a rapid visuomotor decision within the macaque frontal eye field (FEF). Previous accounts of FEF maintain that, during saccadic choices, different neuron types perform distinct functions: visually-responsive neurons select a target among all visible objects and relay the result to the motor neurons, which then plan an appropriate movement. This account, however, derives from laboratory tasks that strongly promote a serial arrangement --- perceptual processing followed by motor planning --- so whether it applies in general is unclear. We recorded neural activity in monkeys trained to perform the compelled-saccade (CS) task, a task in which, crucially, motor planning always starts ahead of perceptual processing. The resulting saccadic choices are fast, and may be either random or informed, depending on the amount of stimulus viewing time, or processing time, available in each trial. We find that activity in FEF reflects the internal conflict associated with making a choice, and both the time at which the conflict is resolved and its intensity depend strongly on processing time. The results generalize to a standard, sequential choice task, and agree closely with predictions from a model in which perceptual information acts by accelerating or decelerating the ongoing motor plans. Notably, and contrary to straightforward expectations, the influence of perception is weakest on visually-responsive cells and strongest on motor cells, which calls for a re-evaluation of the functional hierarchy in FEF. The results indicate that motor preparation does not wait for cognitive or perceptual events to unfold, but rather is an ongoing process that takes them into account whenever they occur.

8:30 - 9:00 (E2) Task-level brain-machine interfaces

Emo Todorov (University of Washington)

Brain-machine interfaces (BMIs) have attracted a lot of attention, partly because of their promise to restore lost motor function, and partly because of the underlying scientific interest in decoding motor commands from brain activity. The accuracy of such decoding however is rarely sufficient for engineering purposes. This is especially problematic for BMIs aiming to control prosthetic devices or functional electrical stimulators with many degrees of freedom.

If BMIs are to achieve wide-spread use, they will likely have to be non-invasive and be able to accomplish the desired functional task almost all the time. We do not see how decoding of low-level motor commands will get us there anytime soon. At the same time, such decoding is not really necessary from an engineering perspective. The critical information that the BMI must provide is what task the user wants to perform and when. The details of how the task should be performed can be left to an automatic controller. In fact BMI researchers sometimes use automatic control in their demos to supplement decoding, however they tend to see this as a deficiency to be overcome later, while we see it as a feature to be exploited and fully developed.

Another benefit of focusing on task-level BMIs is that task descriptions are part of natural human interaction, and so decoding of brain activity may be altogether unnecessary. In particular, the large majority of potential users of motor prostheses have eye movements and speech (perhaps not fluent speech, but ability to say isolated words). Suppose a BMI user wants to make his prosthetic arm move an object on a table. He could simply say "move this here". When saying "this" it is natural to look at the object of interest. When saying "here" it is natural to look at the desired new location of the object. Now suppose the BMI includes an eye tracker and a microphone, as well as off-the-shelf speech recognition software. Such a BMI can "decode" the task-level information without analyzing brain activity. In fact, given how expressive human speech is, it would be surprising if a BMI based on brain activity could ever extract task-level information that could not be communicated using speech.

In this talk we will describe our ongoing work on a system that uses eye tracking and speech recognition to obtain task specifications from a user, and then "accomplish" the specified tasks in a 3D virtual environment. Presently this is done by non-physical forces acting directly on the object of interest. This is proof of concept. Translating it into a usable BMI system requires advances in automatic control, so as to make the prosthetic device accomplish the specified task.

In the second part of the talk we will describe our efforts to develop better methods for automatic control. We now have algorithms that can synthesize fully automatically a wide range of complex human behaviors, including full-body tasks such as walking, running, getting up, climbing; as well as hand manipulation tasks including grasping, reorienting, drawing, twirling objects between the fingers. The input to these algorithms is a high-level task specification in the form of a cost function, whose minimum is achieved when the task is accomplished. For example the task of running is encoded with a quadratic cost on the horizontal velocity of the center of mass, while all details of the limb movements and foot-ground contact interactions emerge from numerical optimization. The optimizer relies on an efficient physics simulator we have developed, as well as new mathematical models of the physics of contact that enable gradient-based optimization in the presence of seemingly discontinuous dynamics. Some of these methods already work in real-time and can be used for prosthetic control.

9:00 - 9:30 (E3) The encoding of fixed motor memories through fluctuating synaptic patterns
Robert Ajemian (Massachusetts Institute of Technology), and Emilio Bizzi

From throwing a baseball to playing the piano to using the latest I-Phone keypad, humans are constantly acquiring novel sensorimotor skills throughout the course of their lives. A fundamental goal of neuroscience has been and continues to be an elucidation of neuroplasticity – that is, the neural mechanisms underlying motor memory acquisition and storage. For quite some time, the computer metaphor has dominated the community's thinking regarding the transfer and storage of information. According to this viewpoint, the nervous system lays down a synaptic trace during learning, and, while the details of this process are quite complex (LTP, LTD, spike-timing dependent plasticity, etc.), the interpretation of the memory is unambiguous. The memory IS the desired synaptic trace. Further, as long as this trace remains intact, so too does the memory. However, there are clear functional and architectural differences between the inorganic circuitry of a computer chip and the biochemical environment of a neuron. From a functional standpoint, neurons embody computing elements whose signals are corrupted with noise, subjected to constantly fluctuating operating conditions, and propagated at relatively slow speeds. In contrast, signal processing in computer chips is virtually noiseless, wholly reproducible, and conducted at transmission velocities approaching the speed of light. From an architectural standpoint, neurons in our brain are highly interconnected for parallel processing (each neuron connects, on average, to 10,000 other neurons), whereas computer architectures utilize localized circuit connectivity in an essentially serial manner. With this perspective in mind, we propose a uniquely biological theory of motor memory formation based on three assumptions: 1) neural signal processing and synaptic change are both extremely noisy processes, 2) synapses are constantly being modified through learning-dependent mechanisms at extremely high rates (hyperplasticity), and 3) the motor system is highly redundant at all levels. Computer simulation of the theory shows that motor memories can be maintained even as the underlying patterns of synaptic connectivity are constantly changing. Predictions of the theory are tested against the findings of 2-photon microscopy experiments looking at the rate of creation and decay of dendritic spines in the cortex during motor learning tasks. These experiments have consistently shown a level of dendritic spine fluctuation difficult to reconcile with a static conception of motor memory. Finally, additional psychophysical and neurophysiological experimental evidence in support of this theory will be presented and discussed. Our ultimate conclusion is that, at least for the case of motor memories, mnemonic permanence is NOT to be found at the level of synaptic structure but rather in the patterns of neural activity thereby elicited.

9:30 - 10:00 (E4) Statistical estimation in grip force control
Maurice Smith (Harvard University), Alkis Hadjiosif, and Jordan Brayanov

10:30 - 12:30 (E5) Grand Challenges
Kurt Thoroughman & David Van Essen (Washington University), Hilel Chiel & Peter Thomas (CWRU), Kenneth Whang (NSF), Yuan Liu & Dennis Glanzman, (NIH)