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ACTION SYSTEMS: PLANNING AND EXECUTION

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It has been proposed that the central nervous system (CNS) generates movement as a shift of the limb's equilibrium posture. This equilibrium- point hypothesis has been corroborated by experimental results obtained in studies involving single- and multi-joint motions. Work on single-joint movements has, in fact, provided evidence for the spring-like behavior of muscles and has led to the suggestion that this property may play an important role in the control of posture and movement. These studies support the idea that posture control is achieved by the CNS through the choice of agonist-antagonist torque-angle curves that determine the equilibrium position for the limb and the stiffness about the joints. These results are also consistent with the idea that the CNS produces single- and multi-joint arm trajectories by generating a control signal that defines a series of equilibrium postures. These studies have achieved a unified description of posture and movement. The importance of the equilibrium- point hypothesis is that it drastically simplifies the computations the CNS presumably must make to accomplish multi-joint movements. Because the neuromuscular system is spring-like, at each instant the difference between the arm's actual position and the equilibrium position specified by the neural activity is sufficient to generate the torques required for movement. The complex problem of computing the torques at the joints (the so-called "inverse dynamic" problem) is avoided.

Up to this time, the experimental evidence for the equilibrium-point hypothesis rested upon data derived from psychophysical and behavioral experiments, and no experimental paradigm existed with which to test the implications of this hypothesis at the neurophysiological level. Recently, we have investigated the organization of limb motor space in the frog's spinal cord and found that microstimulation of the spinal cord's premotoneural network produces goal-directed leg movements that bring the leg to a particular position in the animal's motor space. These results provide the neurophysiological underpinning for the equilibrium-point hypothesis.

The forward modeling approach in speech production and limb control

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The problem of learning to control an unknown environment is essentially that of finding an inverse of the state transition function of the environment. The forward modeling approach to motor learning (Jordan, 1990) is an indirect approach to finding such an inverse. The idea is to first learn a forward model of the state transition function (over an appropriate subdomain) and then to learn the identity mapping across the composition of the controller and the forward model. This process solves implicitly for an inverse mapping. The forward modeling approach is particularly appropriate for systems with excess degrees of freedom and it allows a priori knowledge to be incorporated during learning in the form of general constraints on the particular solution.

In this presentation I illustrate aspects of the forward modeling approach in the domains of speech production and limb control. The first example demonstrates that in a stochastic estimation problem the approach leads to biased inverse mappings that have smaller variance than the exact inverse mapping. This implies that over successive generations the targets that are passed from one learner to another tend to evolve to configurations of minimal variance. In the domain of speech production, this evolution corresponds to the claim of Stevens (1989) that sound inventories of languages tend to be composed of phonemes that have maximally stable articulatory configurations. I demonstrate this evolutionary process using a simulated vocal tract and the learning of a vowel system. The second example demonstrates that the forward modeling approach provides a technique for learning the virtual equilibrium trajectories associated with limb movements. I show that the use of virtual equilibrium trajectories as control signals leads to advantages associated with the stability of the learning process. Finally, I show that the forward modeling approach provides an account of a speed-accuracy tradeoff known as Fitt's Law.

References

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