Optimal Feedback Control as a Theory of Motor Coordination

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How multiple actuators are coordinated towards the achievement of a common goal has remained a central problem in motor control for nearly 70 years. The predominant view that redundancy is being eliminated at a planning stage, by prescribing a detailed trajectory for each degree of freedom, is unacceptable as a model of human movement. Instead the motor system appears to take advantage of redundancy: task-related parameters (e.g. endpoint kinematics) somehow remain invariant while low-level parameters (e.g. muscle activity, joint angles) are quite variable. Originally described by Bernstein, this pattern has now been documented in a wide range of behaviors. Yet there is no explanation of why and how it arises, and how it is even possible to achieve high-level goals in the presence of substantial actuator variability.

Here I will show that variability and goal achievement are not only compatible, but variability is actually needed for skilled performance. Given a description of the stochastic plant and an index of task performance, I compute the feedback control law that maximizes expected performance. It turns out that this control law does not enforce a predefined trajectory, but only corrects deviations that interfere with the high-level goal. As a result, state fluctuations in redundant dimensions are allowed to accumulate, giving rise to task-constrained variability and synergetic coupling of actuators.

I will also present experimental results from complex hand manipulation, table tennis, and via-point tasks. In all cases the observed patterns of variability contradict the hypothesis that trajectories are being planned, and support the present model.