Optimal control of movement

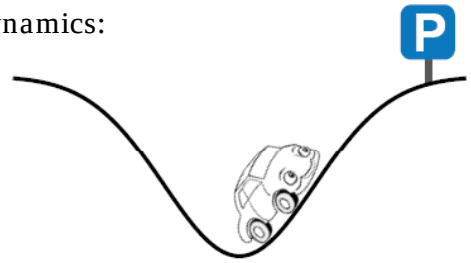
Emo Todorov

Applied Mathematics
Computer Science and Engineering

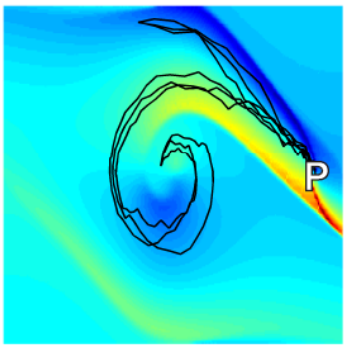
University of Washington

simple assumptions -> interesting predictions

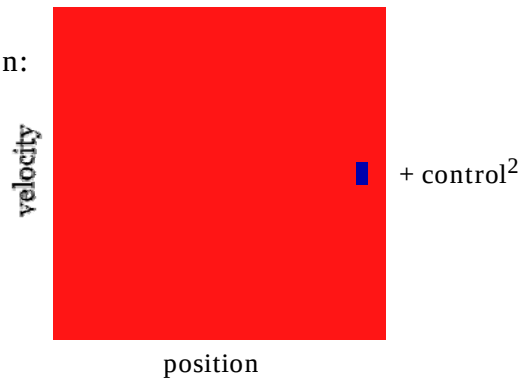
dynamics:



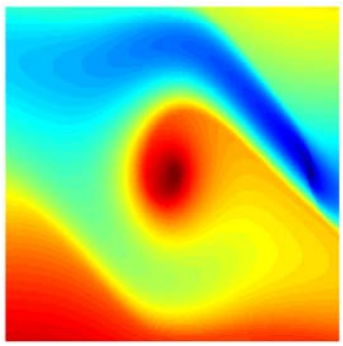
optimal control law:



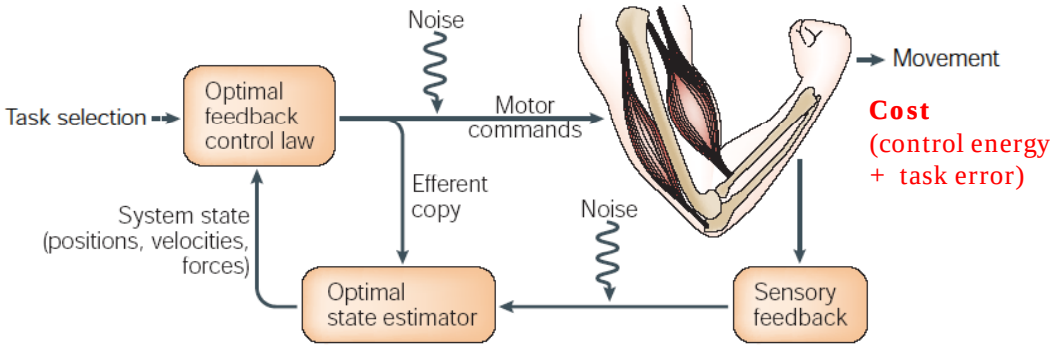
cost function:



optimal cost-to-go function:



Stochastic optimal control and estimation



many models of movement data:

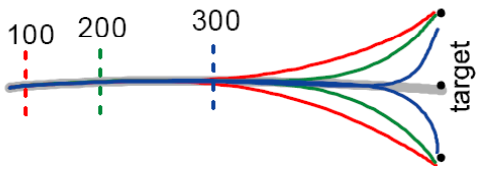
- eye movements
- arm movements
- walking, running, jumping
- sit-to-stand
- cycling

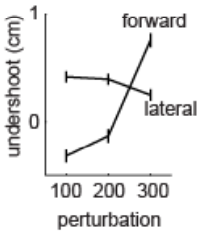
some models of physiological data:

- muscle activity
- neural activity in the spinal cord
- neural activity in primary motor cortex

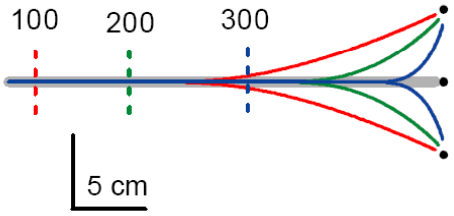
Incomplete error correction

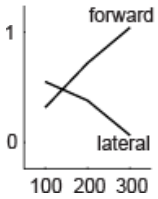
human data:



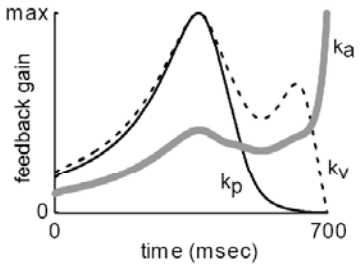


model (LQG)





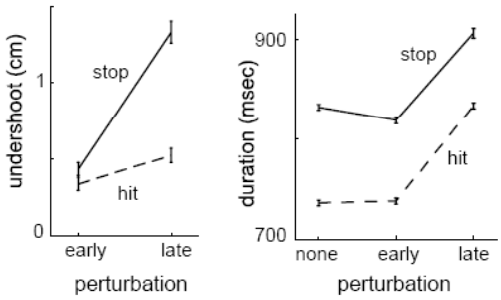
explanation:
stability-accuracy trade-off



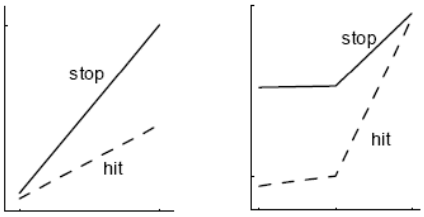
prediction:
undershoot will decrease if stopping is not required

Testing the prediction

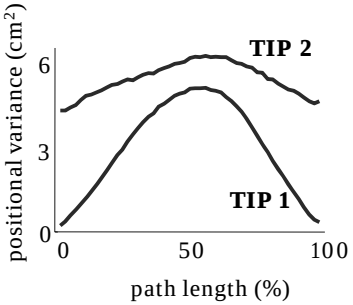
human data:

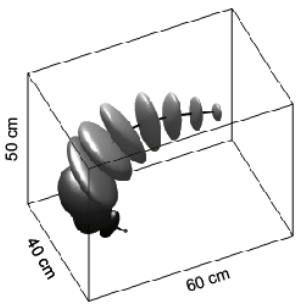


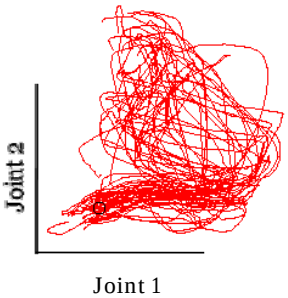
extended model (MDP):



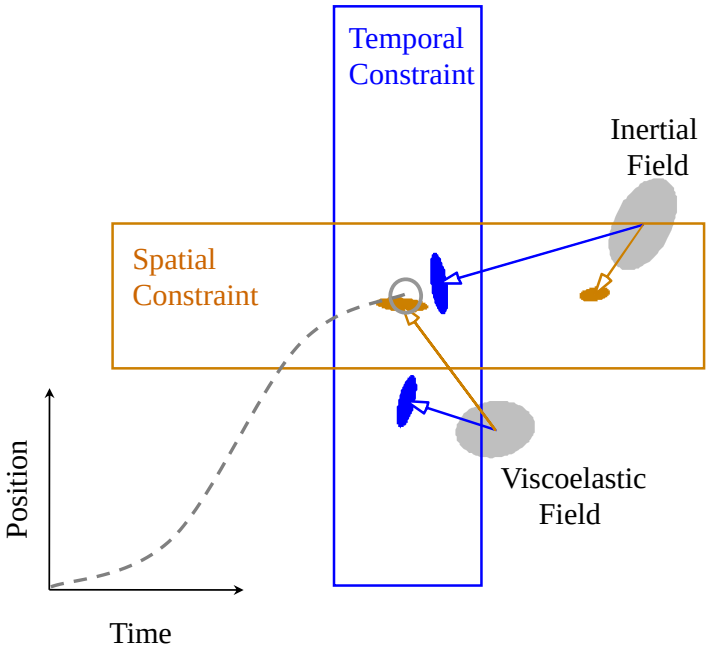
Increased variability in redundant dimensions







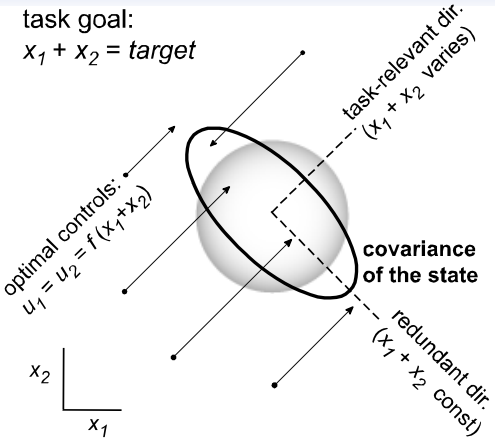
Reduced adaptation in redundant dimensions



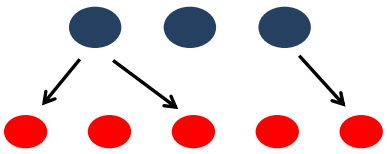
Features of optimal control laws in redundant tasks

optimal control laws in redundant tasks
suppress task-relevant fluctuations,
and allow variability in redundant dimensions

this strategy minimizes both control energy
and signal-dependent noise



the optimal control signals are coupled,
creating the appearance of **motor synergies**



abstract
controls

muscles

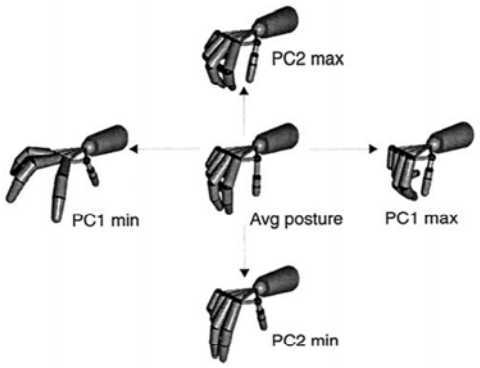
synergies in control are like **features** in perception

Motor synergies

Grasping virtual objects

2 PCs explain 85% variance

EMG synergies ...



Hierarchical control of complex systems