Good Enough

~~Optimal~~ Control

~~Internal Models~~

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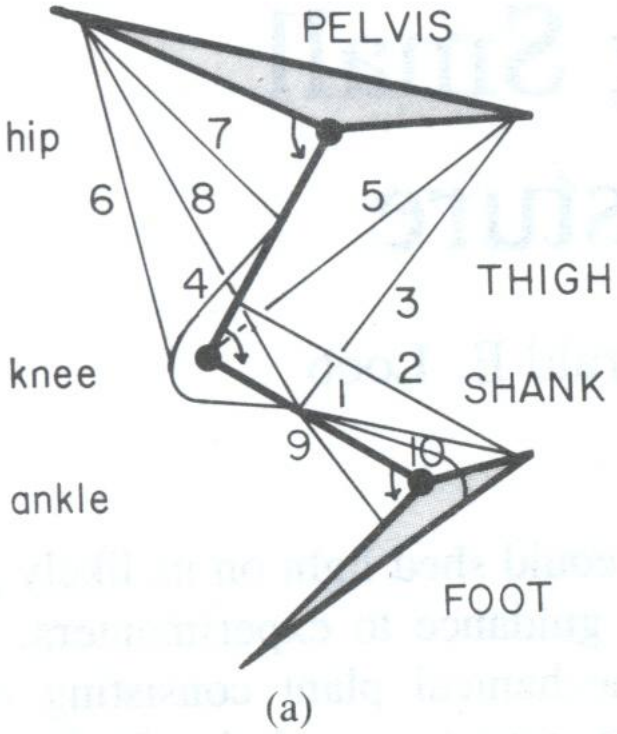
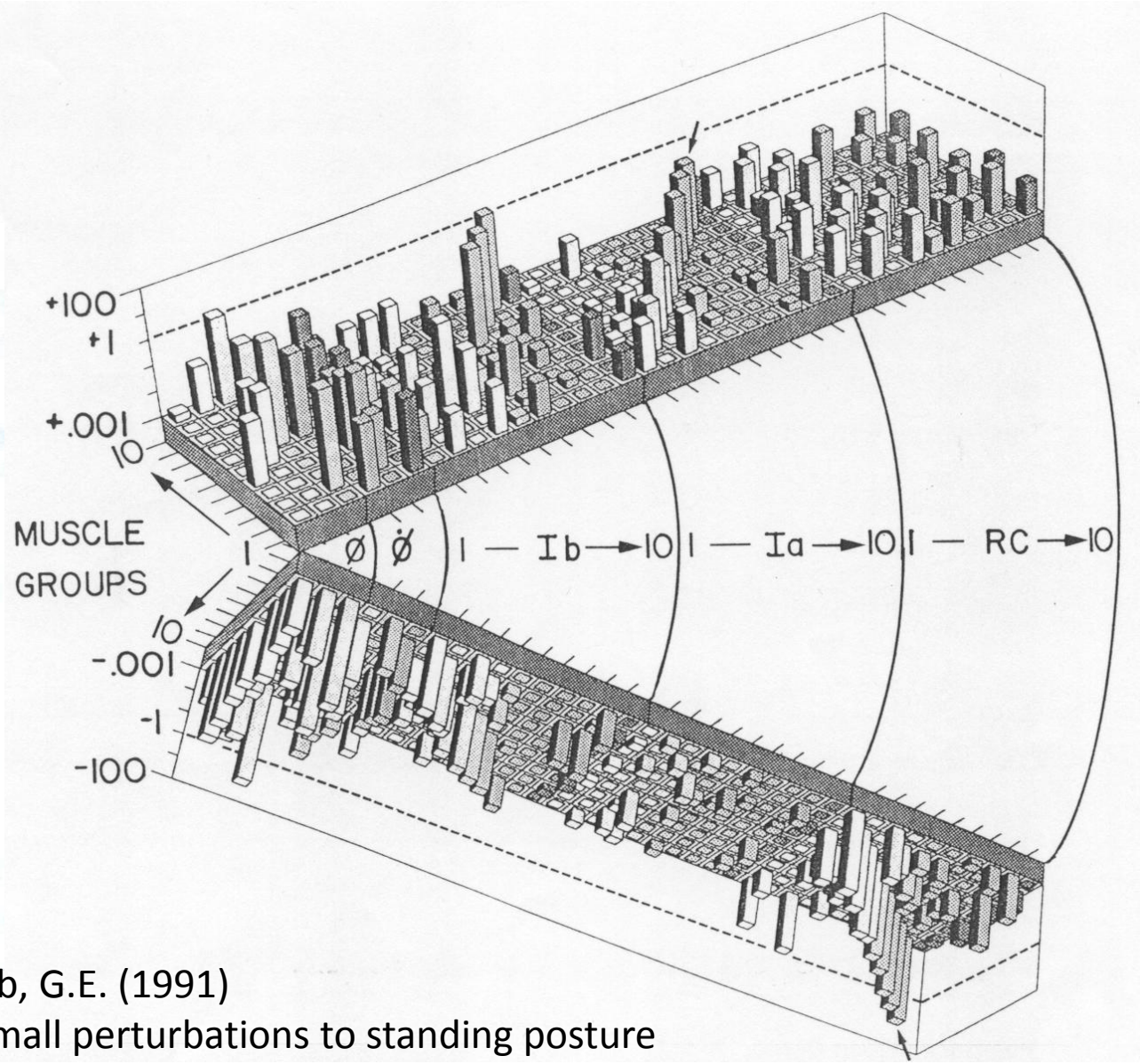
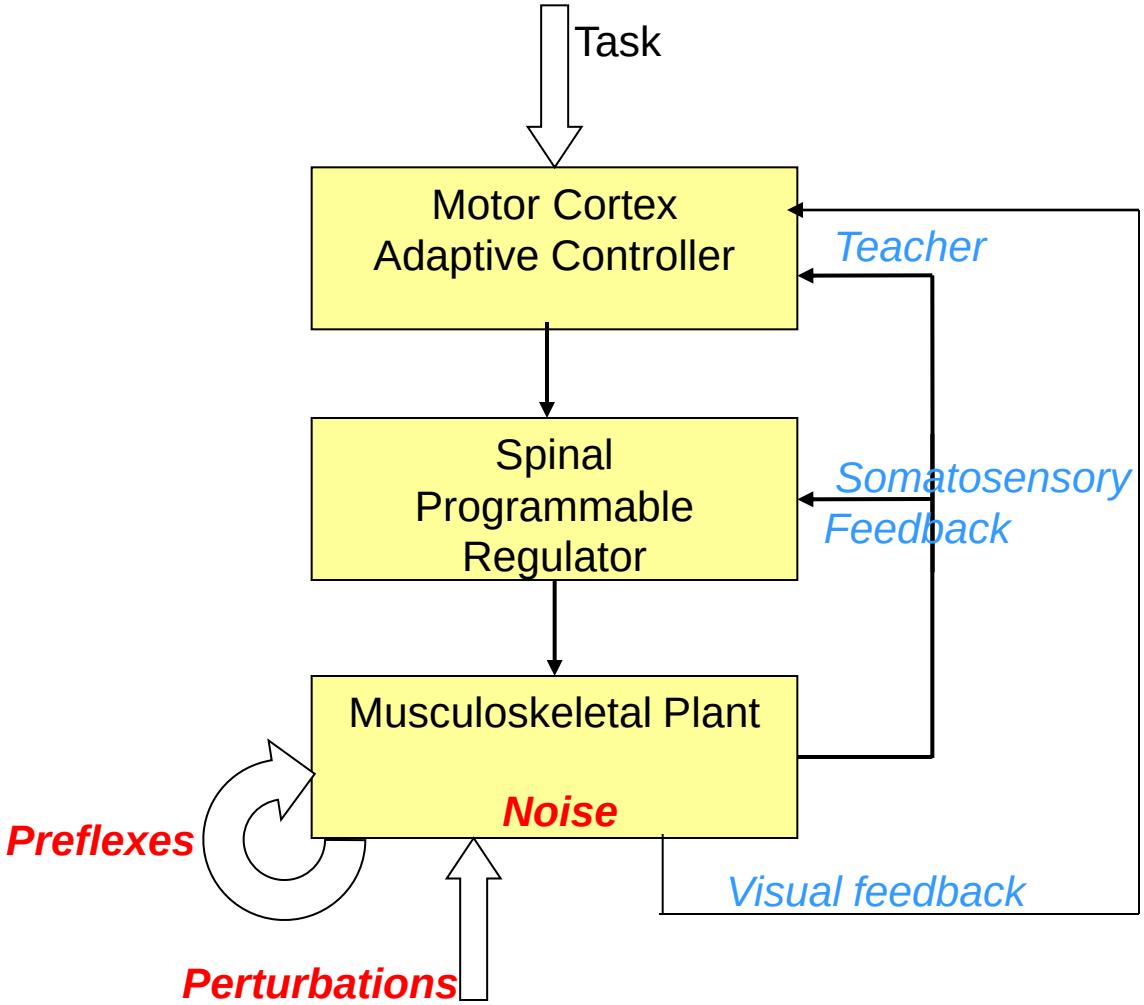
Spinal Circuitry as Optimal Regulator





He, Jiping, Levine, W.S. and Loeb, G.E. (1991)
Feedback gains for correcting small perturbations to standing posture
IEEE Trans on Automatic Control, 36:322-332

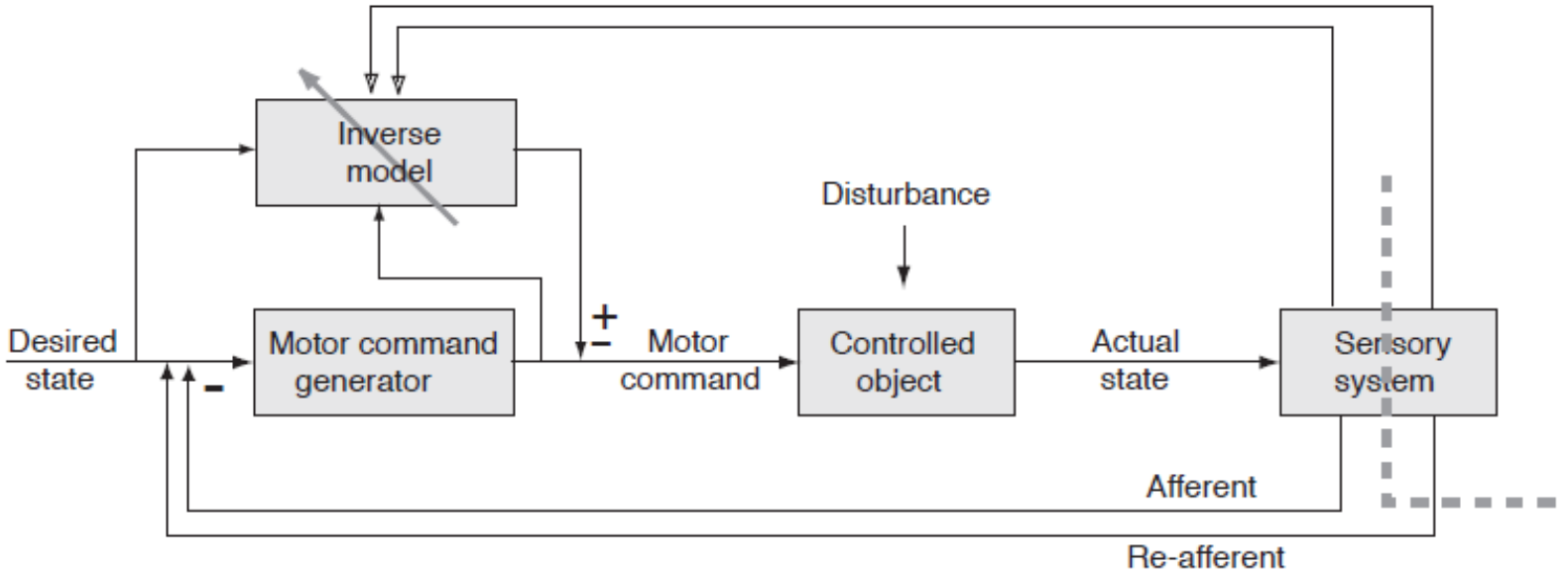
Spinal Circuitry as Optimizable Regulator

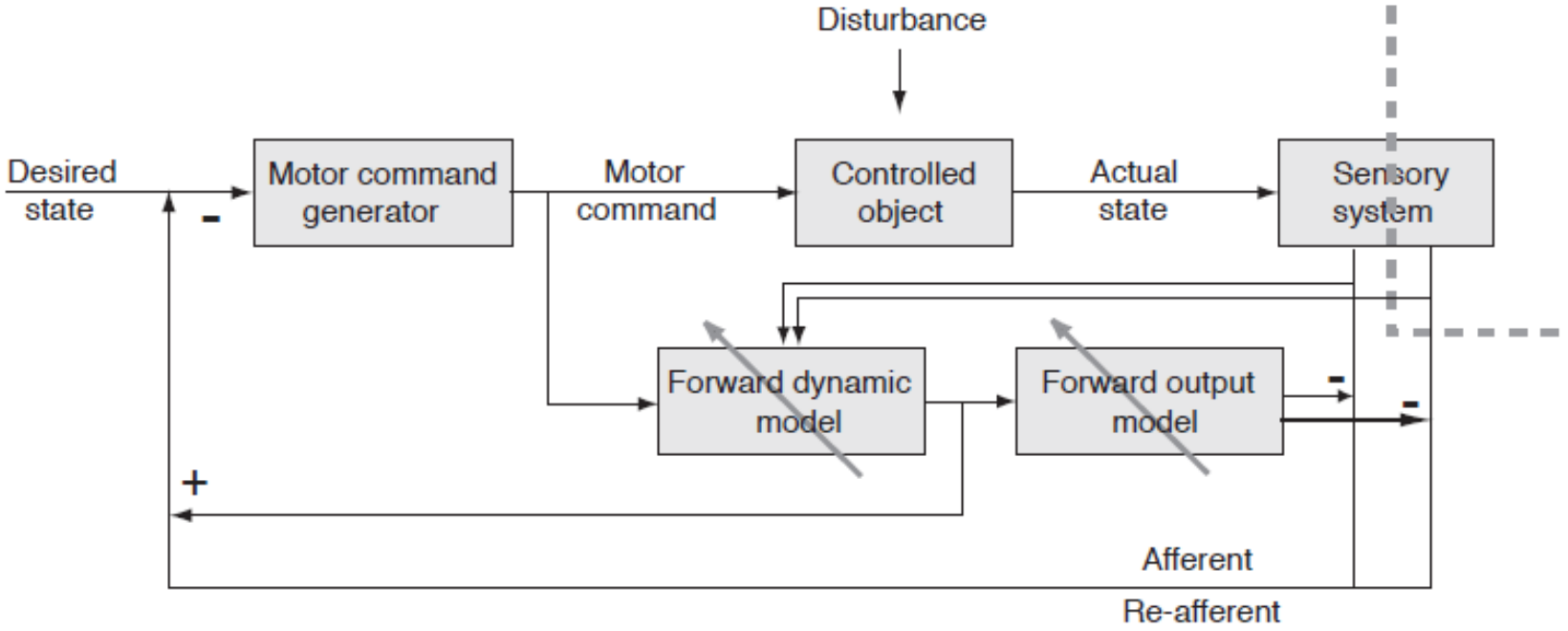


Loeb, Levine and He, Understanding sensorimotor feedback through optimal control, Cold Spring Harbor Symp. Quant. Biol. 55:791-803, 1990

Loeb, Brown and Cheng, A hierarchical foundation for models of sensorimotor control, Exp. Brain Res. 126: 1-18, 1999.

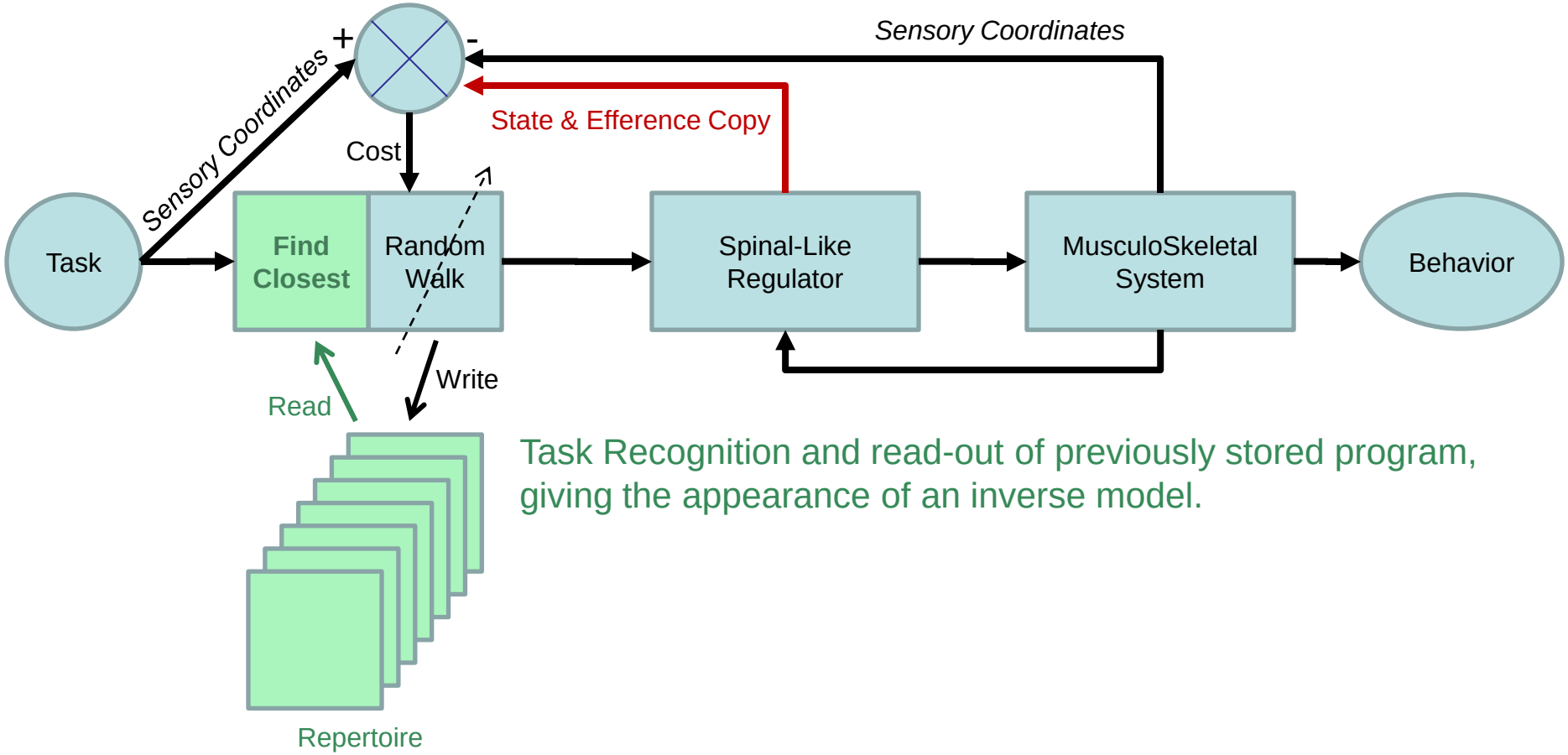
Internal Models for Computing Optimal Control





Pseudo-Internal Models

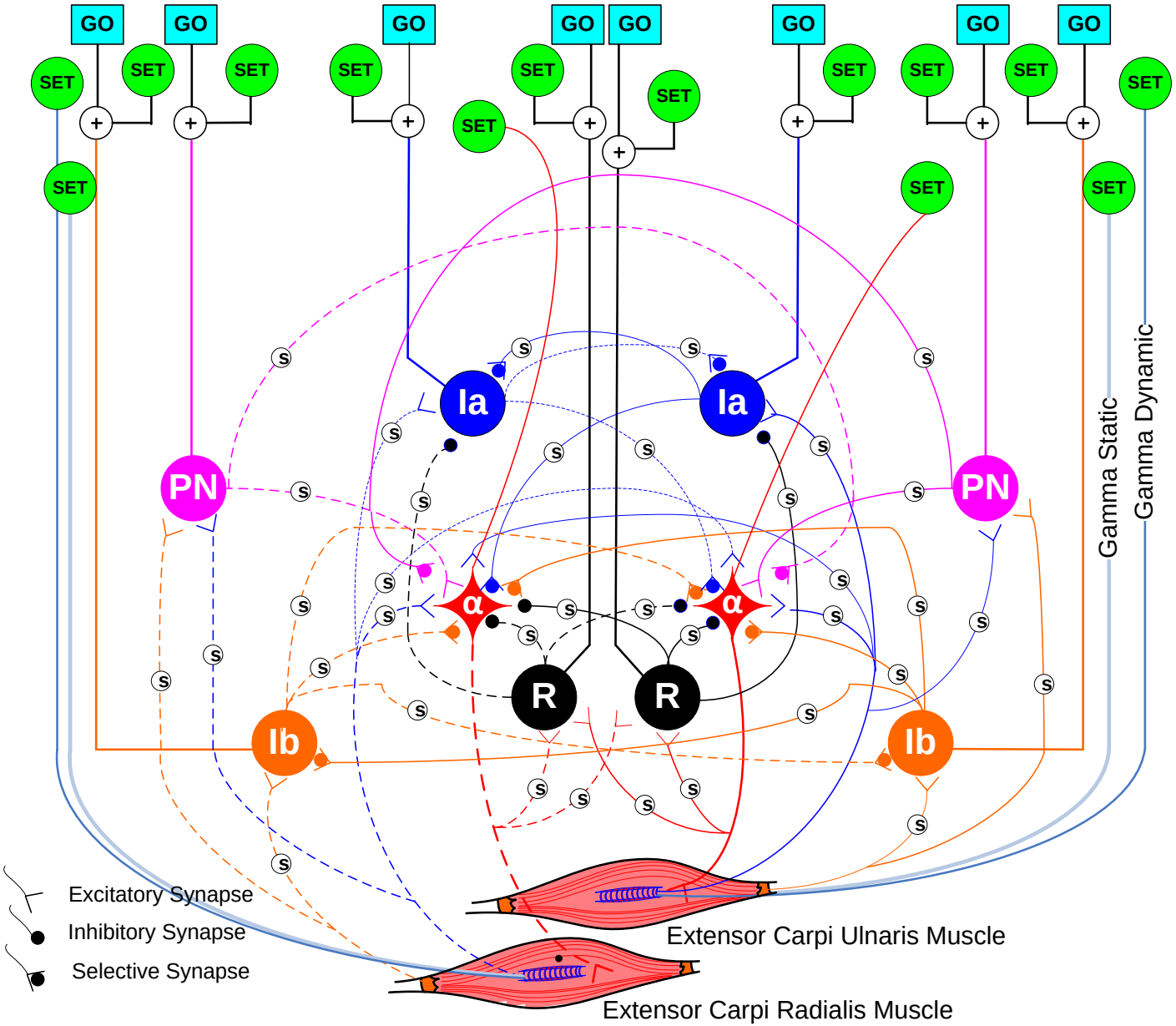
State & Efference Copy allows negative latency adjustment, giving the appearance of a forward model.



Task Recognition and read-out of previously stored program, giving the appearance of an inverse model.

Small Subset of Spinal Interneuronal Circuitry

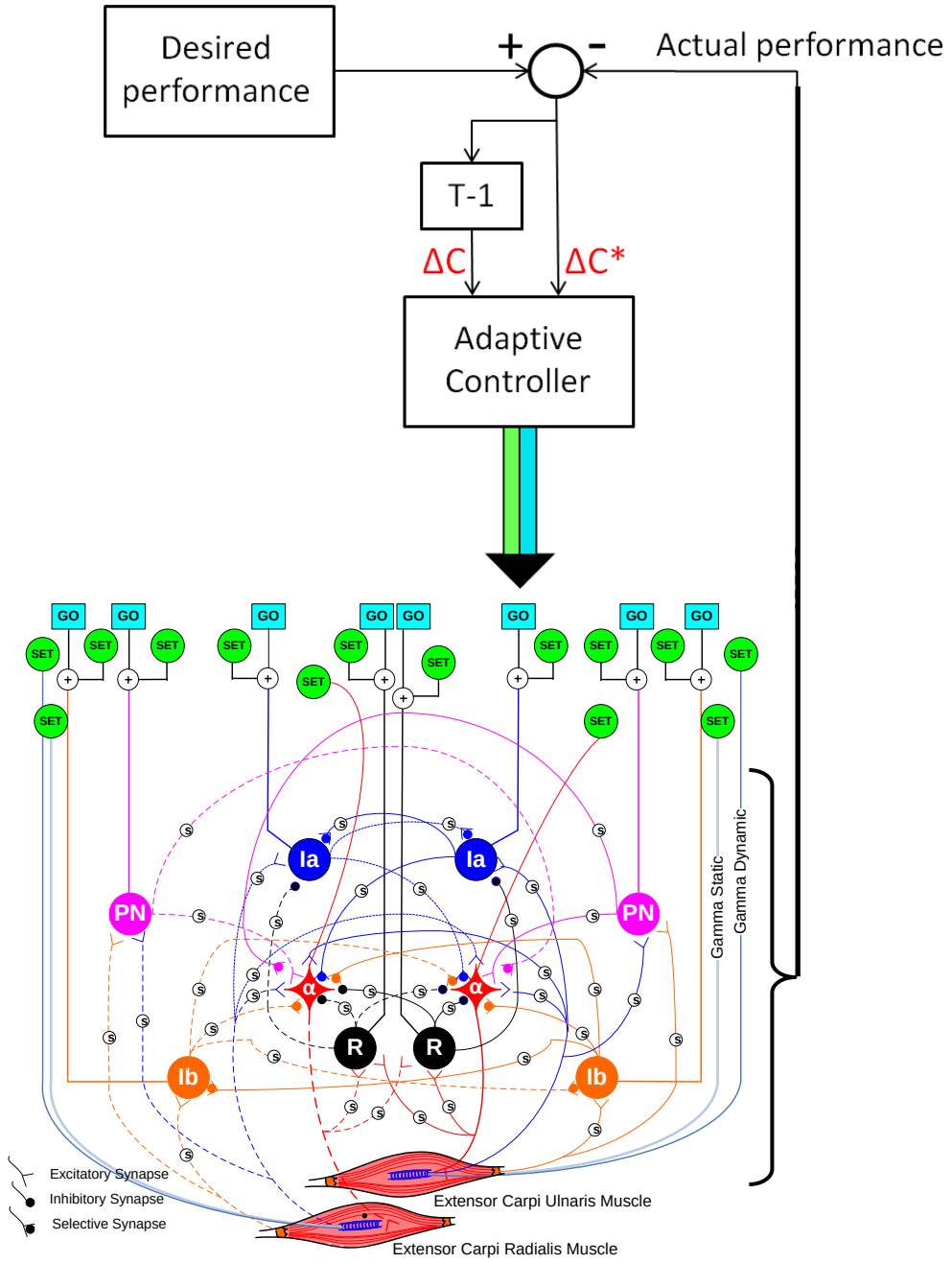
Is this really modeled in the brain?



Modeled Pathways

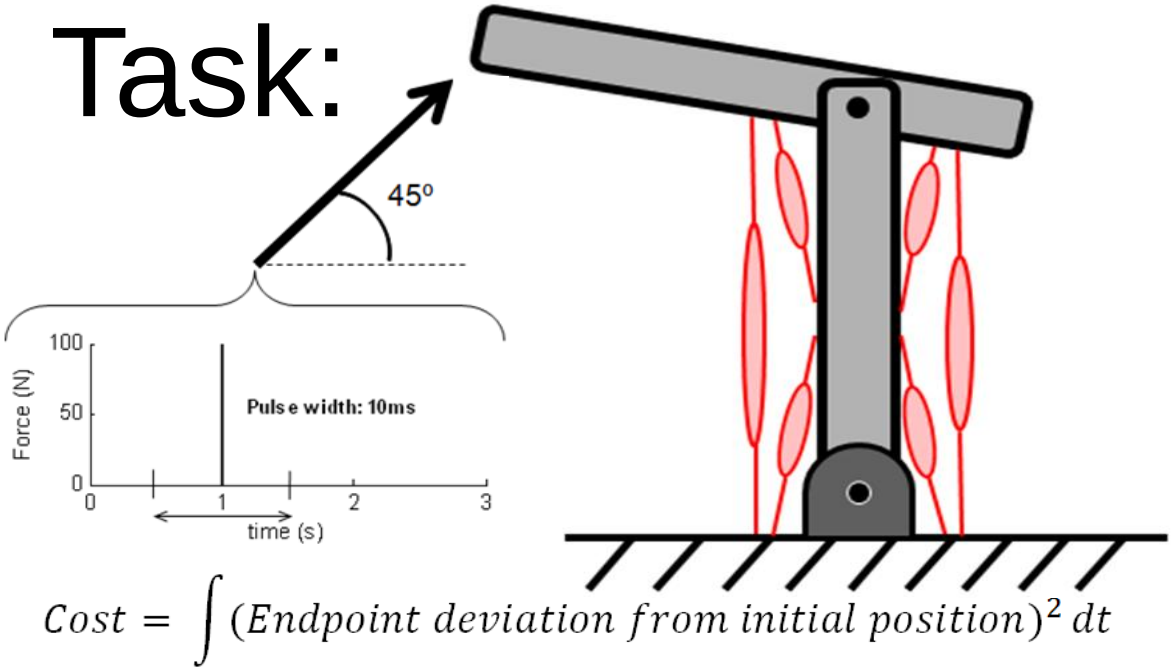
1. Propriospinal
2. Monosynaptic Ia
3. Reciprocal Ia
4. Renshaw
5. Ib inhibitory

…or does the brain learn by trial-and-error to send commands that result in useful behaviors?



Raphael, G., Tsianos, G.A. and Loeb, G.E. Spinal-Like Regulator Facilitates Control of a Two-Degree-of-Freedom Wrist J. Neuroscience, 30:9431-9444 (2010)

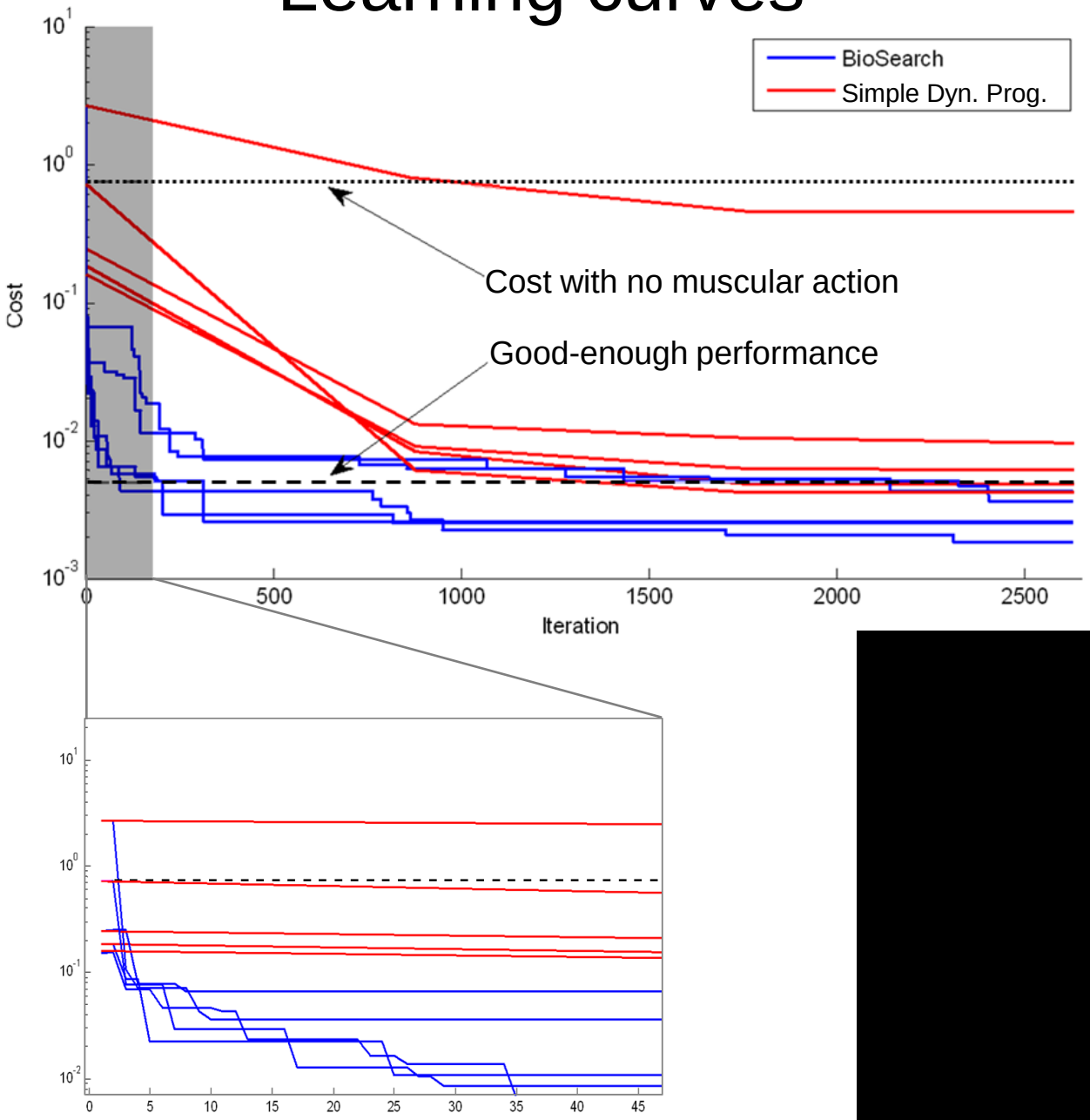
Task:



$$Cost = \int (Endpoint\ deviation\ from\ initial\ position)^2\ dt$$

SET the gains of the SLR to resist an impulsive perturbation at the endpoint.

Learning curves



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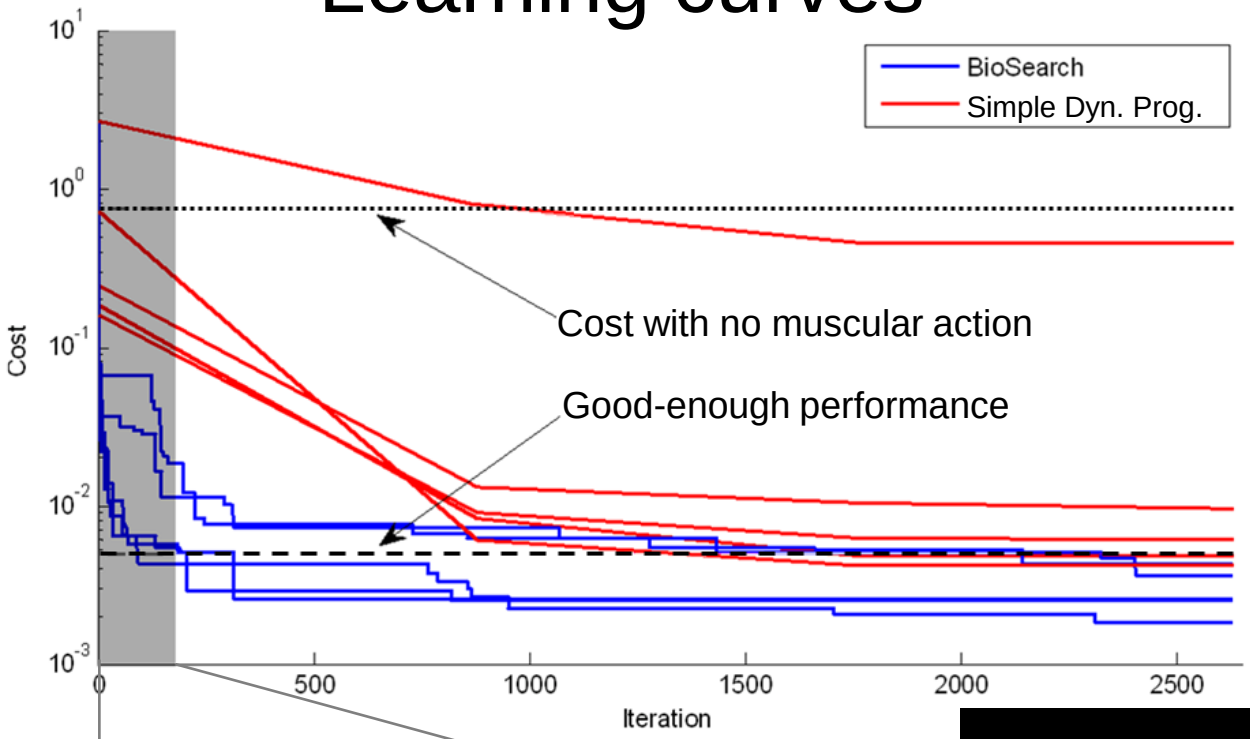
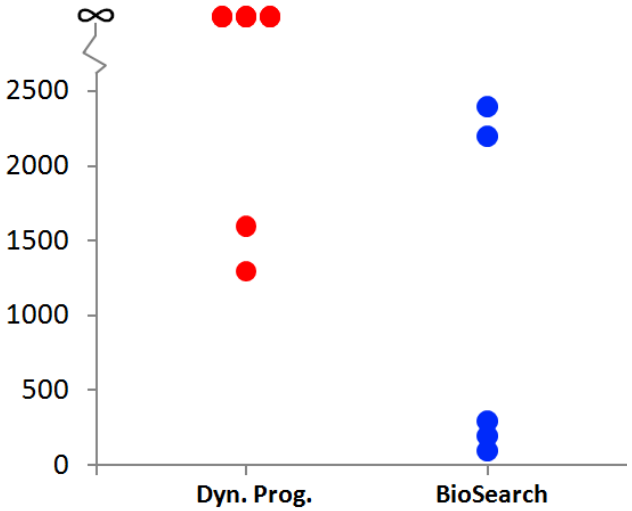
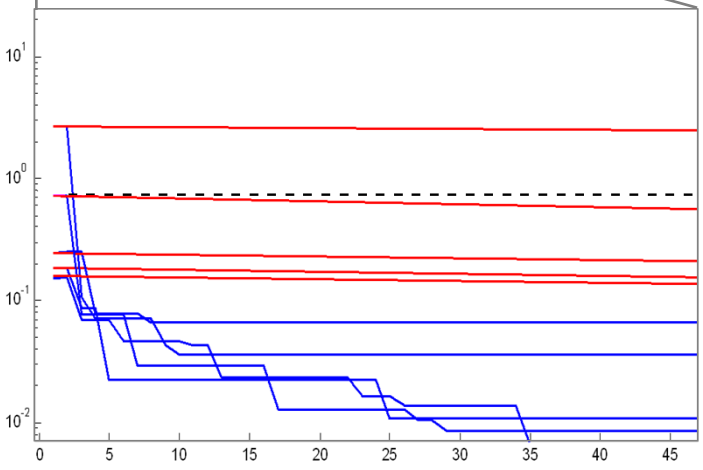
Learning curves



Convergence rate





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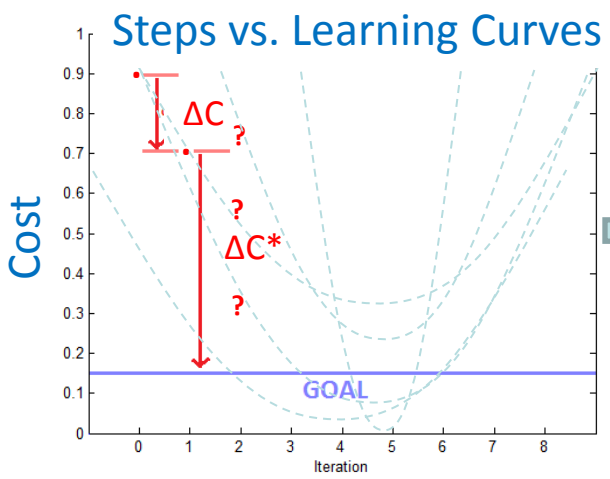
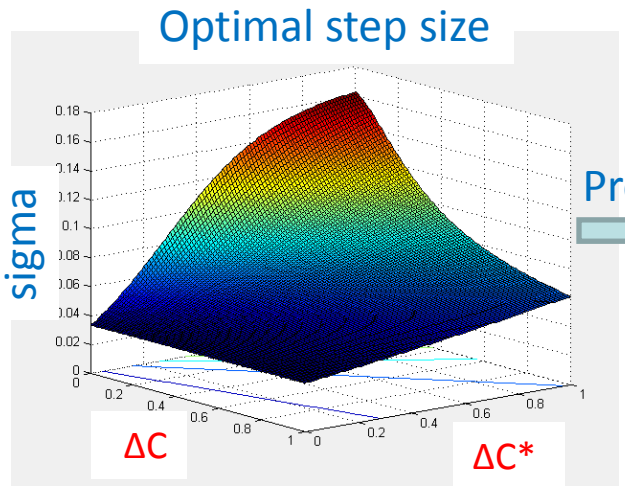
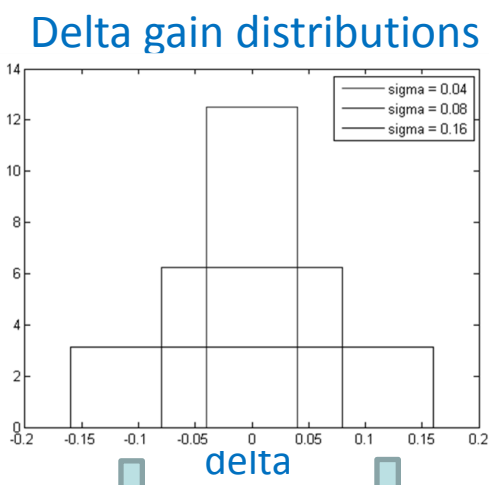
BioSearch™ Corticospinal Learning Algorithm

Hypothesis: Landscape has so many "good enough" local minima that a Random Walk is a viable learning process





Prob.



Cost

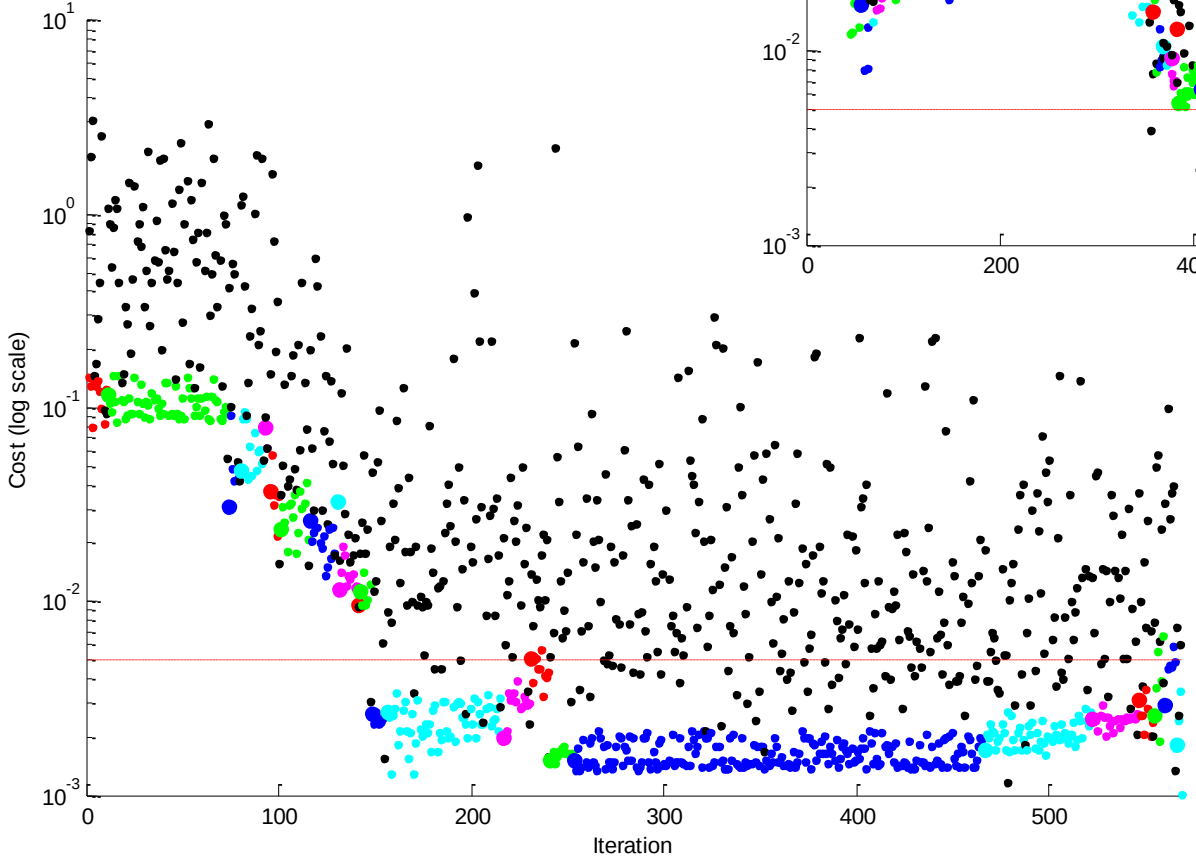
Simulation

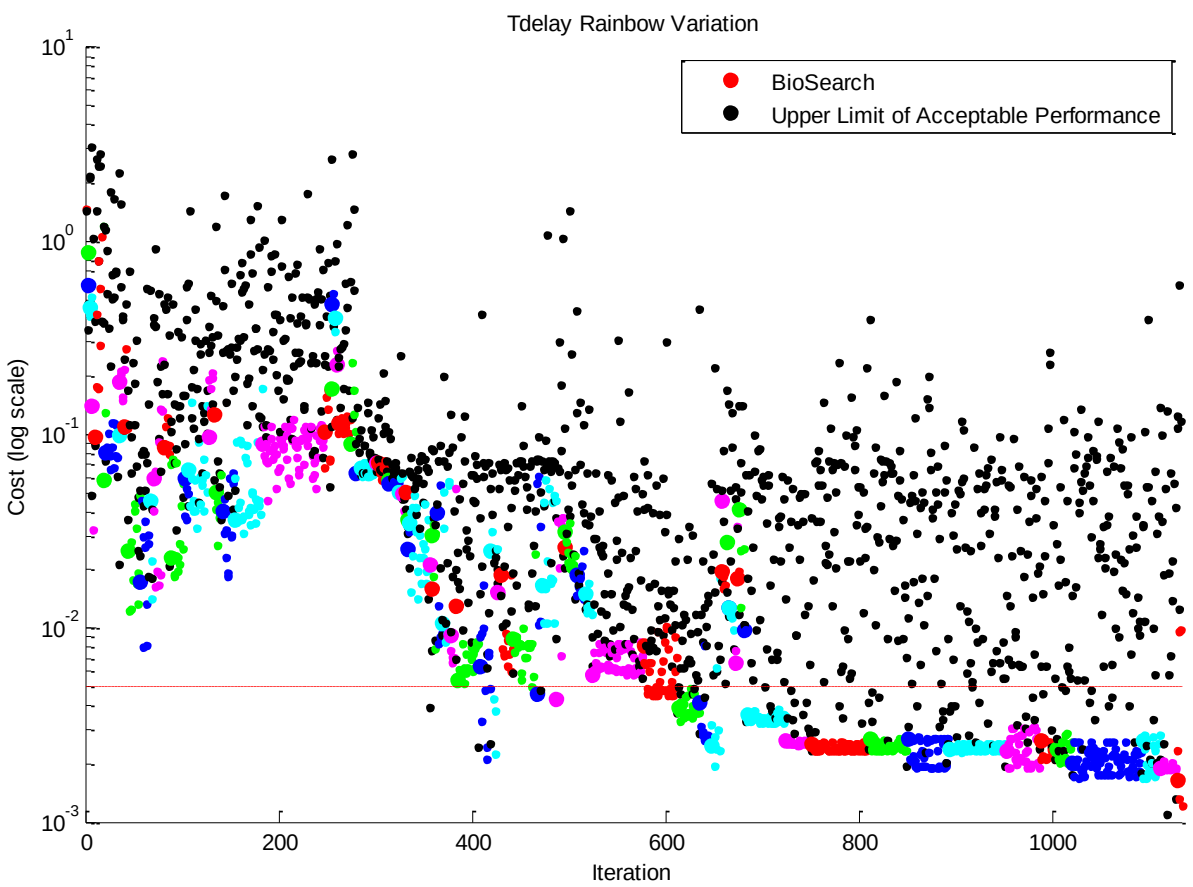
gain1
gain2
gain3
…
gain4

delta $_{gain1}$
delta $_{gain2}$
delta $_{gain3}$
…
delta $_{gain400}$

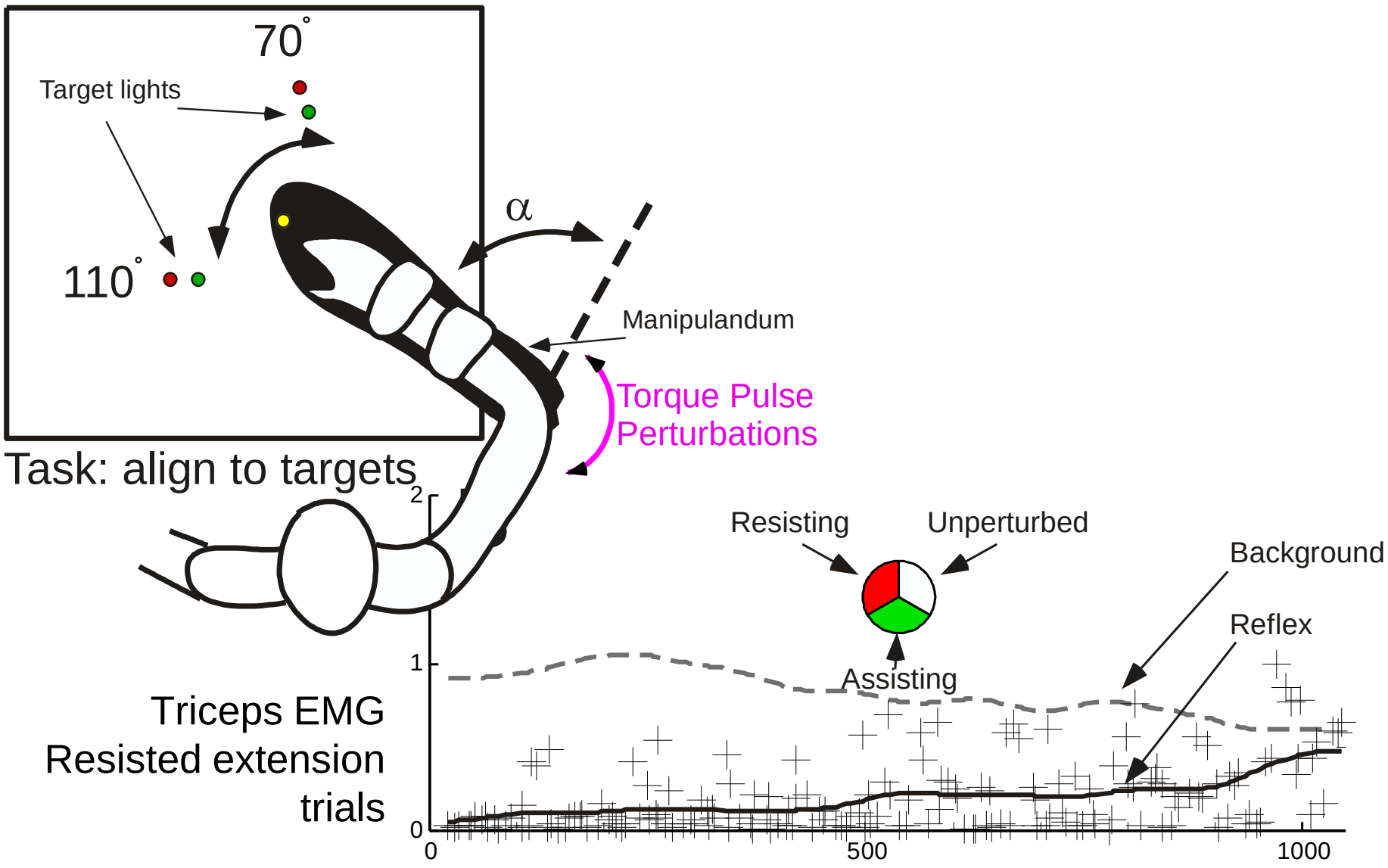
BioSearch Learning Curves

perturbing impulse at randomized times





Motor Learning ≠ Task Recognition



Cheng, E.J. and Loeb, G.E. (2008)
Journal Neural Engineering 5:232-253.

Take your pick…

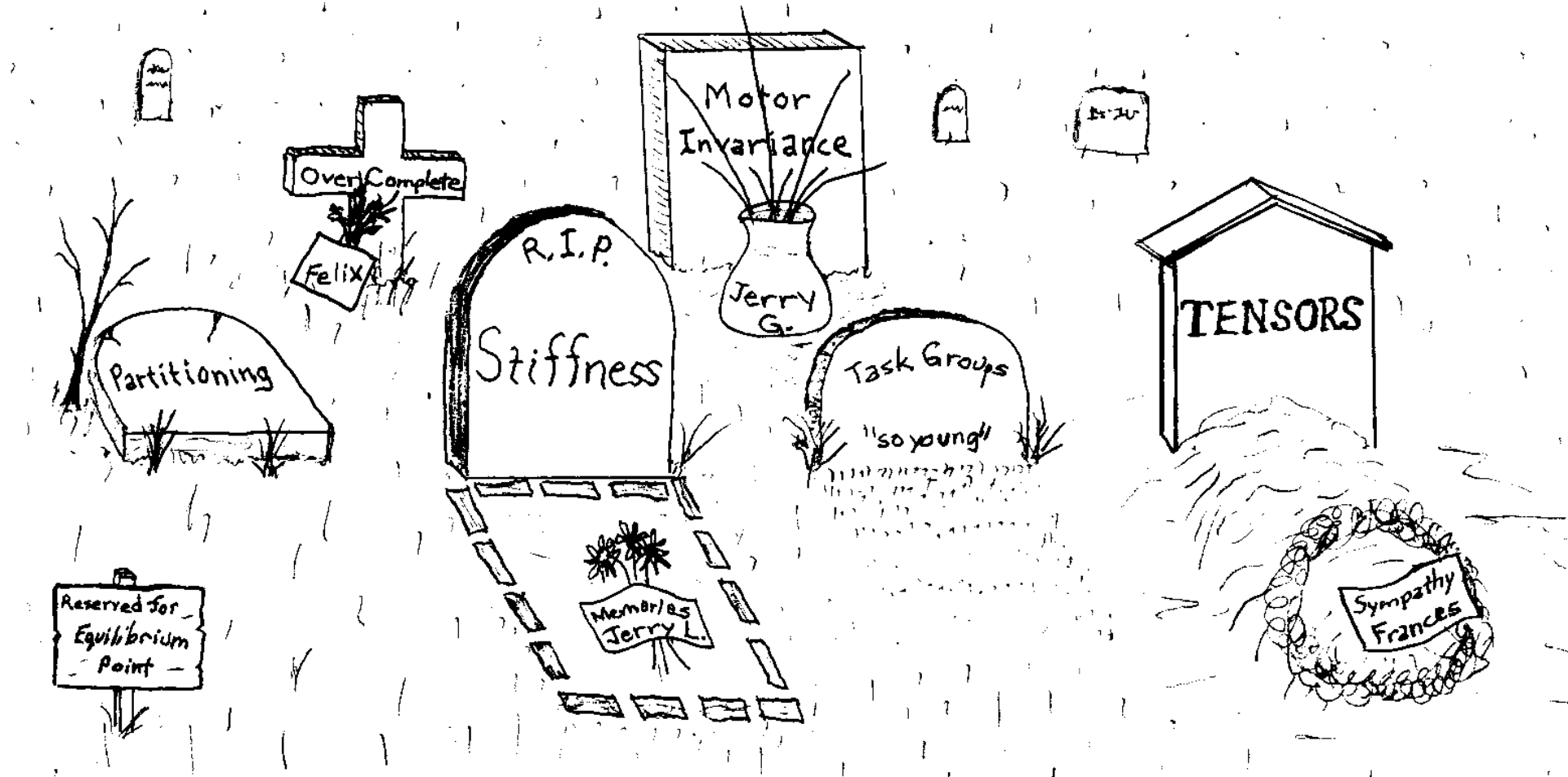
System Design	Model-Based	Model-Free
Goal	Globally optimal	Good enough
Real-time control	Computational	Look-up tables
Redundancy	Avoided	Embraced
Synergies	Hardwired	Learned
Learning curve	Steady improvement	Random walk
Storage format	Models of components	Repertoire of programs

Engineers build models to understand complex systems,

e.g. posters at this meeting by Li, Loeb & Levine; Tsianos, Goodner & Loeb.

The brain doesn't build models and it doesn't understand itself.

A Brief History of Theoretical Sensory-Motor Neuroscience



Graveyard of the Biomechanically Damned