Systems Neuroscience CISC 3250

Motor control

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Classes of motion

Voluntary

Somatic		Skeletal muscle
Autonomic	Sympathetic Fight or Flight	Smooth muscle
	Parasympathetic Resting state	Cardiac muscle

Involuntary

2

Pathways to motion in (typically) 2 synaptic steps

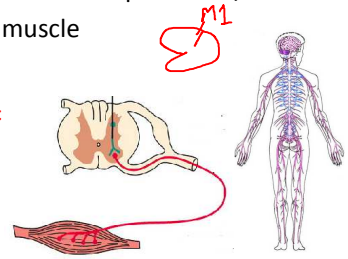
0 Command from primary motor cortex (M1)

1 Synapse onto neuron in spinal cord/cranial nerve

2 Synapse onto muscle

Efferent – motor message **out**

Afferent – perceptual message **in**

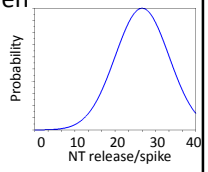


3

Precise motion in an imprecise world

Imprecise neurons

- Efferent signal for motion will present variable number of NT molecules per spike
- Number of spikes may vary between movement repetitions



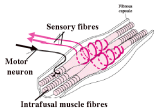
Unreliable world

- Wind blows while you pick up a bag
- You trip on unseen object while walking

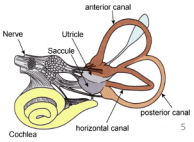
4

Monitoring body motion

- Seeing body move (covered in earlier lecture)
- Skin stretch (covered in earlier lecture)
- Muscle stretch/contraction – muscle spindles



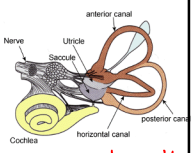
- Head rotations – inner ear; semi-circular canals

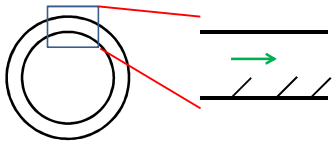


5

Vestibular system

Three canals on left and right side of head: anterior, posterior, horizontal





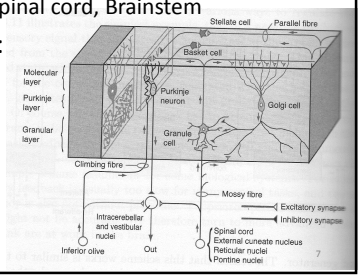
relative to wall of canal

1. Head rotates
2. Fluid flows
3. Hairs displaced

6

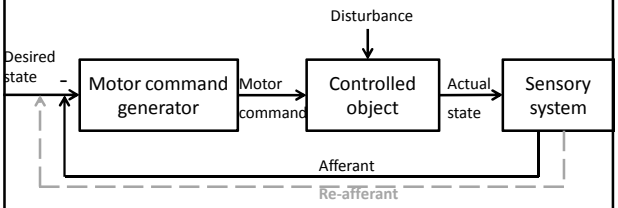
Adjusting motion with the cerebellum

- Compare motor commands to actual motion
- Cerebellar inputs:
  - Climbing fiber from Inferior Olive (brainstem)
  - Mossy fiber from Spinal cord, Brainstem
- Cerebellar outputs:
  - Purkinje cells – inhibition to brainstem



Control theory

Correcting errors in motion



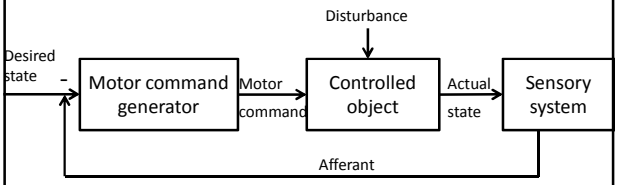
Afferant – muscle sensors — faster

Re-afferant – visual sensors — more processing, slower

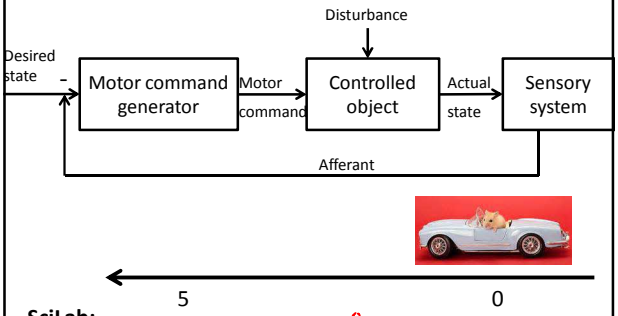
Motor command generation

each motion can have many muscles associated with it

swing leg forward -> rotate leg using muscle force



Motion with basic feedback system

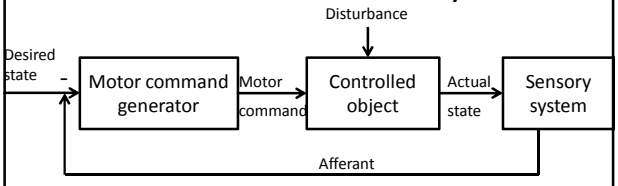


5 0

SciLab:

bodyPosition=feedbackSim(5,0.5,0,50);

Motion with basic feedback system



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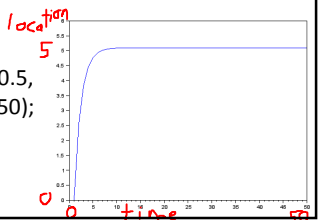
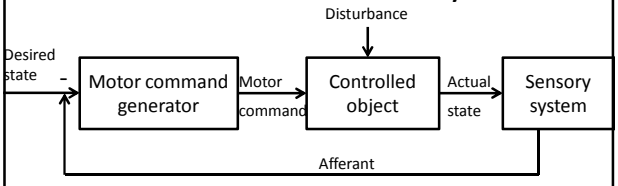
bodyPosition=feedbackSim(5,0.5,0,50);



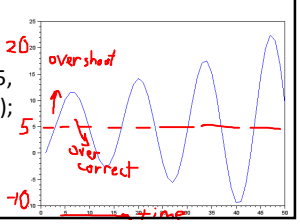
Motion with basic feedback system



SciLab:

bodyPosition=feedbackSim(5,0.5,2,50);

2 step delay



Expanded control theory

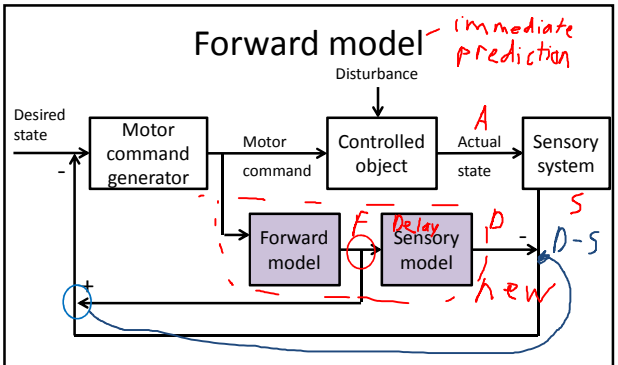
Challenge: Waiting for afferent feedback is slow

Solutions:

- Anticipate typical motion progress – **forward model**
- Account for typical motion progress from the beginning – **inverse model**

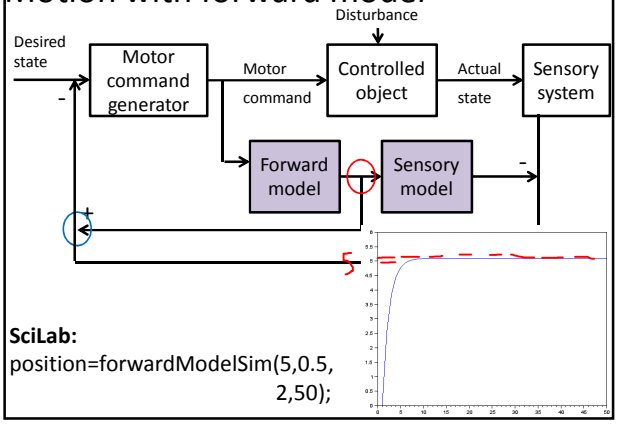
13

Forward model



- Adjust motion based on predicted position
- Adjust predicted error based on actual position
- Adjust models (over longer experience)

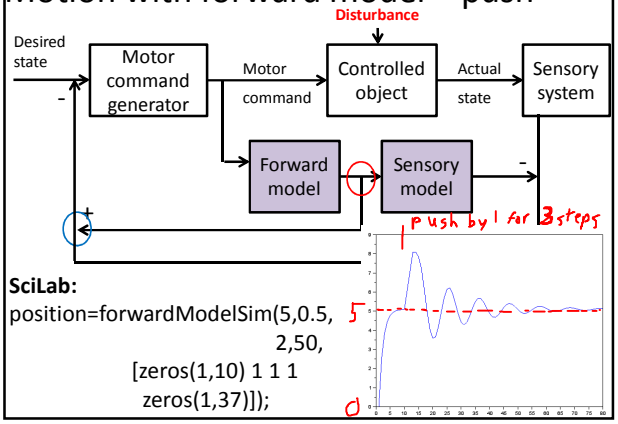
Motion with forward model



SciLab:

```
position=forwardModelSim(5,0.5,
                         2,50);
```

Motion with forward model + push



SciLab:

```
position=forwardModelSim(5,0.5,
                         2,50,
                [zeros(1,10) 1 1 1
                 zeros(1,37)]);
```

desired location = 5 starting location = 0 sensory delay = 2
push forward by 2 at time 1 no other

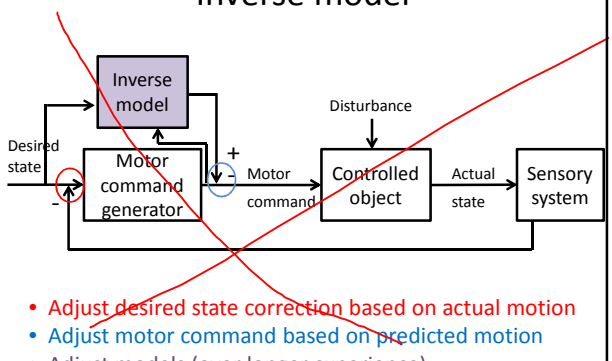
Moved by +2.5 Pushed by +2 | Moved by +1.25 | Moved by +0.63 | Moved by +0.32-2

	1	2	3	4	5
A	0	4.5	5.75	6.38	4.7
F	0	2.5	3.75	4.38	3.7
S	0	0	0	4.5	5.75
D	0	0	0	2.5	3.75

Compare model motion and actual motion after 2 time step delay

17

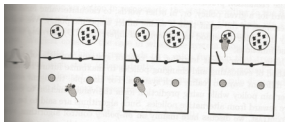
Inverse model



- Adjust desired state correction based on actual motion
- Adjust motor command based on predicted motion
- Adjust models (over longer experience)

18

Motor learning



Mouse learns to press button
after hearing a bell to get food

- How to associate bell with button press?
- How to know which button to press?

19

Motor learning: value assignment

Learn value in (desire to be in) each *state*

- $V^{\pi}(s)$ – one value for each state
- Q(s,a) – one value for ~~each action taken~~ at each state

states represented by neural firing patterns

actions as transitions between states

20

Motor learning: temporal delta rule

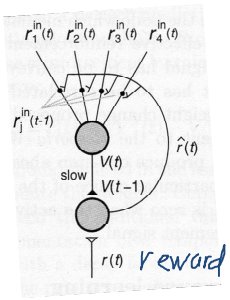
$$V(s) = \sum_i w_i(t) r_i^{in}(s)$$

$$w_i^{t+1} = w_i^t + \alpha * \hat{r}(t+1) r_i^{in}(s)$$

$$\hat{r}(t+1) = r(t+1) - V(t)$$

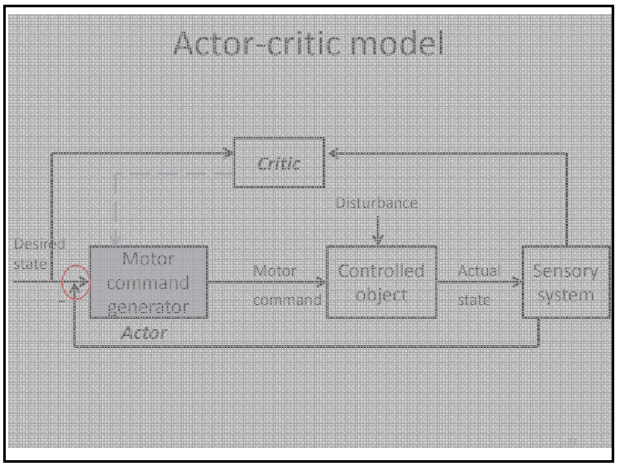
actual value — predicted value

choice of door $r_i^{in}(s)$
* (actual vs. predicted value)



21

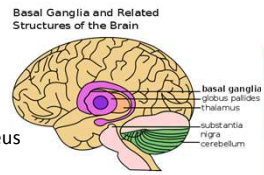
Actor-critic model

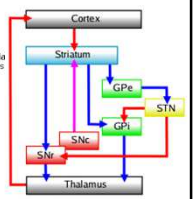


Motor learning biology: basal ganglia

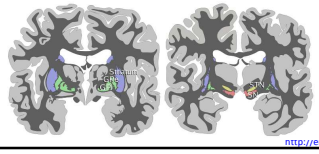
Striatum
- Putamen
- Caudate nucleus

Globus pallidus
Substantia nigra
Sub-thalamic nucleus (STN)





Input through Spiny Neurons in Striatum



SN – dopamine learning

Excitatory
Inhibitory
Modulatory (DP)