Systems Neuroscience CISC 3250

Motor control

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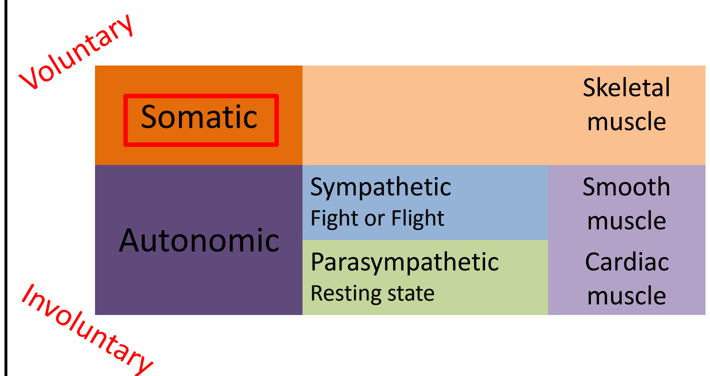
JMH 332

Classes of motion



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Pathways to motion in (typically) 2 synaptic steps

0 Command from primary motor cortex (M1)

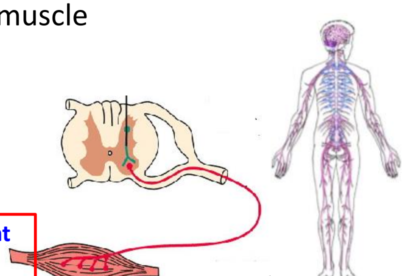
1 Synapse onto neuron in spinal cord/cranial nerve

2 Synapse onto muscle

Efferent – motor message **out**

Afferent – perceptual message **in**

Cortical commands sent to contralateral side of body



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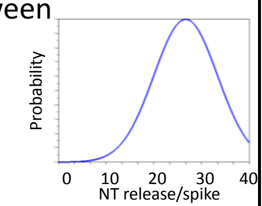
Precise motion in an imprecise world

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

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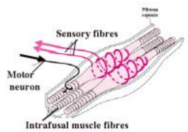
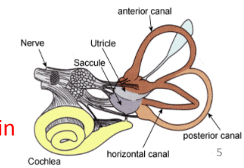
Monitoring body motion

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



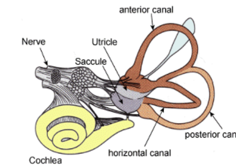
- Head rotations – inner ear; semi-circular canals

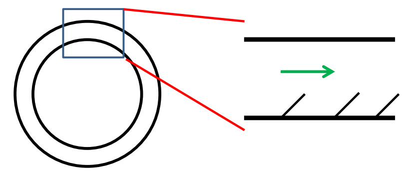


Anterior: Sagittal spin **Posterior**: Coronal spin
Horizontal: Axial spin

Vestibular system

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

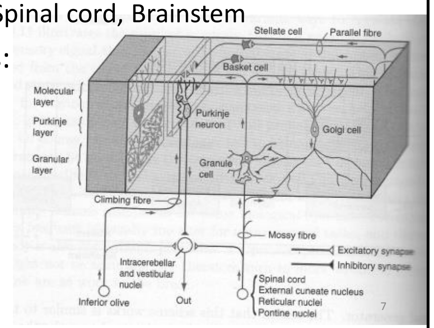




1. Head rotates
2. Fluid flows
3. Hairs displaced

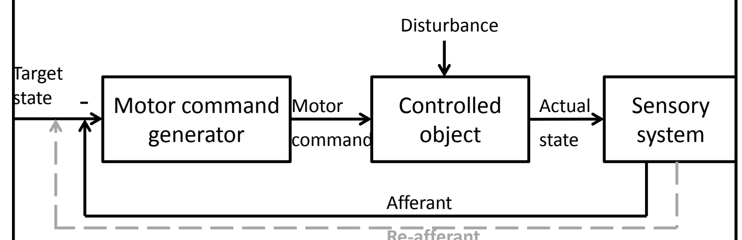
Adjusting motion with the cerebellum

- 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

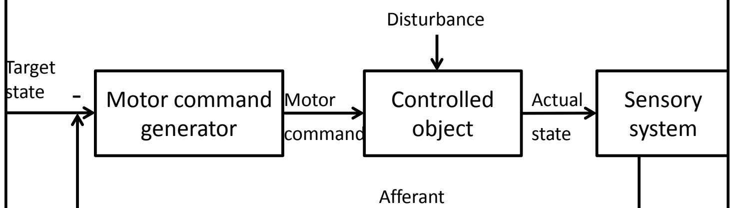


Afferant – muscle sensors

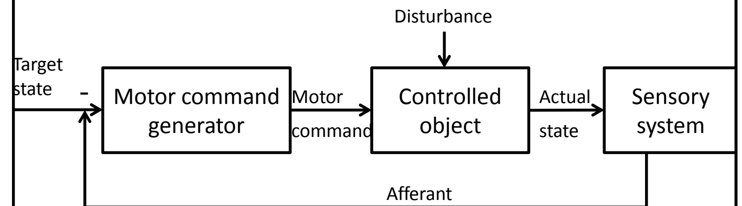
Re-afferant – visual sensors

Motor command generation

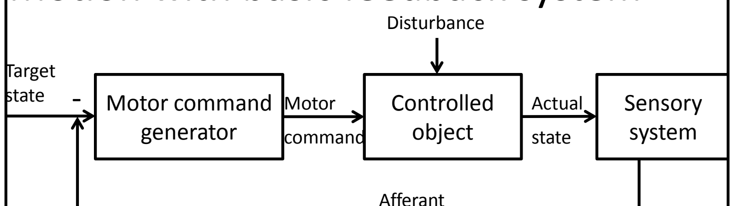
swing leg forward -> rotate leg using muscle force



Motion with basic feedback system

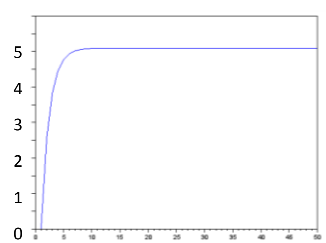


Motion with basic feedback system

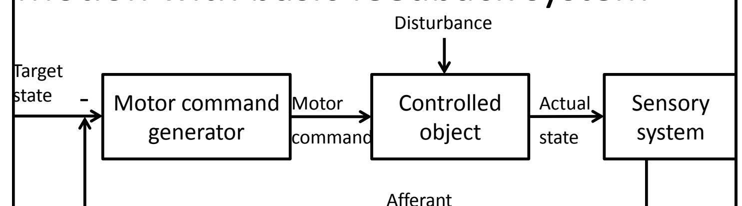


Move = 1/2 x (Target-Current)

Target: 5
t=1 Start at 0

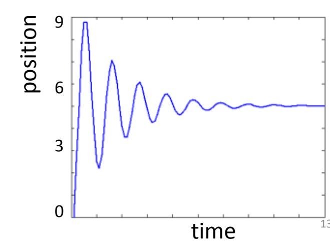


Motion with basic feedback system



Move = 1/2 x (Target-Sensed)

Target: 5
t=1 Start at 0
Sense delay: 2 time points



Motion strategy

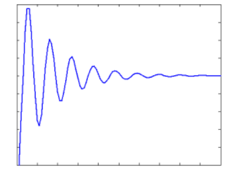
Move = 1/2 x (**T**arget-**S**ensed)

	t=1	t=2	t=3	t=4	t=5	t=6
Sense	0	0	0	2.5	5	7.5
Move	+2.5	+2.5	+2.5	+1.25	0	-1.25
Actual	0	2.5	5	7.5	8.75	8.75

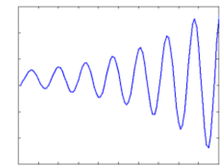
Target: 5
t=1 Start at 0
2 time point sensation delay

Delay-based Oscillations

Update: ½
Delay=2 time points



- If sense delay and update fraction (**1/2**x(Targ-Sens)) are small, oscillations will converge to target
- If sense delay and/or update fraction (**1/2**x(Targ-Sens)) are large, oscillations will get larger and NOT converge to target



Update: ½
Delay=3 time points

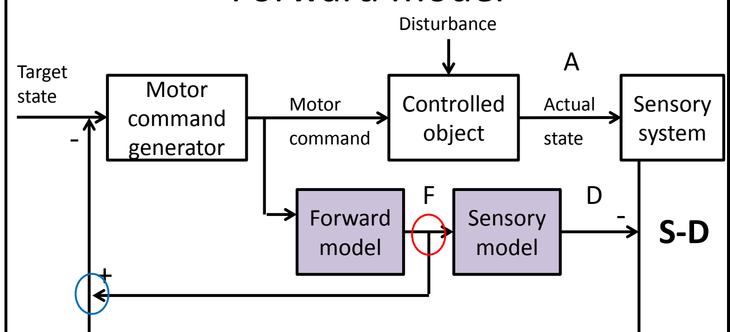
Expanded control theory

Challenge: Waiting for afferent feedback is slow

Solutions:

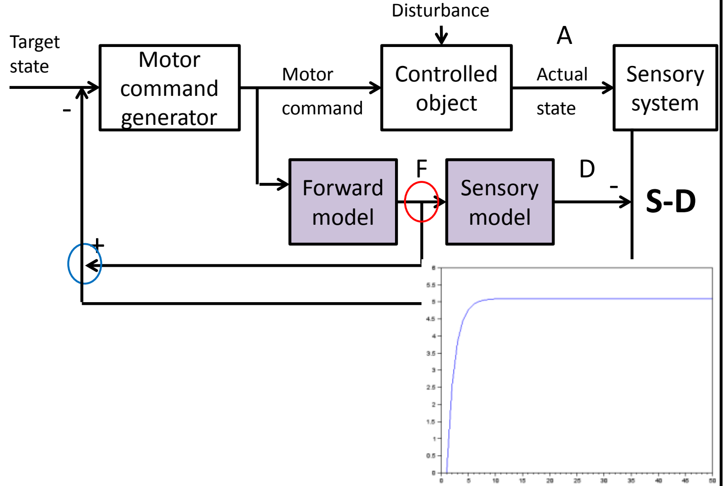
- Anticipate typical motion progress – **forward model**
- Account for typical motion progress from the beginning – **inverse model**

Forward model



- Forward: Adjust motion based on predicted position
- Delay: Predicted motion with time delay
- Sense: Adjust predicted error based on actual position
- Adjust models (over longer experience)

Motion with forward model



Motion strategy

Move = 1/2 x (**T**arget-**F**orward-(**S**ensed-**D**elay))

	t=1	t=2	t=3	t=4	t=5	t=6
Sense	0	0	0	2.5	3.75	4.38
Forward	0	2.5	3.75	4.38	4.69	4.85
Delay	0	0	0	2.5	3.75	4.38
Actual	0	2.5	3.75	4.38	4.69	4.85
Move	**+2.5**	**+1.25**	**+.63**	**+.31**	**+.16**	**+.08**

Target: 5
t=1 Start at 0
2 time point sensation delay

$\mathbf{Forward_t = Forward_{t-1} + Move_{t-1}}$
$\mathbf{Delay_t = Forward_{t-delay}}$

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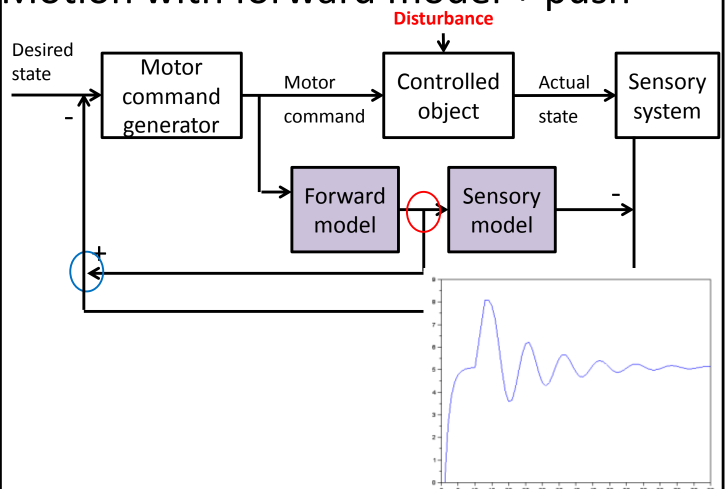
Motion with forward model + push



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 +0.32-2/2	
	1	2	3	4	5
A	0	4.5	5.75	6.38	5.7
F	0	2.5	3.75	4.38	4.7
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

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