# Systems Neuroscience
# CISC 3250

Motor control

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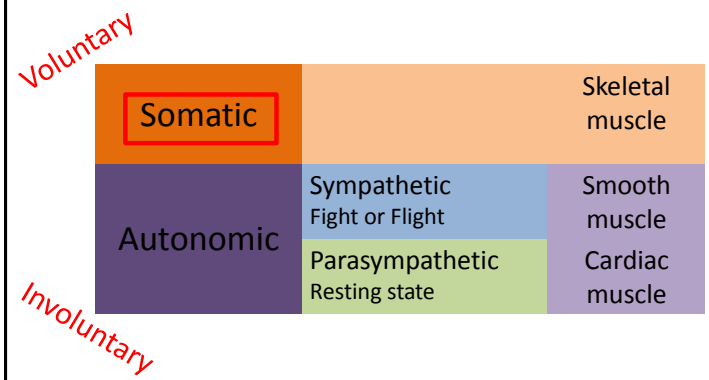
JMH 332

## Classes of motion

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## Pathways to motion in (typically) 2 synaptic steps

0 Command from primary motor cortex (M1)

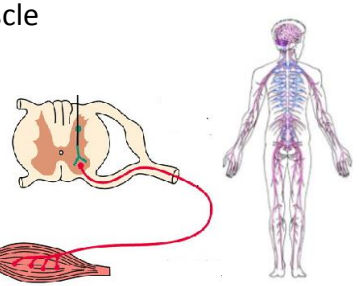
1 Synapse onto neuron in spinal cord/cranial nerve

2 Synapse onto muscle

**Efferent** – motor message **out**

**Afferent** – perceptual message **in**

**Cortical commands sent to contralateral side of body**



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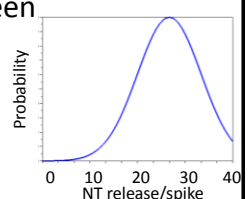
## Precise motion in an imprecise world

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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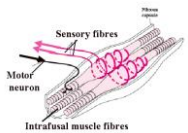
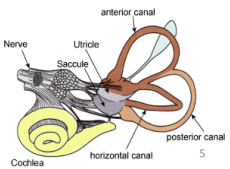
# Monitoring body motion

- 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

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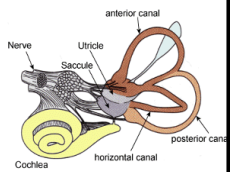
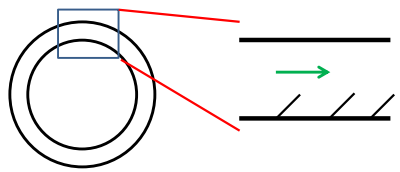
# Vestibular system

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



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

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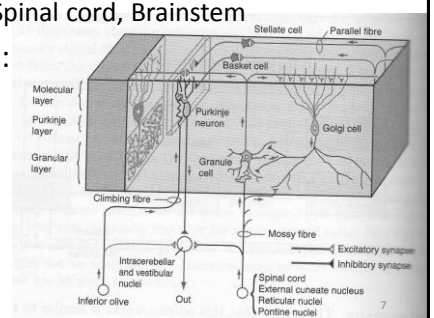
# Adjusting motion with the cerebellum

- 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

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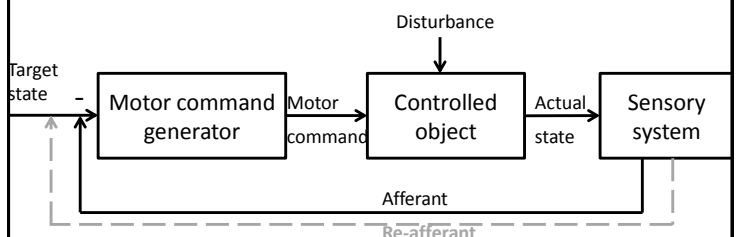
# Control theory

## Correcting errors in motion




Afferant – muscle sensors

Re-afferant – visual sensors

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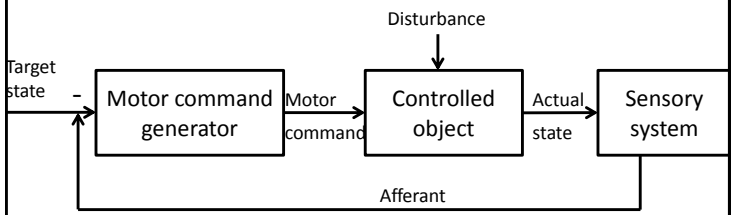
# Motor command generation

swing leg forward -> rotate leg using muscle force

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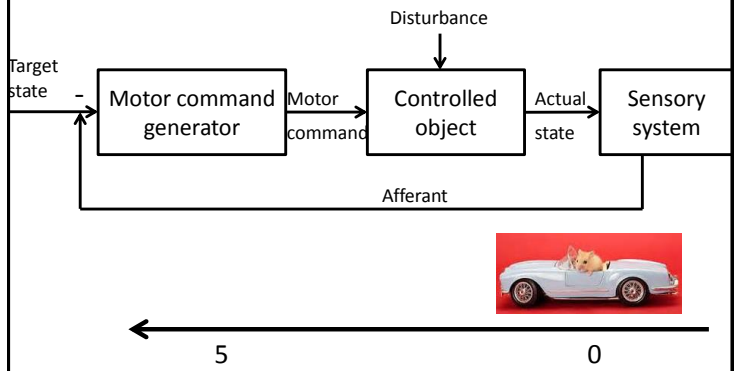
# Motion with basic feedback system

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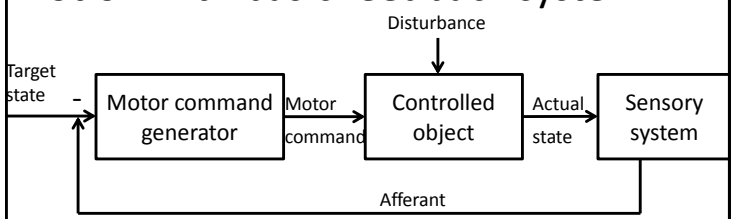
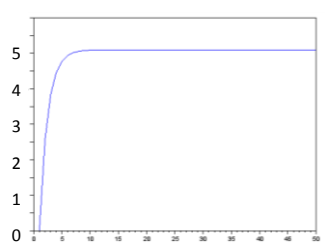
# Motion with basic feedback system




**M**ove = 1/2 x (**T**arget-**C**urrent)

**T**arget: 5
t=1 Start at 0




# Motion strategy

**M**ove = 1/2 x (**T**arget-**C**urrent)

| | t=1 | t=2 | t=3 | t=4 | t=5 |
|---|---|---|---|---|---|
| Sense | 0 | 2.5 | 3.75 | 4.38 | 4.69 |
| Move | +2.5 | +1.25 | +.63 | +.31 | … |
| Actual | 0 | 2.5 | 3.75 | 4.38 | 4.69 |

**T**arget: 5
t=1 Start at 0

$Actual_t = Actual_{t-1} + Move_{t-1}$
$Sense_t = Actual_{t-delay}$

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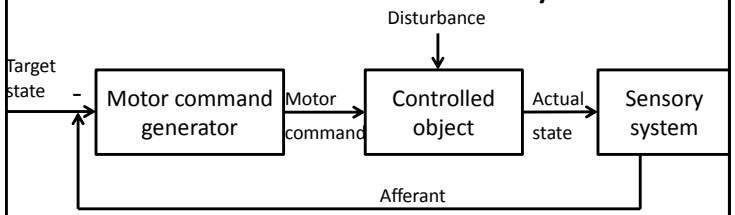
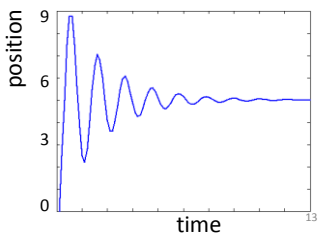
# Motion with basic feedback system




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

**T**arget: 5
t=1 Start at 0
Sense delay: 2 time points

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# Motion strategy

**M**ove = 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 |

**T**arget: 5
t=1 Start at 0
2 time point sensation delay

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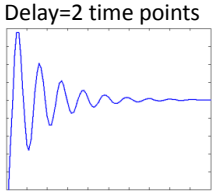
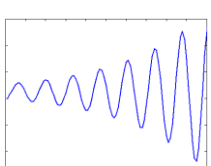
# Delay-based Oscillations

- 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=2 time points





Update: ½
Delay=3 time points

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# Simulating in Matlab

```
target=5;
actual(1)=0;
actual(2)=2.5;
actual(3)=5;
for t=3:49,
  sens(t)=actual(t-2);
  mov(t)=1/2*(target-sens(t));
  actual(t+1)=actual(t)+mov(t);
end;
```

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# 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**

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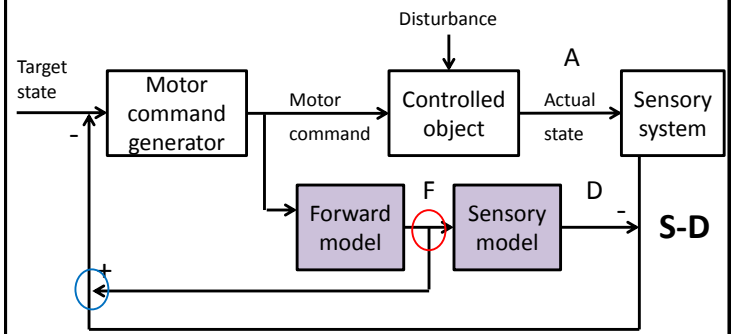
# Forward model




- 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)

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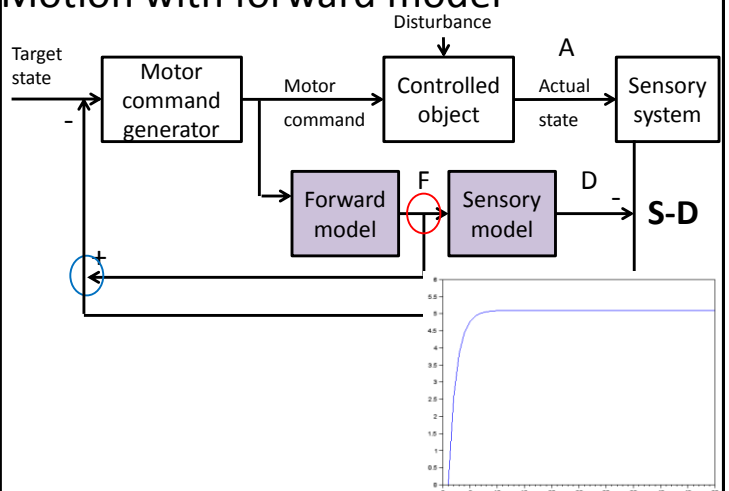
# Motion with forward model




# Motion strategy

**M**ove = 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

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

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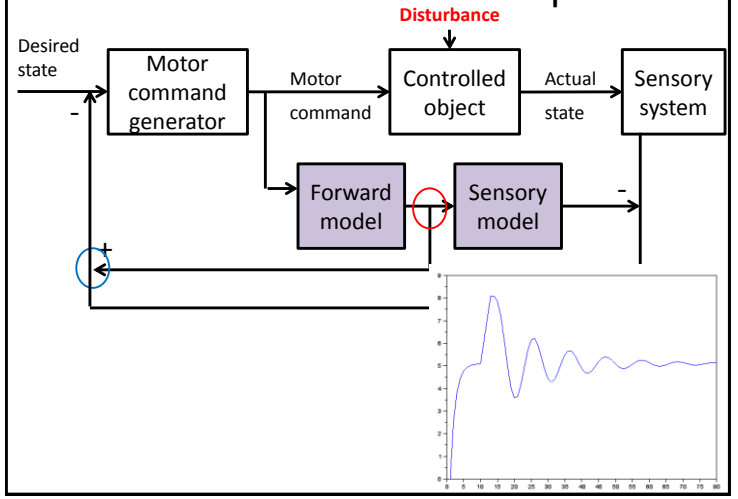
# Motion with forward model + push




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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