**Systems Neuroscience**  
**CISC 3250**

Motor control

Professor Daniel Leeds  
dleeds@fordham.edu  
JMH 332

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**Classes of motion**

<table>
<thead>
<tr>
<th>Voluntary</th>
<th>Involuntary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Somatic</strong></td>
<td><strong>Autonomic</strong></td>
</tr>
<tr>
<td>Skeletal muscle</td>
<td>Smooth muscle</td>
</tr>
<tr>
<td>Sympathetic</td>
<td>Parasympathetic</td>
</tr>
<tr>
<td>Fight or Flight</td>
<td>Resting state</td>
</tr>
<tr>
<td>Cardiac muscle</td>
<td></td>
</tr>
</tbody>
</table>

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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
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

Motor command generator ➔ Motor command ➔ Controlled object ➔ Actual state ➔ Sensory system

Afferant – muscle sensors
Re-afferant – visual sensors
Motor command generation

swing leg forward -> rotate leg using muscle force

Motion with basic feedback system

\[ \text{Move} = \frac{1}{2} \times (\text{Target} - \text{Current}) \]

\( \text{Target}: 5 \)

\( t=1 \) Start at 0

Sense delay: 2 time points
Motion strategy

\[ \text{Move} = \frac{1}{2} \times (\text{Target} - \text{Sensed}) \]

<table>
<thead>
<tr>
<th>t=1</th>
<th>t=2</th>
<th>t=3</th>
<th>t=4</th>
<th>t=5</th>
<th>t=6</th>
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<tbody>
<tr>
<td>Sense</td>
<td>0</td>
<td>0</td>
<td>2.5</td>
<td>5</td>
<td>7.5</td>
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<tr>
<td>Move</td>
<td>+2.5</td>
<td>+2.5</td>
<td>+2.5</td>
<td>+1.25</td>
<td>0</td>
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<tr>
<td>Actual</td>
<td>0</td>
<td>2.5</td>
<td>5</td>
<td>7.5</td>
<td>8.75</td>
</tr>
</tbody>
</table>

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

Delay-based Oscillations

- If sense delay and update fraction \((1/2 \times (\text{Targ} - \text{Sens}))\) are small, oscillations will converge to target
- If sense delay and/or update fraction \((1/2 \times (\text{Targ} - \text{Sens}))\) are large, oscillations will get larger and NOT converge to target

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

\[ \text{Move} = \frac{1}{2} \times (\text{Target} - \text{Forward} - (\text{Sensed} - \text{Delay})) \]

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<td>0</td>
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<td>3.75</td>
</tr>
<tr>
<td>Forward</td>
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<td>3.75</td>
<td>4.38</td>
<td>4.69</td>
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<tr>
<td>Delay</td>
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<td>0</td>
<td>0</td>
<td>2.5</td>
<td>3.75</td>
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<tr>
<td>Actual</td>
<td>0</td>
<td>2.5</td>
<td>3.75</td>
<td>4.38</td>
<td>4.69</td>
</tr>
<tr>
<td>Move</td>
<td>+2.5</td>
<td>+1.25</td>
<td>+.63</td>
<td>+.31</td>
<td>+.16</td>
</tr>
</tbody>
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Target: 5
\( t=1 \) Start at 0
2 time point sensation delay

Motion with forward model + push

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

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<tbody>
<tr>
<td>A</td>
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<td>4.5</td>
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Compare model motion and actual motion after 2 time step delay

\( \text{Moved by } +2.5 \) Pushed by +2
\( \text{Moved by } +1.25 \) -
\( \text{Moved by } +0.63 \) -
\( \text{Moved by } +0.32-2/2 \)