Agenda

14:00 – 14:15	Welcome and goals of workshop *– Jen Hicks*
14:15 – 14:35	**Inverse dynamics and static optimization: how it works, exercises, & practice** ***– Jeff Reinbolt***
14:35 – 15:00	Guided analyses and exploration on your own *– Jeff Reinbolt & You*
15:00 – 15:20	Forward dynamics simulation: how it works, exercises, & practice *– Jeff Reinbolt*
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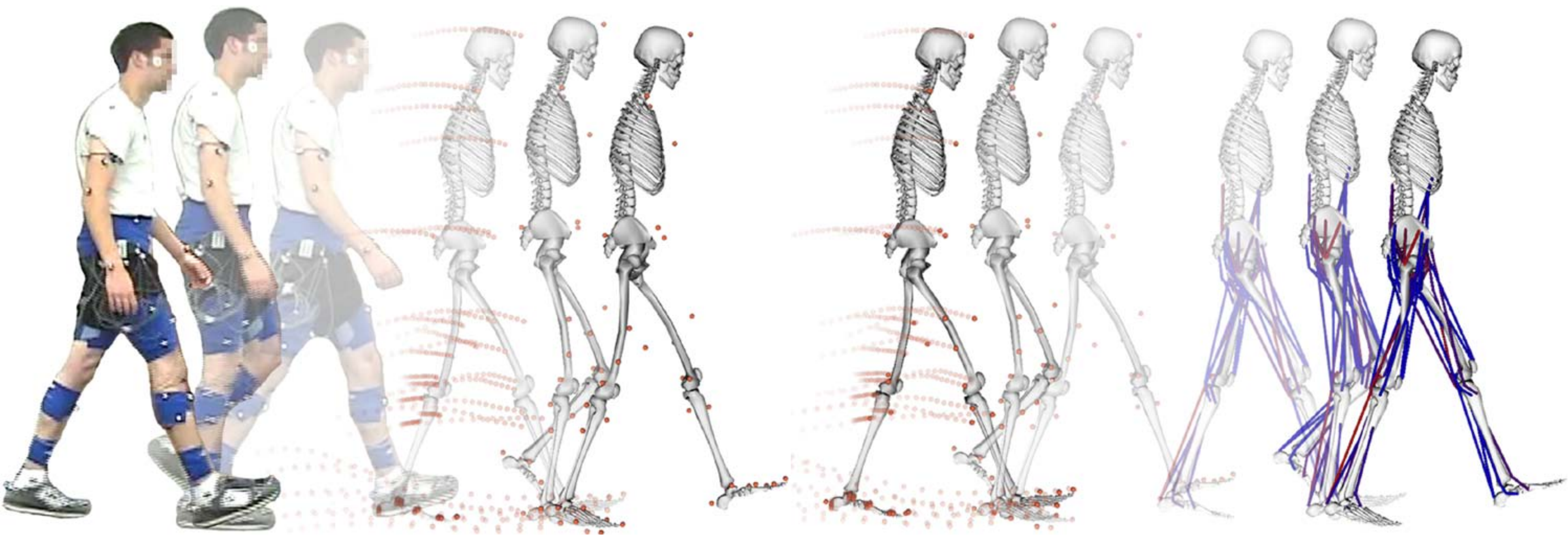
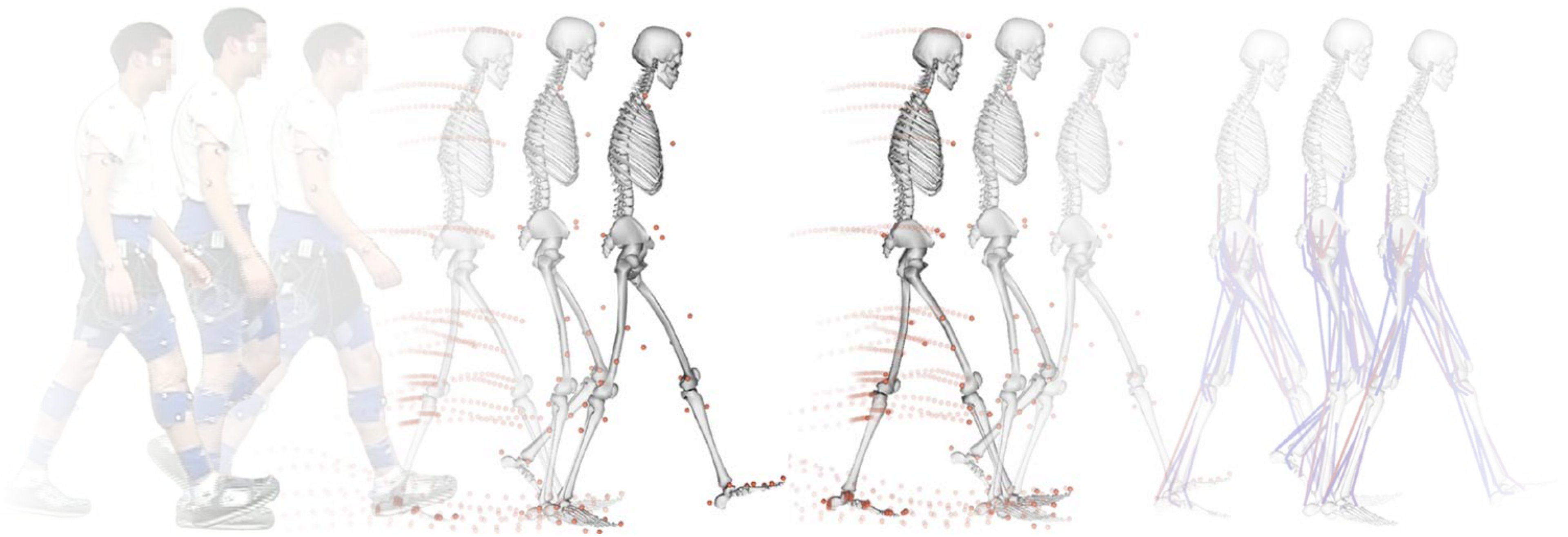
15:45 – 16:05	Interfacing OpenSim models with MATLAB/Simulink *– Jeff Reinbolt*
16:05 – 16:55	Guided control system design and exploration on your own *– Jeff Reinbolt & You*
16:55 – 17:00	Closing remarks *– Jen Hicks*



Inverse Kinematics

Inverse Dynamics

Static Optimization



Inverse Kinematics

Inverse Dynamics

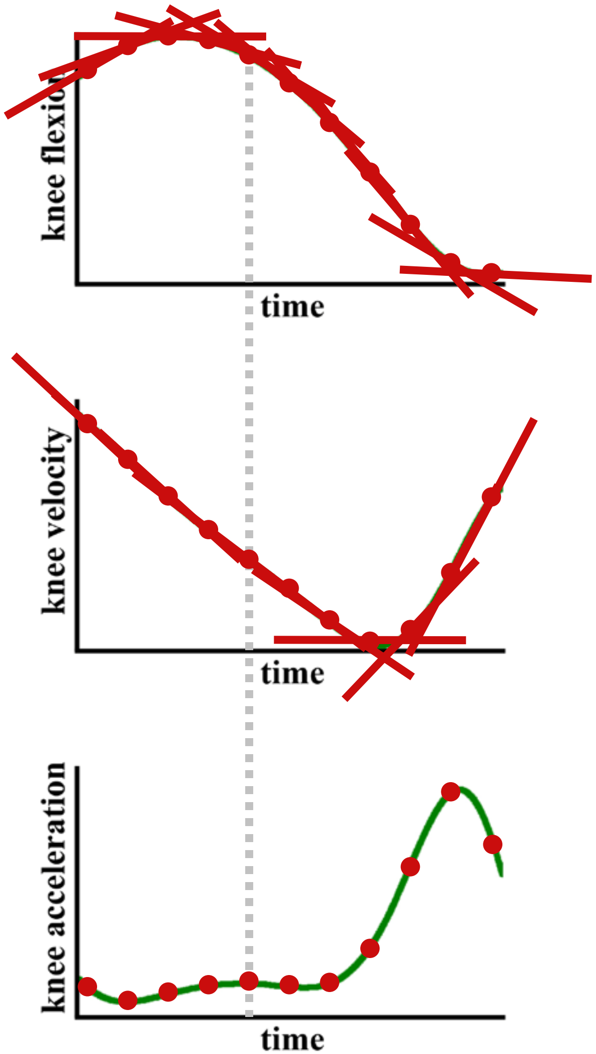
Static Optimization

Key Concepts

- **Kinematics** coordinates and their velocities and accelerations
- **Kinetics** forces and torques
- **Dynamics** equations of motion

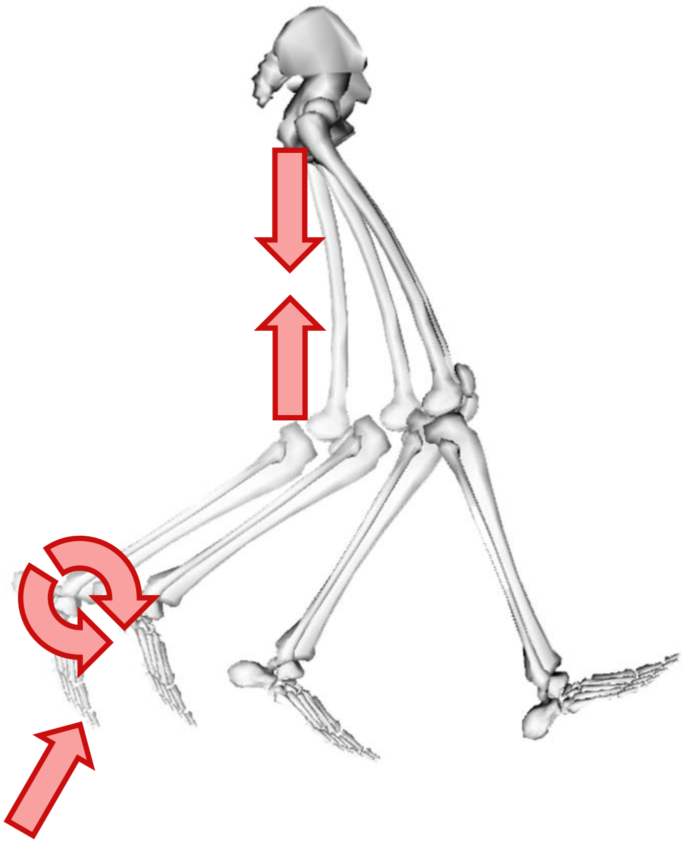
Kinematics: Coordinates and their Velocities and Accelerations

- Coordinate
  - Joint angle or distance specifying relative orientation or location of two body segments
- Coordinate velocity
  - Derivative (rate of change) of a coordinate with respect to time
- Coordinate acceleration
  - Time derivative of a coordinate velocity with respect to time
- Kinematics
  - Set of all coordinates and their velocities and accelerations



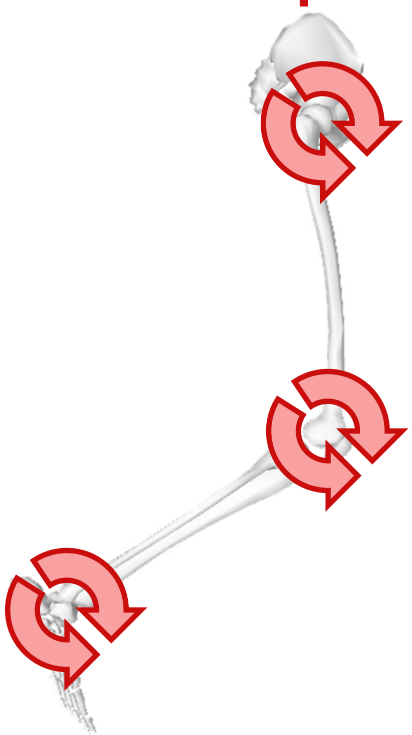
Kinetics: Forces and Torques

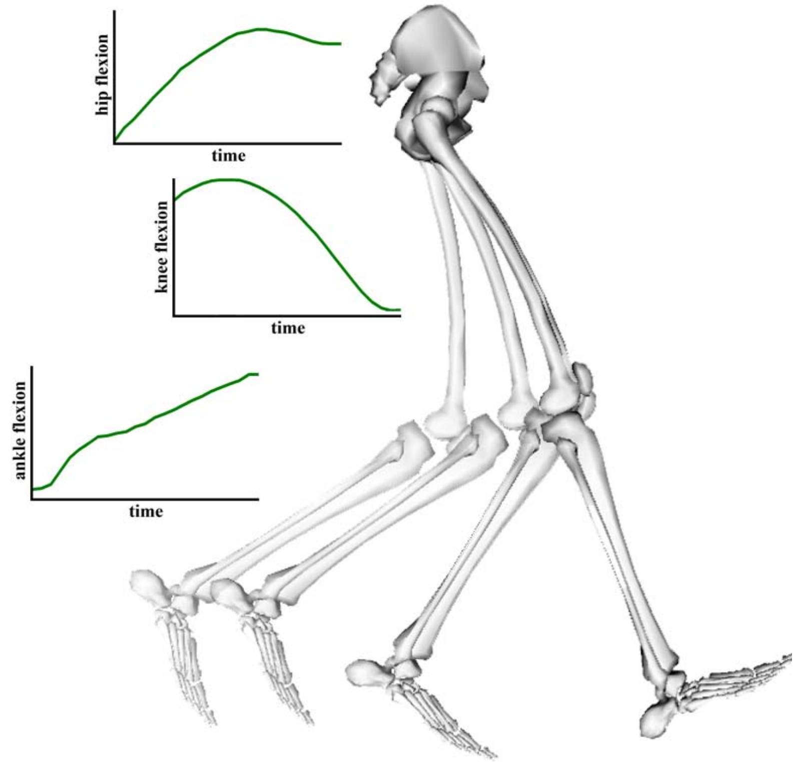
- Kinetics
  - Forces and torques cause the model to accelerate
- Force
  - Applied to points (e.g., ground reactions) or between points (e.g., muscles)
- Torque
  - Applied to a coordinate (e.g., joint torque)



Dynamics: Equations of Motion

$$\underbrace{\boldsymbol{\tau}}_{\text{unknowns}} = \underbrace{\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} - \boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}}) - \boldsymbol{G}(\boldsymbol{q}) - \boldsymbol{F}}_{\text{knowns}}$$





Exercise

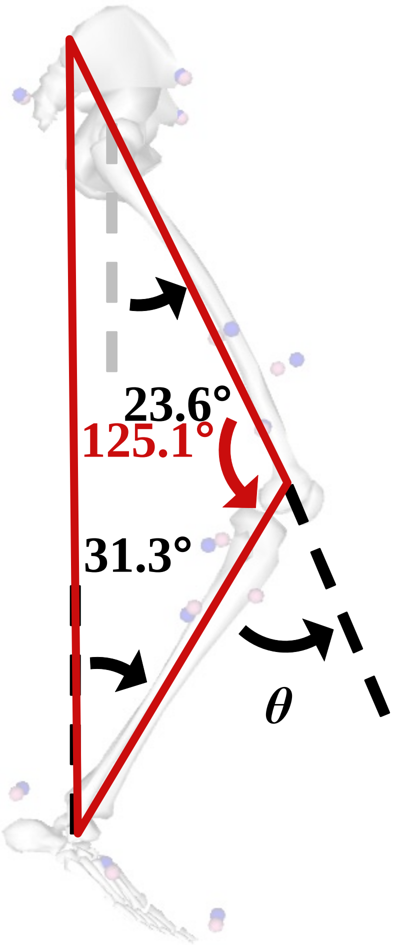
1. For the model shown on the right, what is the **value ($\boldsymbol{\theta}$)** of the **knee** coordinate (*Note:* **extension is +**)?

   A. 23.6°

   B. -54.9°

   C. 31.3°

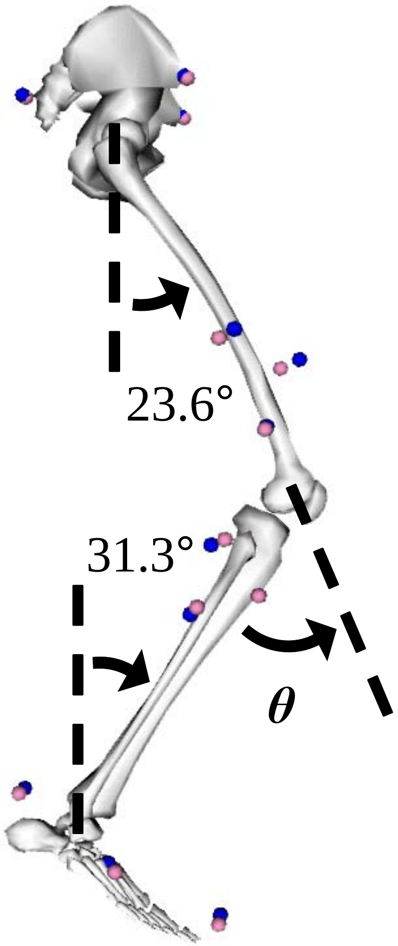
   D. -125.1°



Exercise

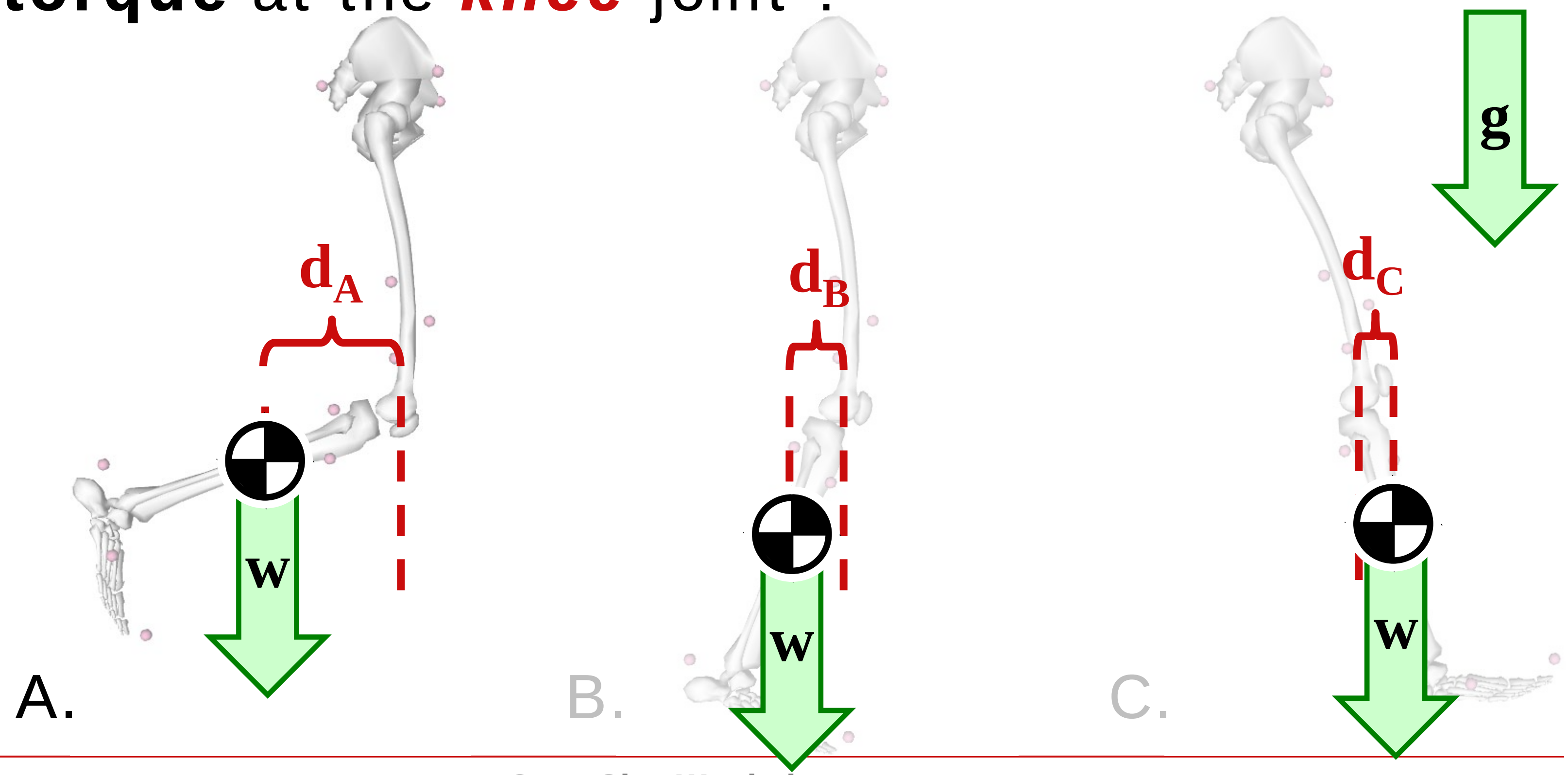
2. Given that the **model** shown on the right is ***at rest***, what is the **velocity** of the knee?

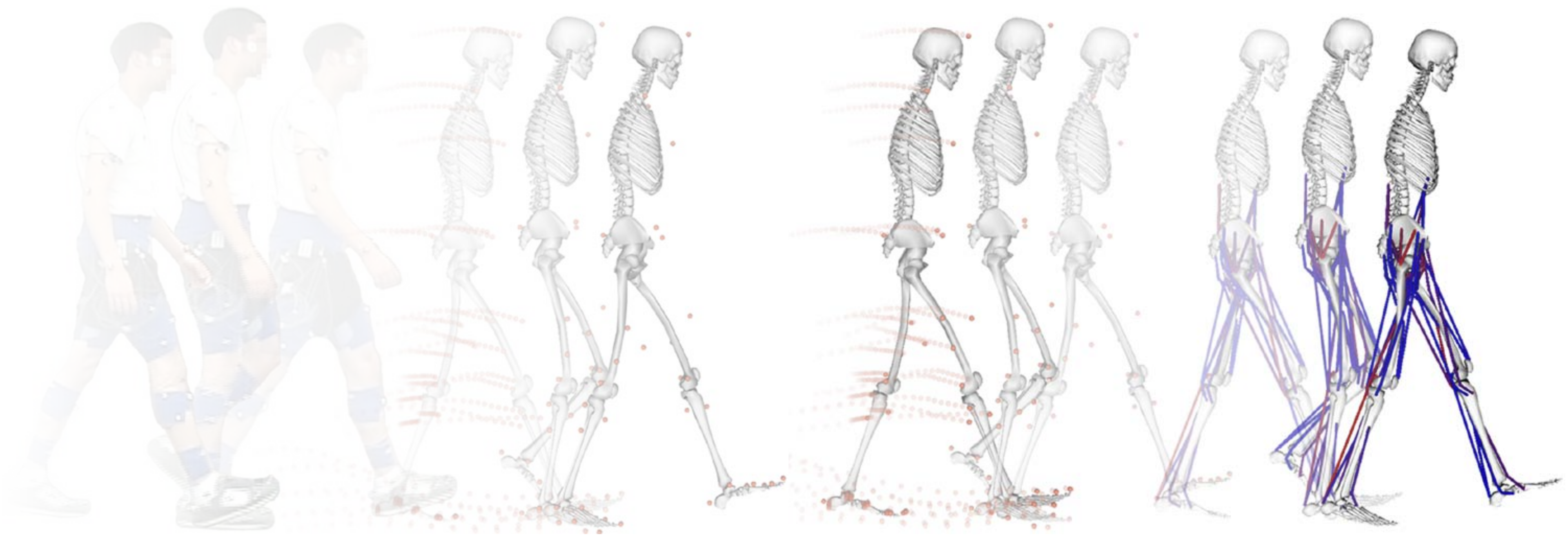
   A. 23.6°/s
   B. -54.9°/s
   C. 3.89°/s
   D. 0°/s



Exercise

3. For the **model poses** shown below ***at rest*** and with **gravity (*g*)** as the ***only force*** acting on the model, **which pose** requires the ***largest* torque** at the ***knee*** joint ?





Inverse Kinematics

Inverse Dynamics

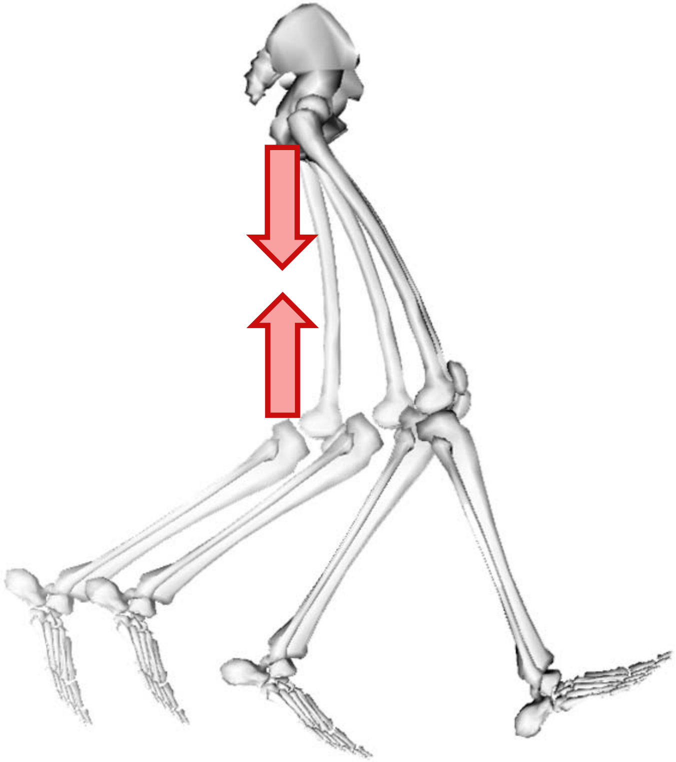
Static Optimization

Key Concepts

• **Kinematics**	coordinates and their velocities and accelerations
• **Kinetics**	muscle forces
• **Muscle physiology**	muscle activation-contraction dynamics and force-length-velocity relations
• **Dynamics**	equations of motion
• **Musculoskeletal geometry**	muscle moment arm
• **Optimization**	the “distribution” problem

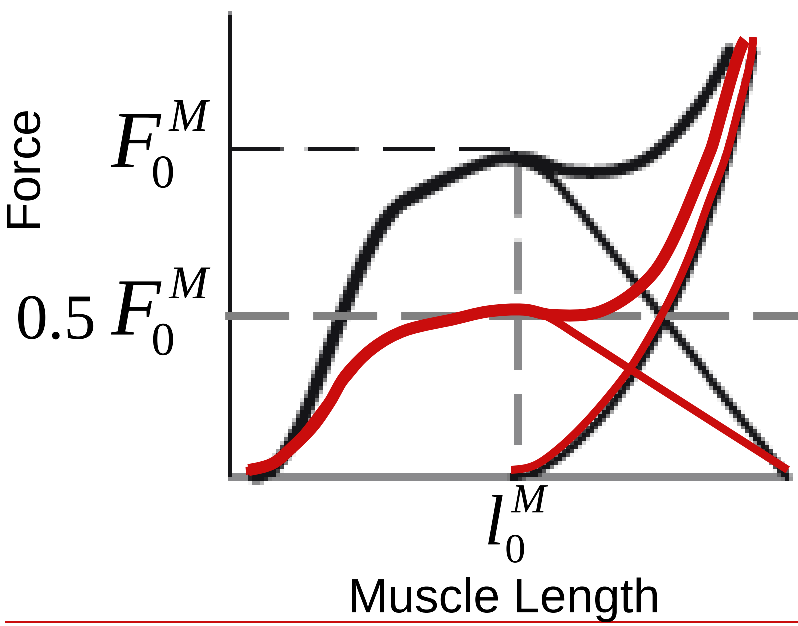
Kinetics: Muscle Forces

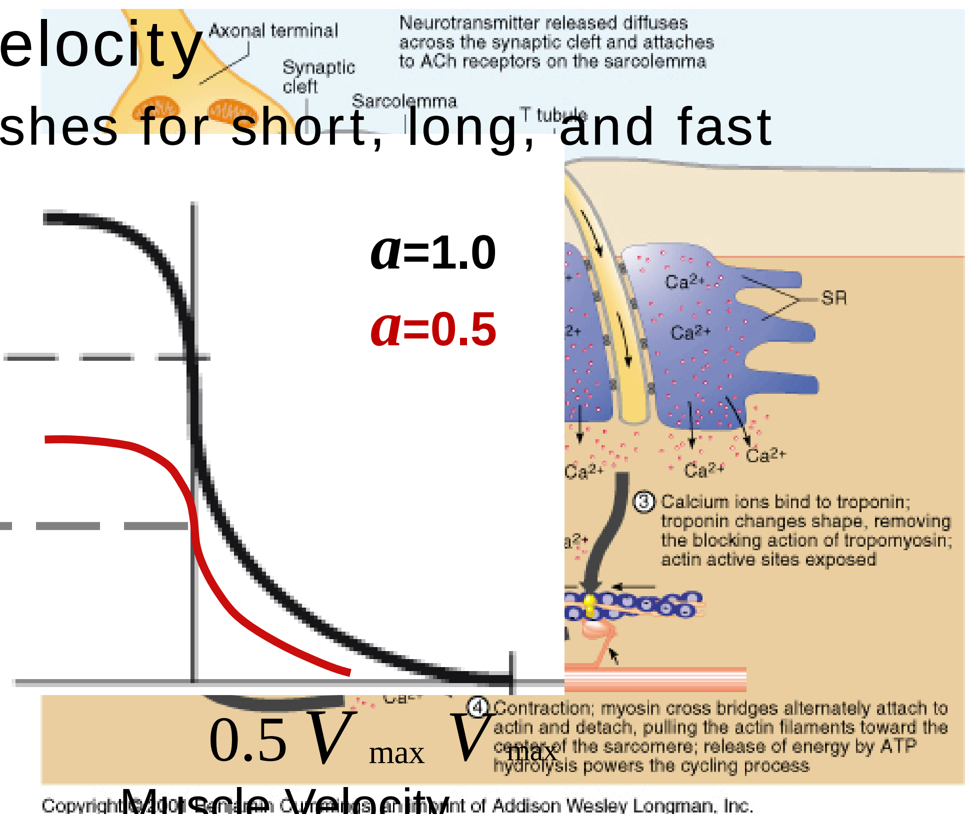
- Kinetics
  - Muscle forces cause the model to accelerate
- Muscle force
  - Applied between origin and insertion points



Muscle Physiology: Muscle Activation-Contraction and Force-Length-Velocity Relations

- Muscle activation-contraction
  - Biochemical reaction that causes a muscle's fibers to contract which produces force
- Muscle force-length-velocity
  - Force production diminishes for short, long, and fast fibers

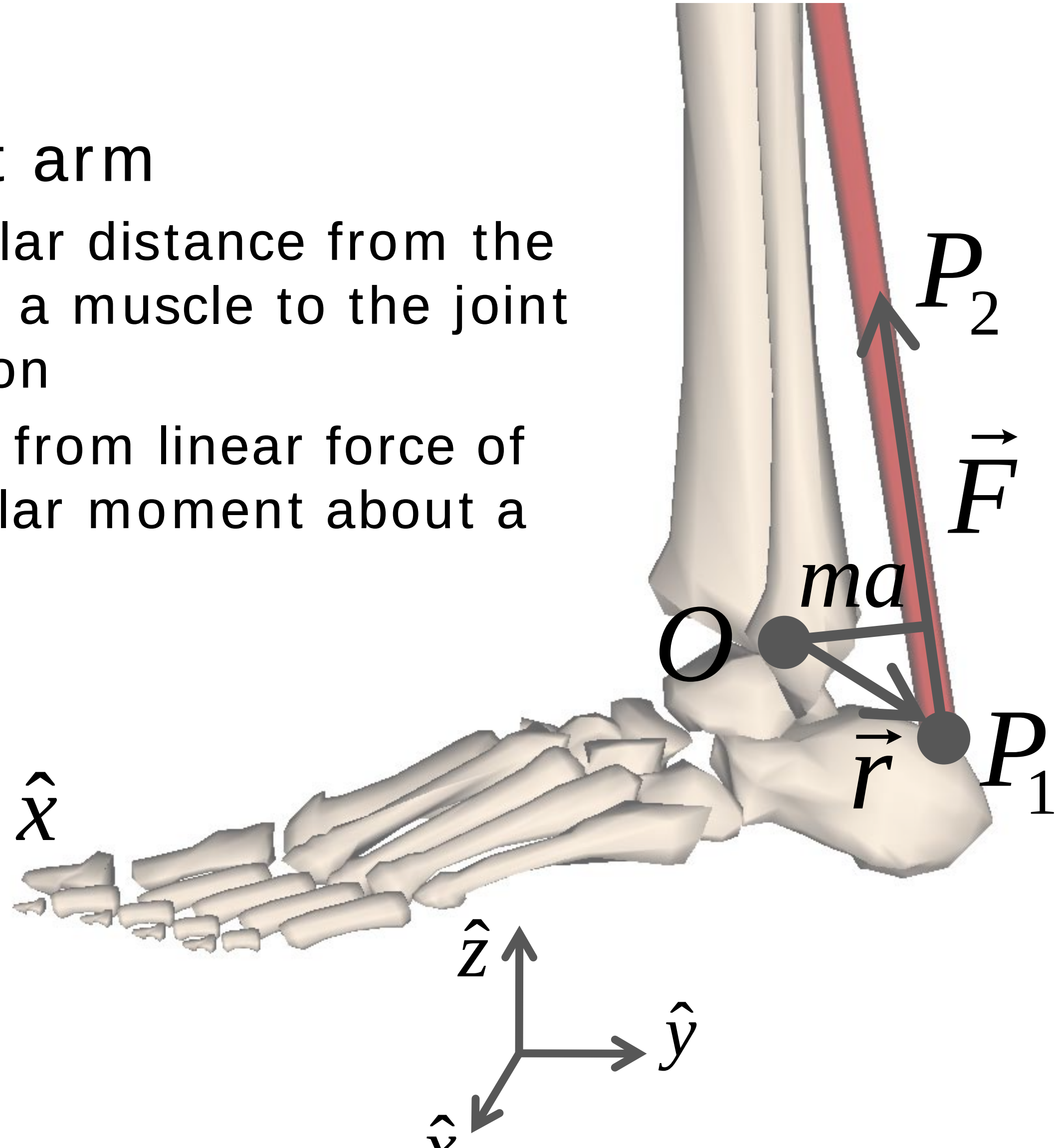




Musculoskeletal Geometry: Muscle Moment Arm

- Muscle moment arm
  - The perpendicular distance from the line of action of a muscle to the joint center of rotation
  - Transformation from linear force of muscle to angular moment about a joint center

$$ma_x = \frac{\vec{r} \times \vec{F}}{\left|\vec{F}\right|} \bullet \hat{x}$$



Optimization: The "Distribution" Problem

- The "distribution" problem
  - There are more unknown muscle forces than the number of coordinates

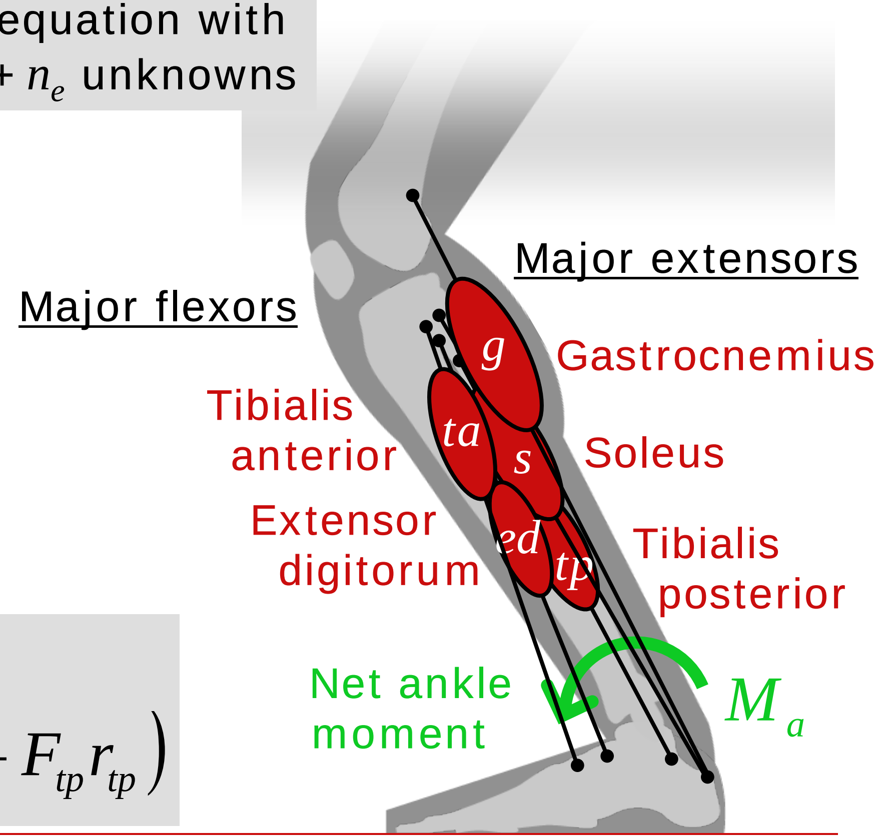
1 equation with $n_f + n_e$ unknowns

number of flexors

number of extensors

$$M_j = \underbrace{\sum_{f=1}^{nf} F_f r_f}_{\text{flexion moment}} - \underbrace{\sum_{e=1}^{ne} F_e r_e}_{\text{extension moment}}$$

moment arm



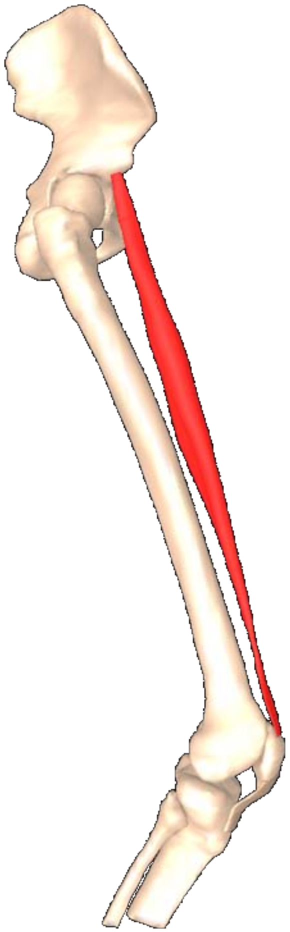
Ankle example

$$M_a = \left(F_{ta} r_{ta} + F_{ed} r_{ed}\right) - \left(F_g r_g + F_s r_s + F_{tp} r_{tp}\right)$$

Exercise

1. Given that the rectus femoris muscle has a peak isometric force of 1169 N and it is at its optimal fiber length and zero velocity, what is the force generated for an activation of 0.86?

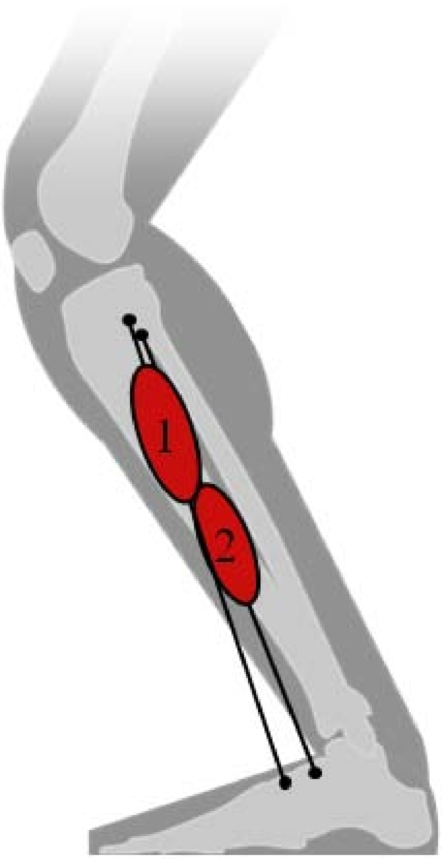
   A. 164 N
   B. 952 N
   C. 1005 N
   D. 1058 N



Exercise

2. For the model shown on the right, which muscle has the largest moment arm about the **ankle** joint?

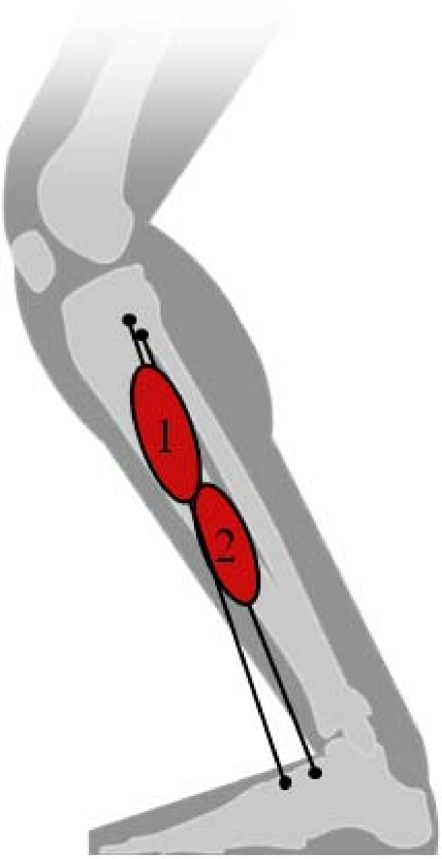
   A. 1
   B. 2
   C. Neither (are identical)



Exercise

3. For the model shown on the right, which muscle has the largest moment arm about the **knee** joint?

   A. 1
   B. 2
   C. Neither (are identical)

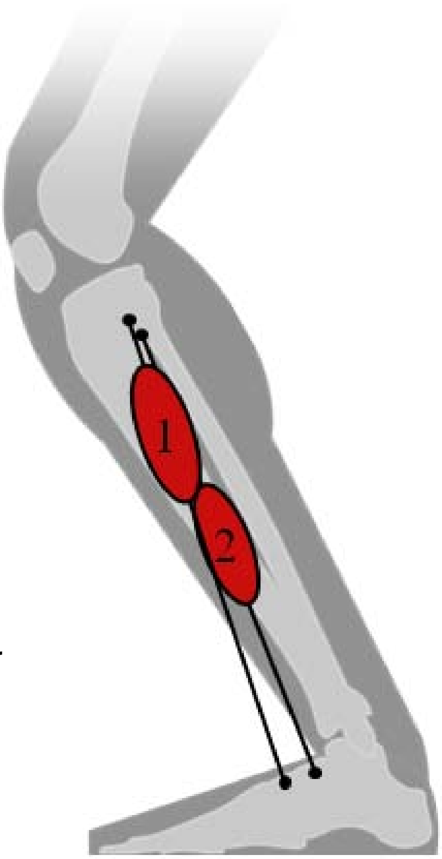


Exercise

4. For the model shown on the right, muscle 1 and 2 have the following properties

Muscle	Peak Isometric Force (N)	Moment Arm (cm)
1	905	3.6
2	512	3.0

To solve the "distribution" problem minimizing the sum of squared activations, which muscle would be activated more for a given dorsiflexion moment?



A. 1
B. 2
C. Neither (are identical)

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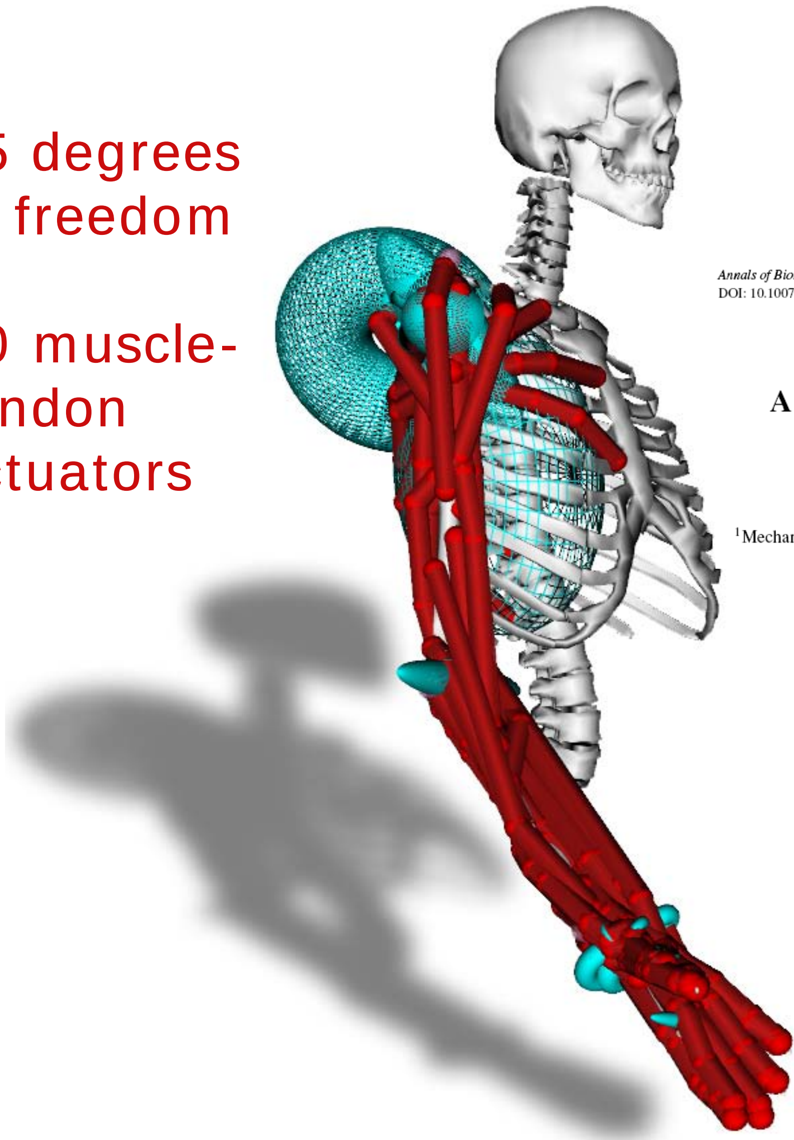
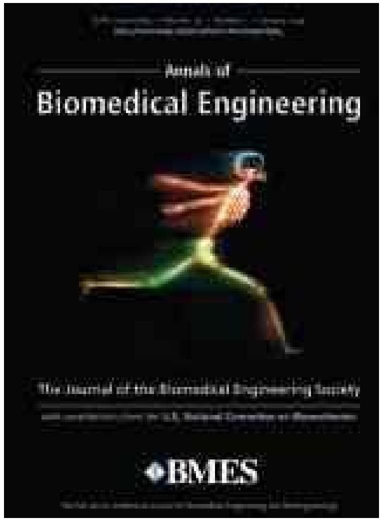
OpenSim Example: Upper Extremity

- 15 degrees of freedom
- 50 muscle-tendon actuators





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A Model of the Upper Extremity for Simulating Musculoskeletal Surgery and Analyzing Neuromuscular Control

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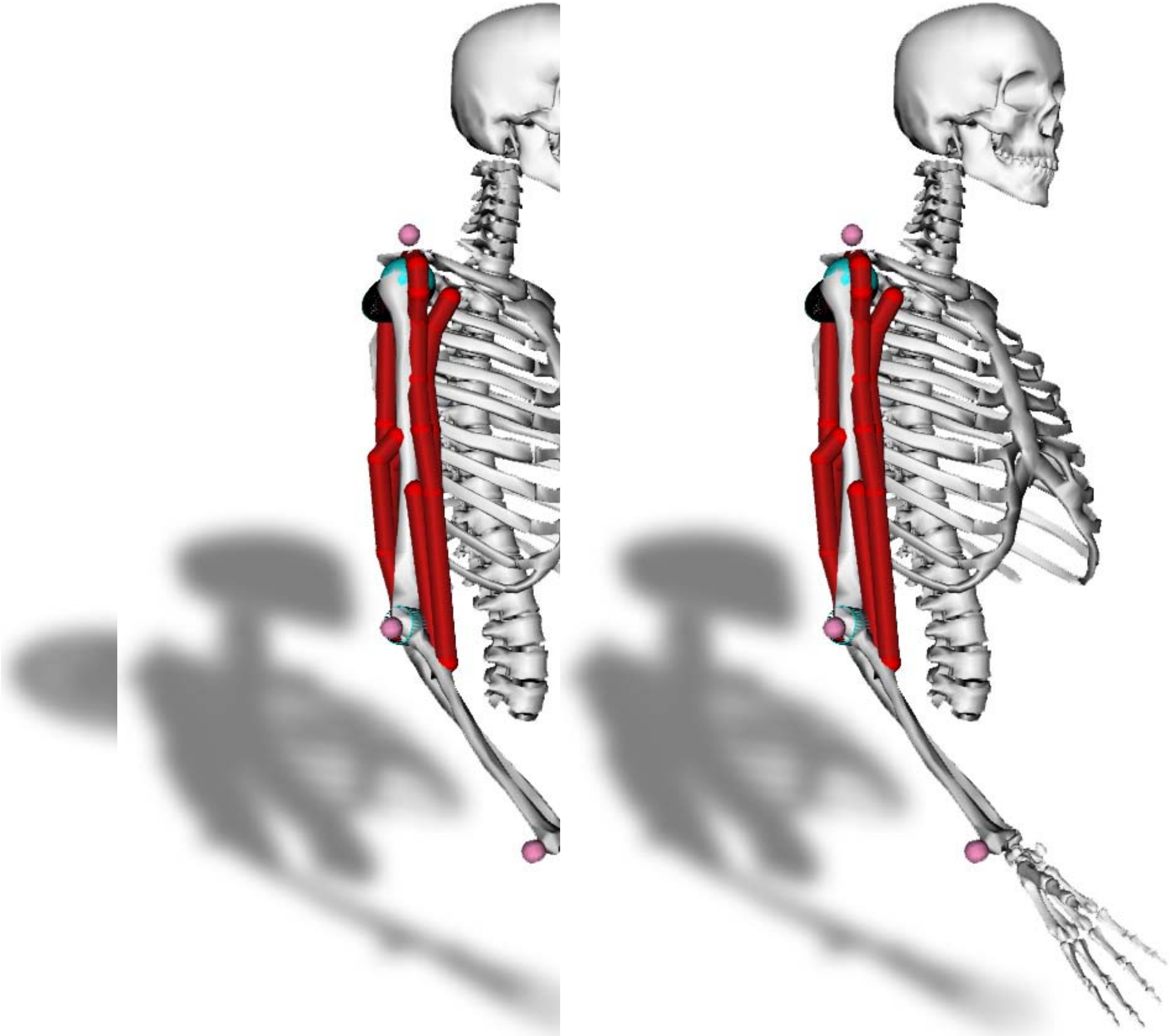
Kate Wendy Scott

OpenSim Example: Upper Extremity



OpenSim Example: Upper Extremity

Inverse Kinematics
- 2 Joints
- 3 Markers

Inverse Dynamics
- 2 Joint Moments

Static Optimization
- 6 Muscle-tendon actuators