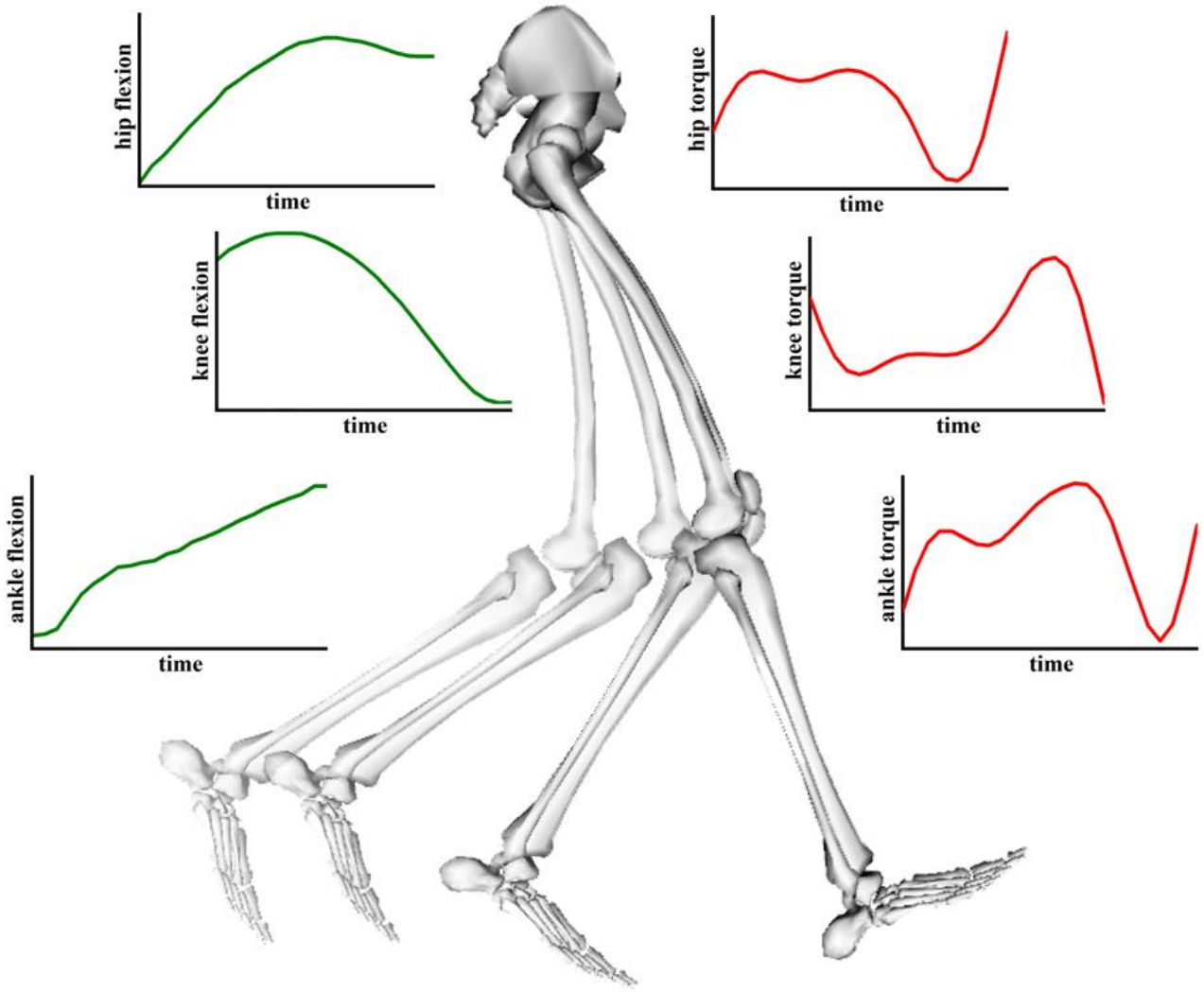


Inverse Dynamics

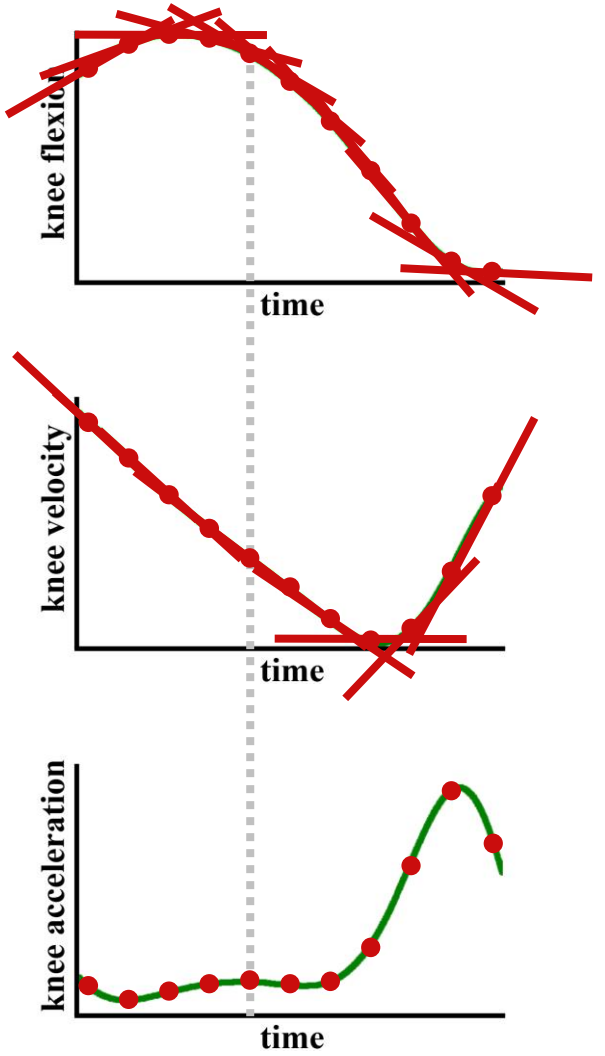
OpenSim Workshop

Key Concepts

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

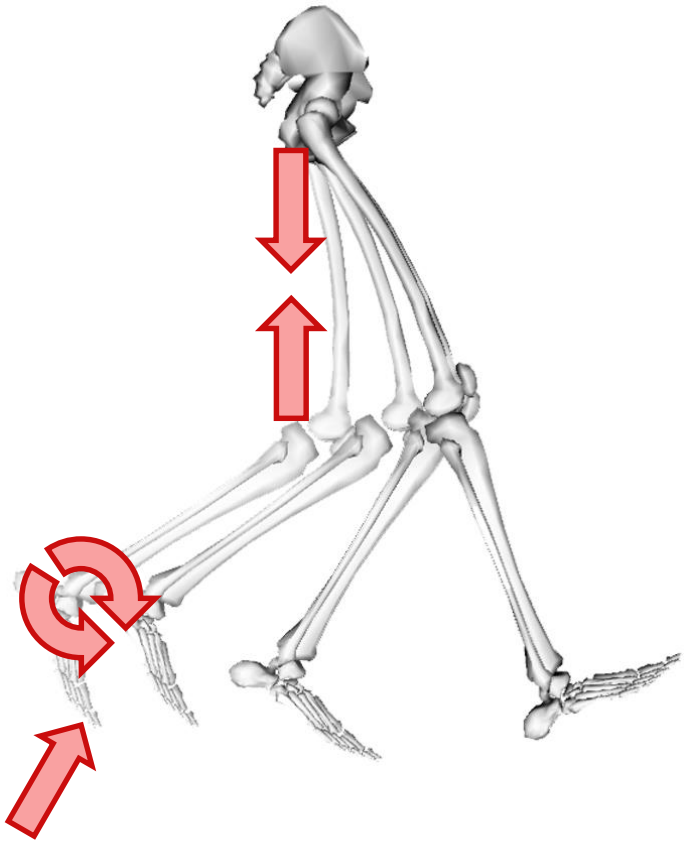
Kinematics: Coordinates and their Velocities and Accelerations

- 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



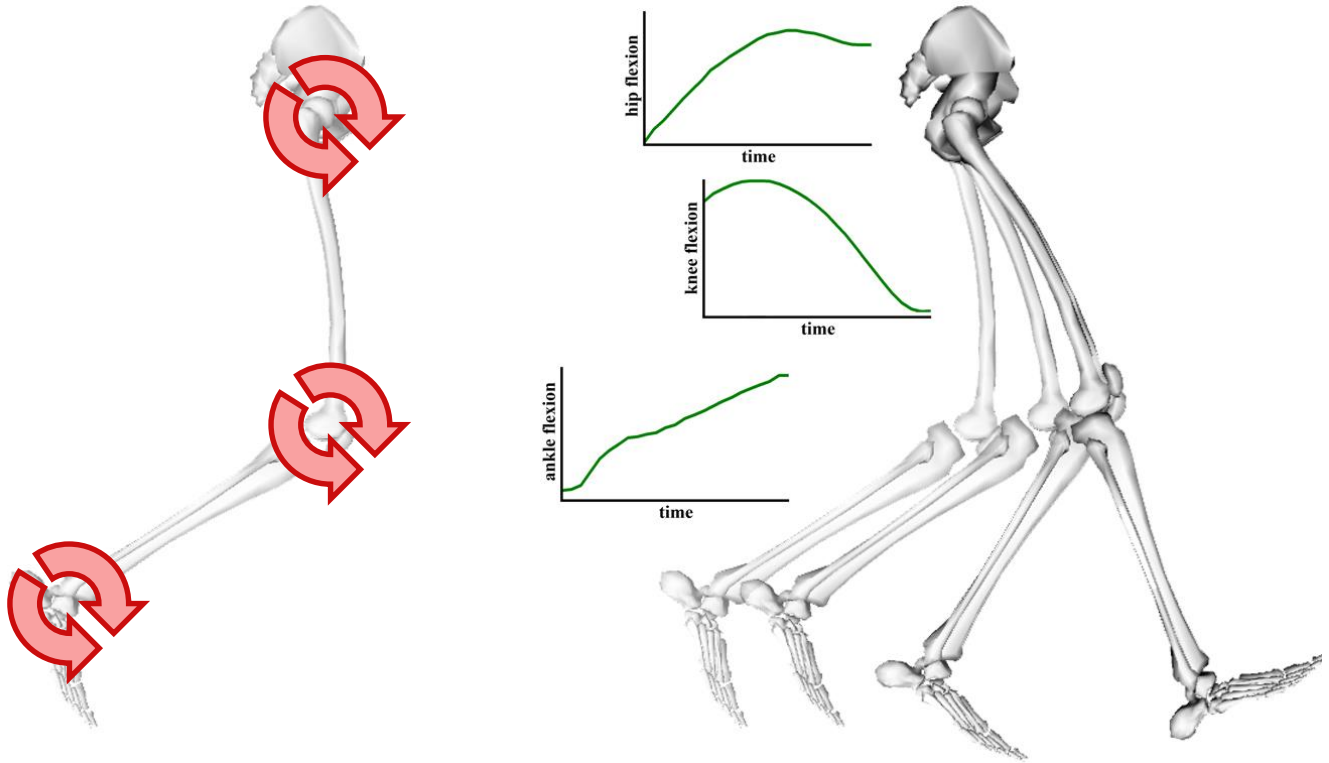
Kinetics: Forces and Torques

- 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)

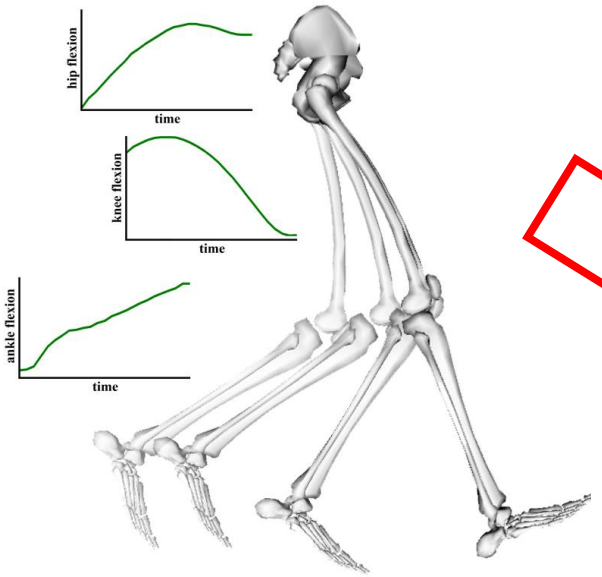


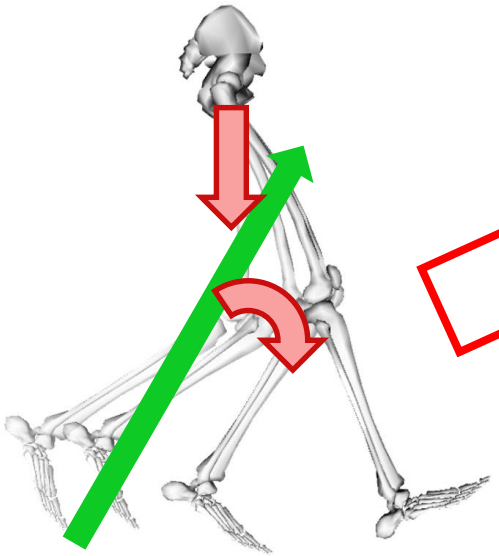
Dynamics: Equations of Motion

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



ID: Summary



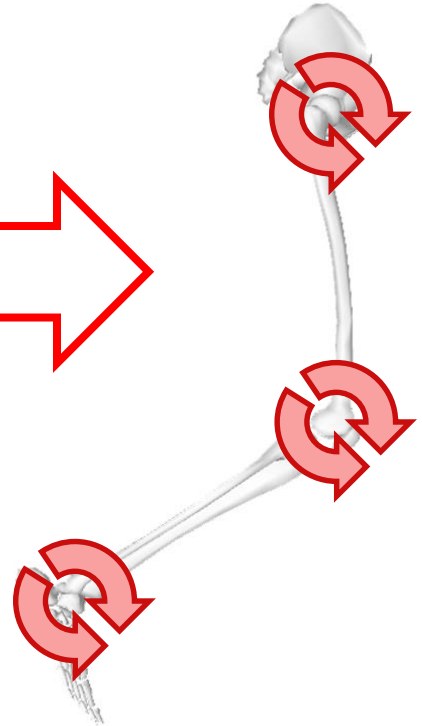


$$\underbrace{\boldsymbol{\tau}}_{\text{unknowns}} = \underbrace{\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} - \boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}}) - \boldsymbol{G}(\boldsymbol{q}) - \boldsymbol{F}}_{\text{knowns}}$$

ID

Generalized (joint) forces

- **NET JOINT FORCES**
- **NET JOINT MOMENTS**



Exercise

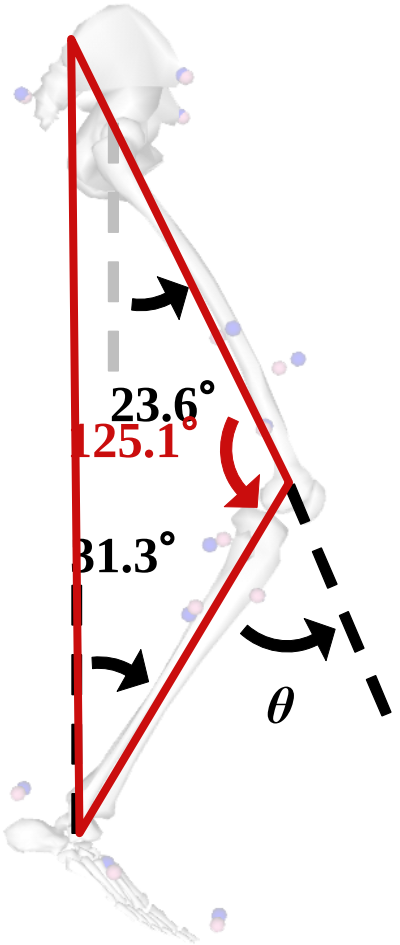
1. For the model shown on the right, what is the **value (*θ*)** of the **knee** coordinate (*Note:* **extension is +**)?

   A. 23.6°

   B. -54.9°

   C. 31.3°

   D. -125.1°



Exercise

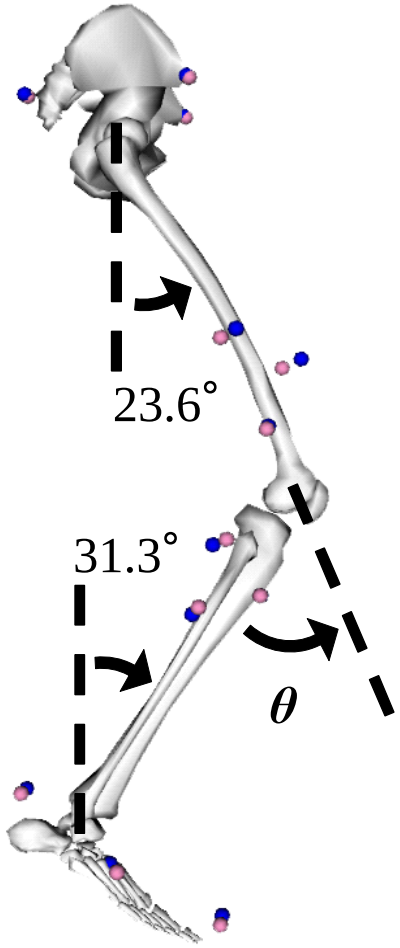
2. Given that the **model** shown on the right is ***at rest***, what is the **velocity** of the knee?

A. 23.6° /s

B. -54.9° /s

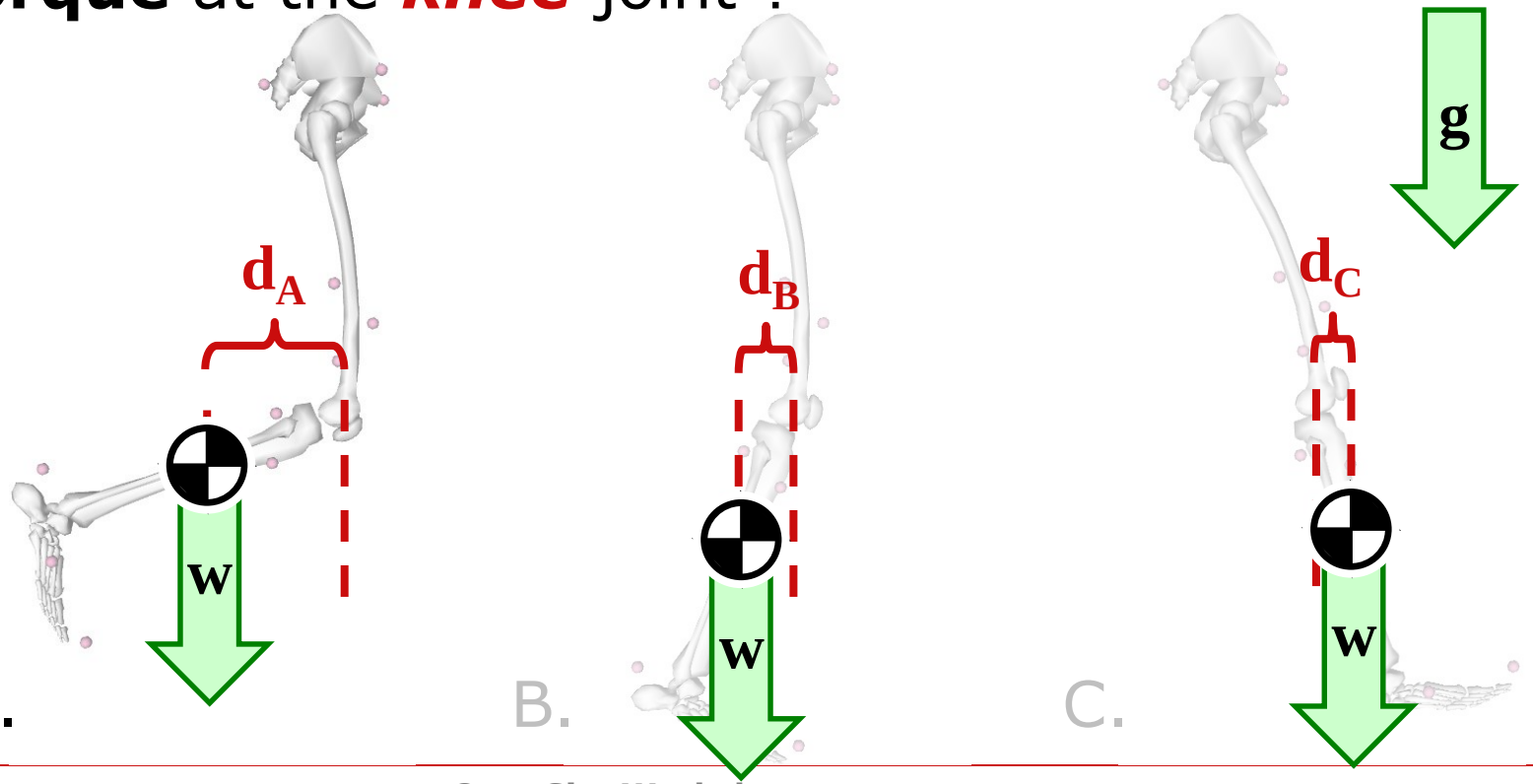
C. 3.89° /s

D. 0° /s



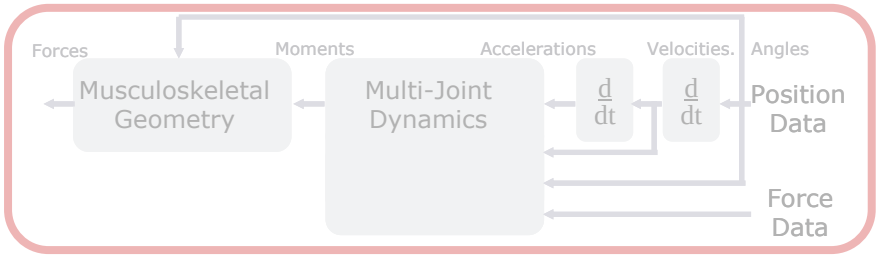
Exercise

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 ?



A. B. C.

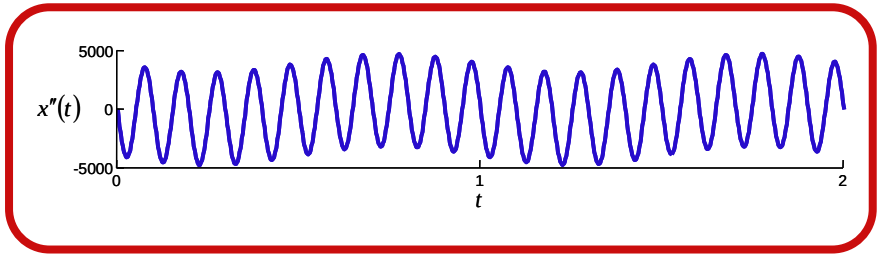
The Inverse Problem



The inverse problem

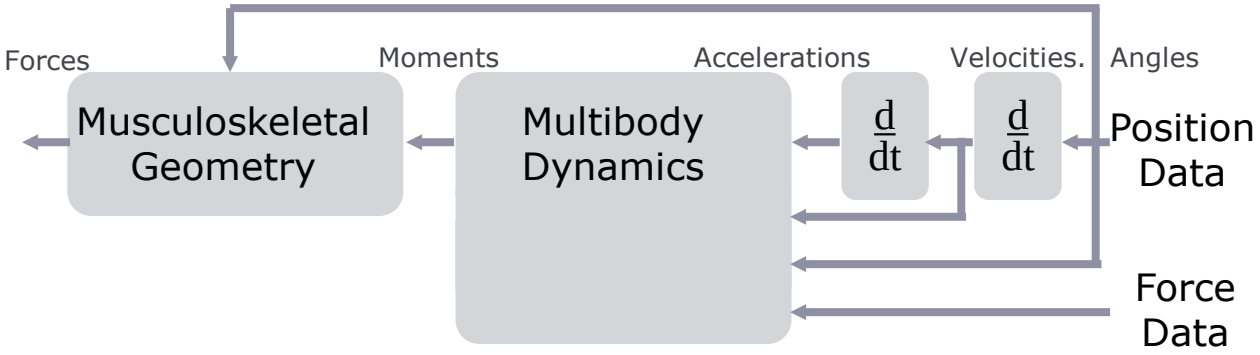
Going from subject motion to joint kinematics

[Inverse Kinematics]

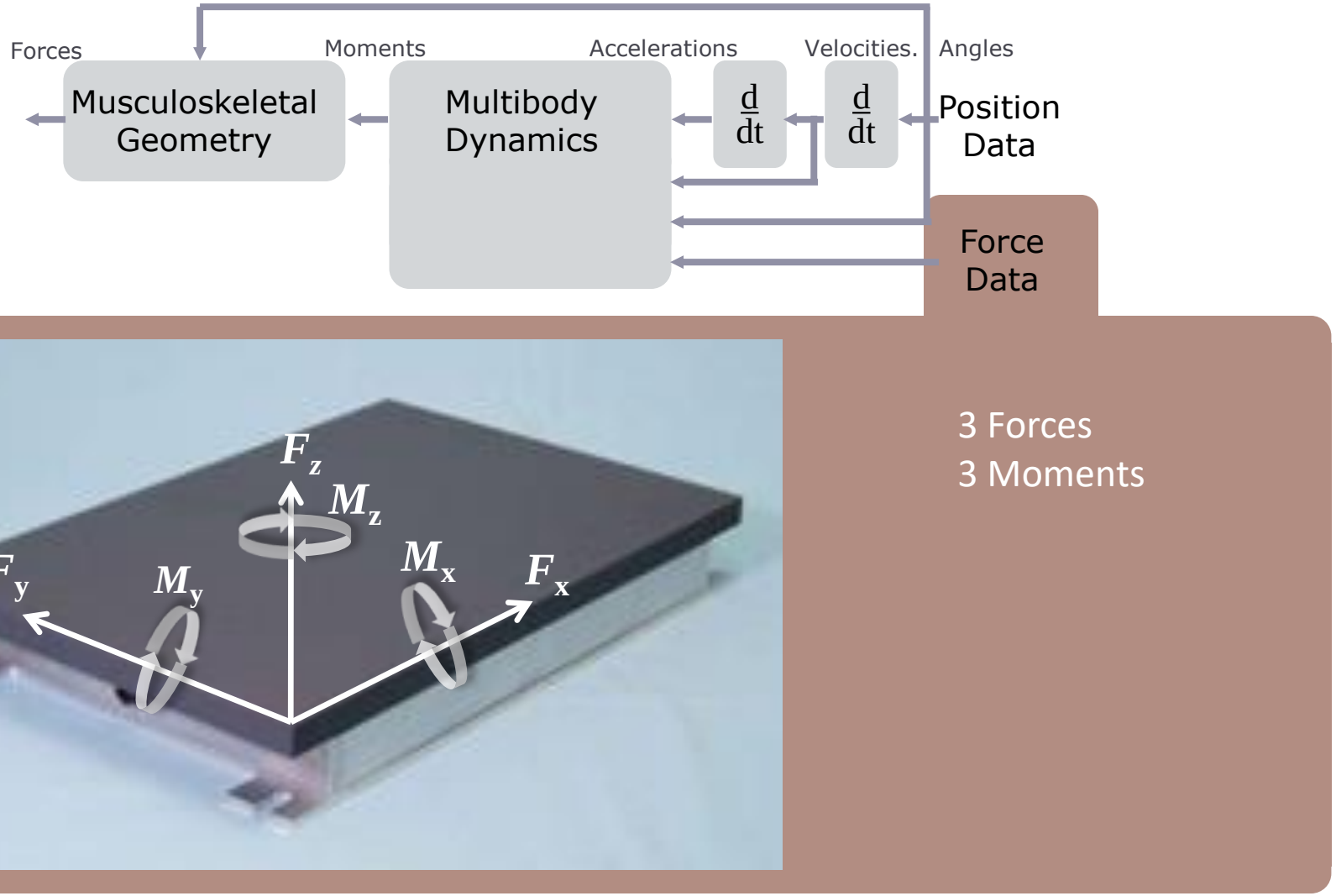


Dealing with noisy data

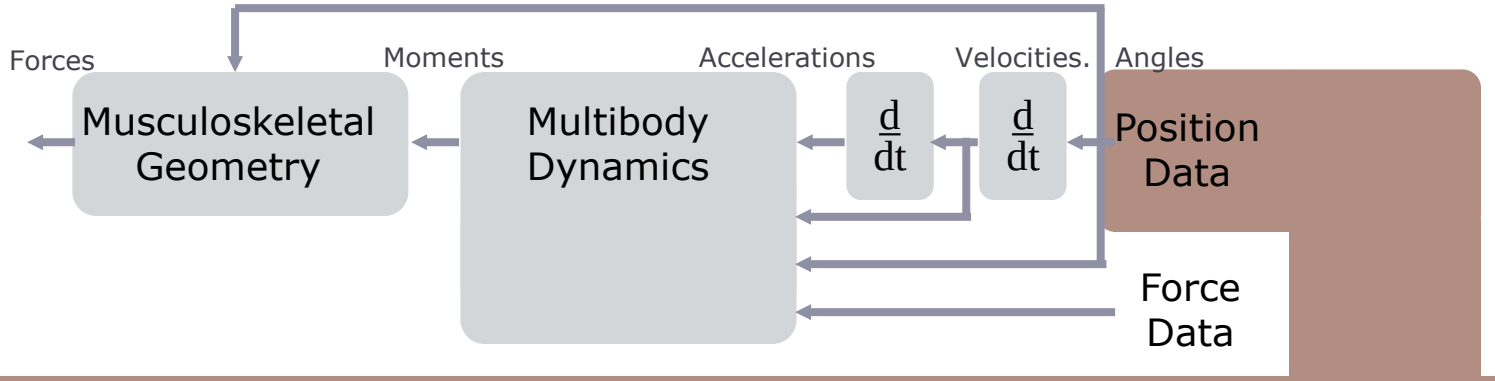
The Inverse Problem



The Inverse Problem

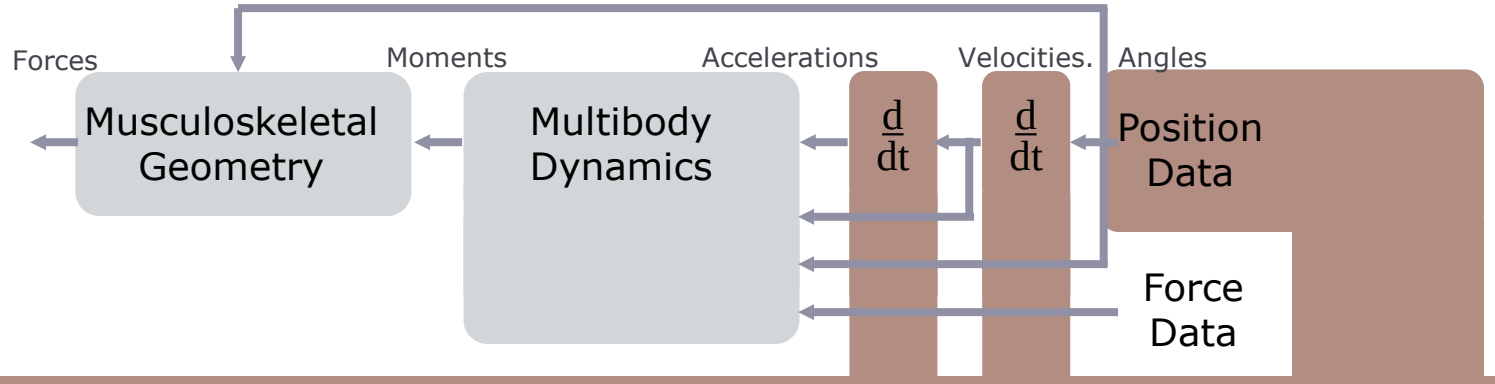


The Inverse Problem



Video Cameras
Reflective Markers

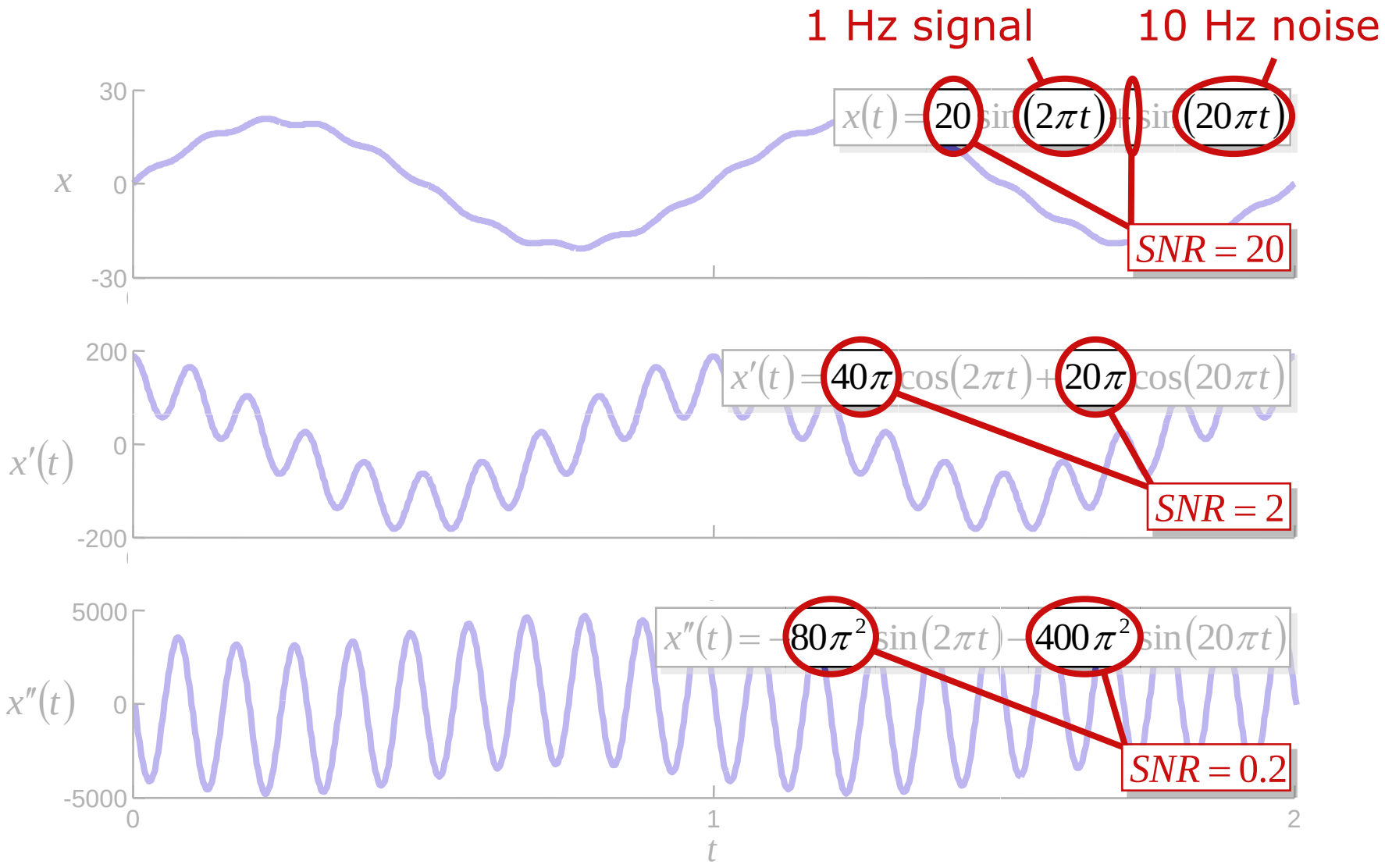
The Inverse Problem



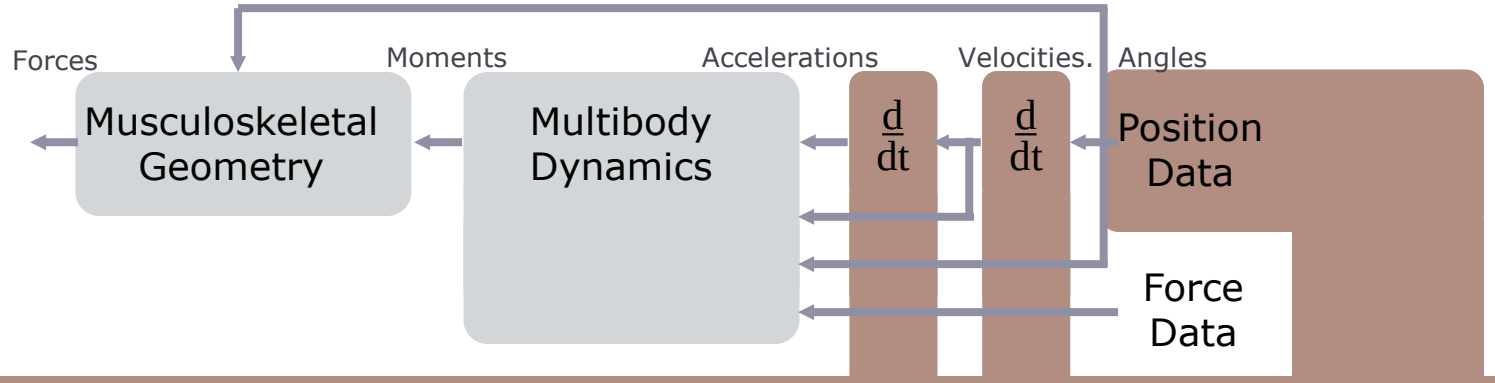
Inverse Kinematics

- Identify research question for the inverse problem
- Determine what should be measured and modeled
- Compute joint kinematics
- Filter and differentiate joint kinematics data

Differentiation Amplifies High-Frequency Noise

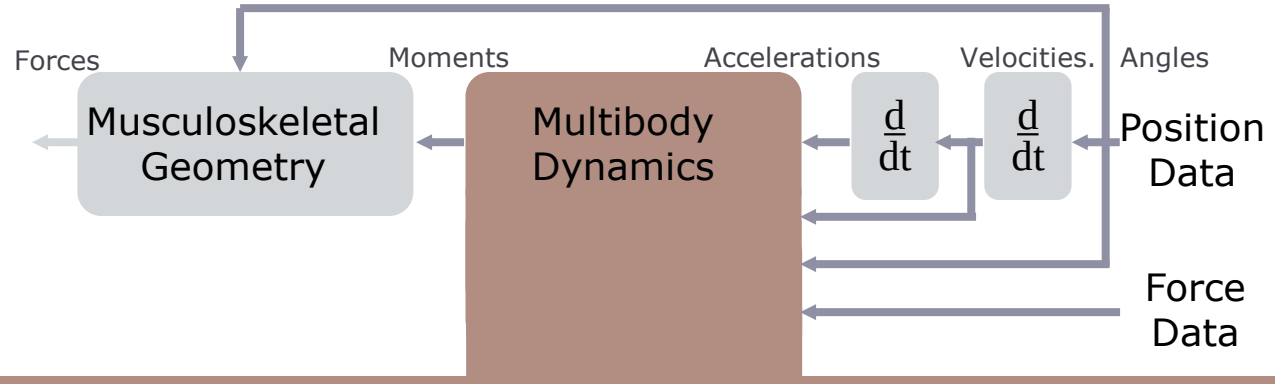


The Inverse Problem



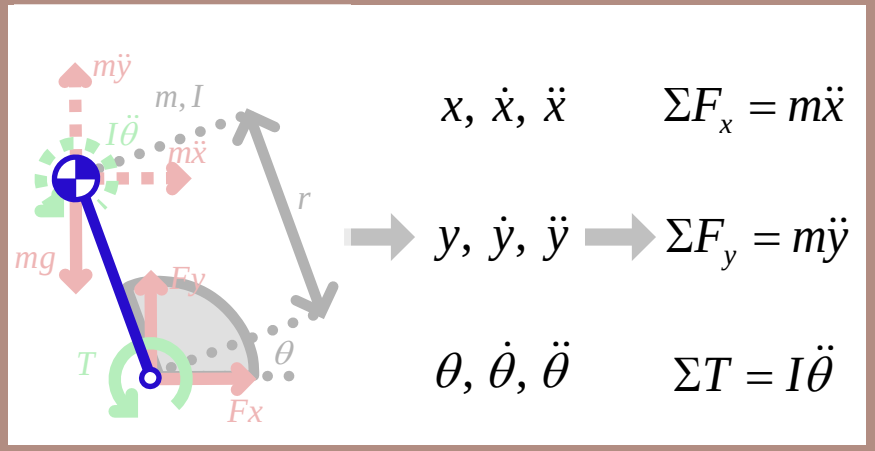
- ✓ Identified research question for the inverse problem
- ✓ Determined what should be measured and modeled
- ✓ Computed joint kinematics
- ✓ Filtered and differentiated joint kinematics data

The Inverse Problem



Inverse Dynamics

Inverse Kinematics



- Derive equations of motion defining the model
- Solve equations of motion for joint moments

A Possible Inverse Dynamics Question

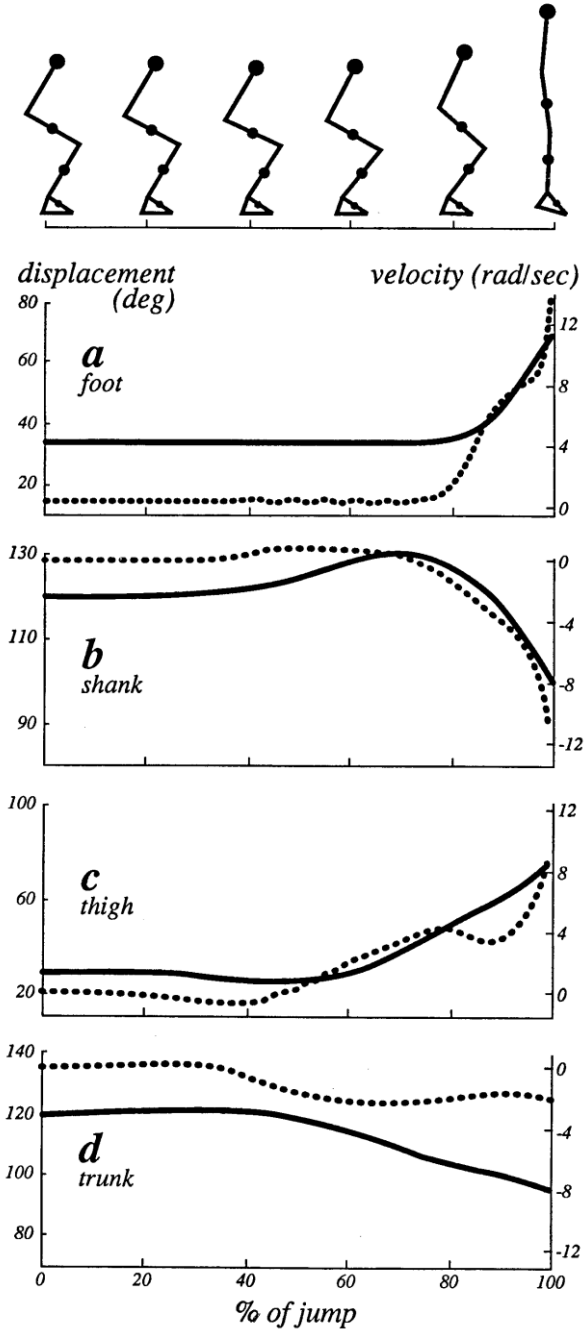
What are the sagittal plane moments about the ankle, knee, and hip during a maximum height jump?

Experimental set-up

Inverse Dynamics Input: The Experimental Results

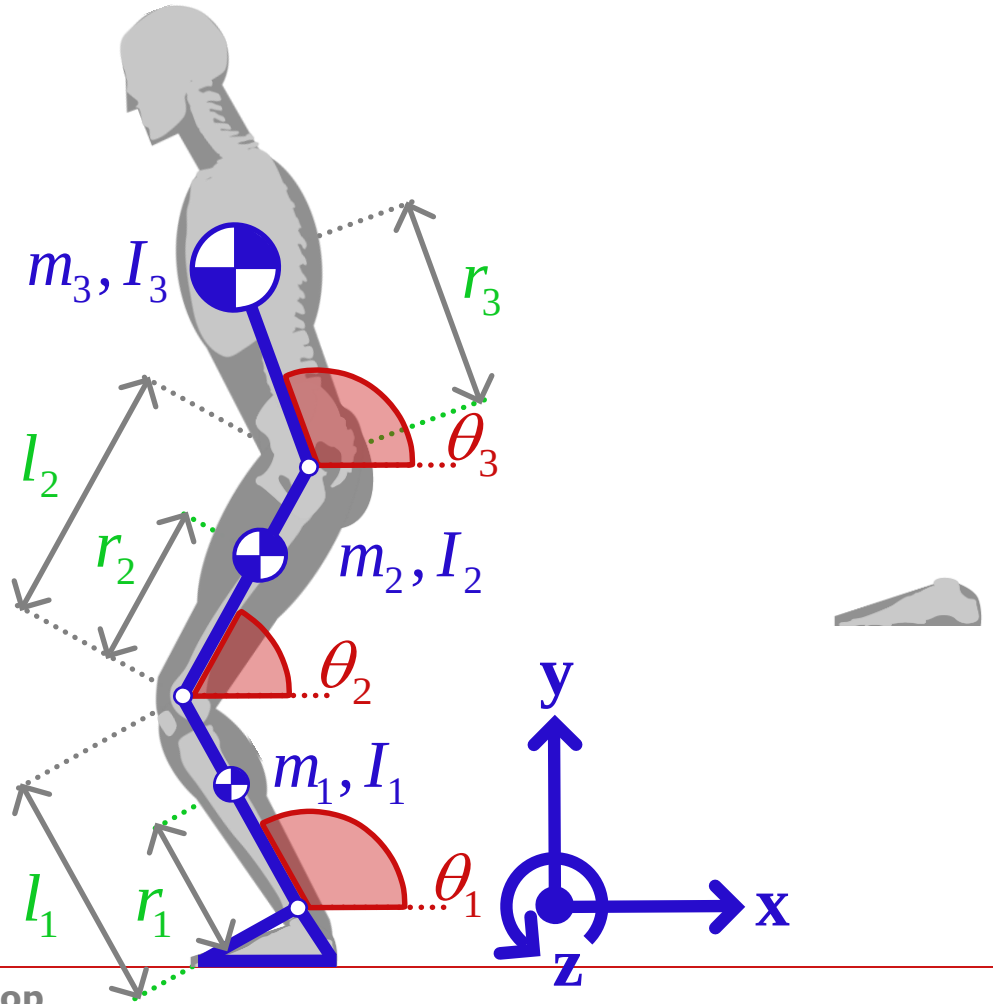
Experiments provide

- joint angles
- angular velocities
- ground reaction forces



Inverse Dynamics Equations: Multibody Dynamics

- Planar 3 degrees of freedom
- Position (orientation) in global coordinate system
- Segment length = l_i
- Distance to mass center = r_i
- Moments of inertia about mass center
- Foot has no mass and remains on ground



Inverse Dynamics Equations: Multibody Dynamics

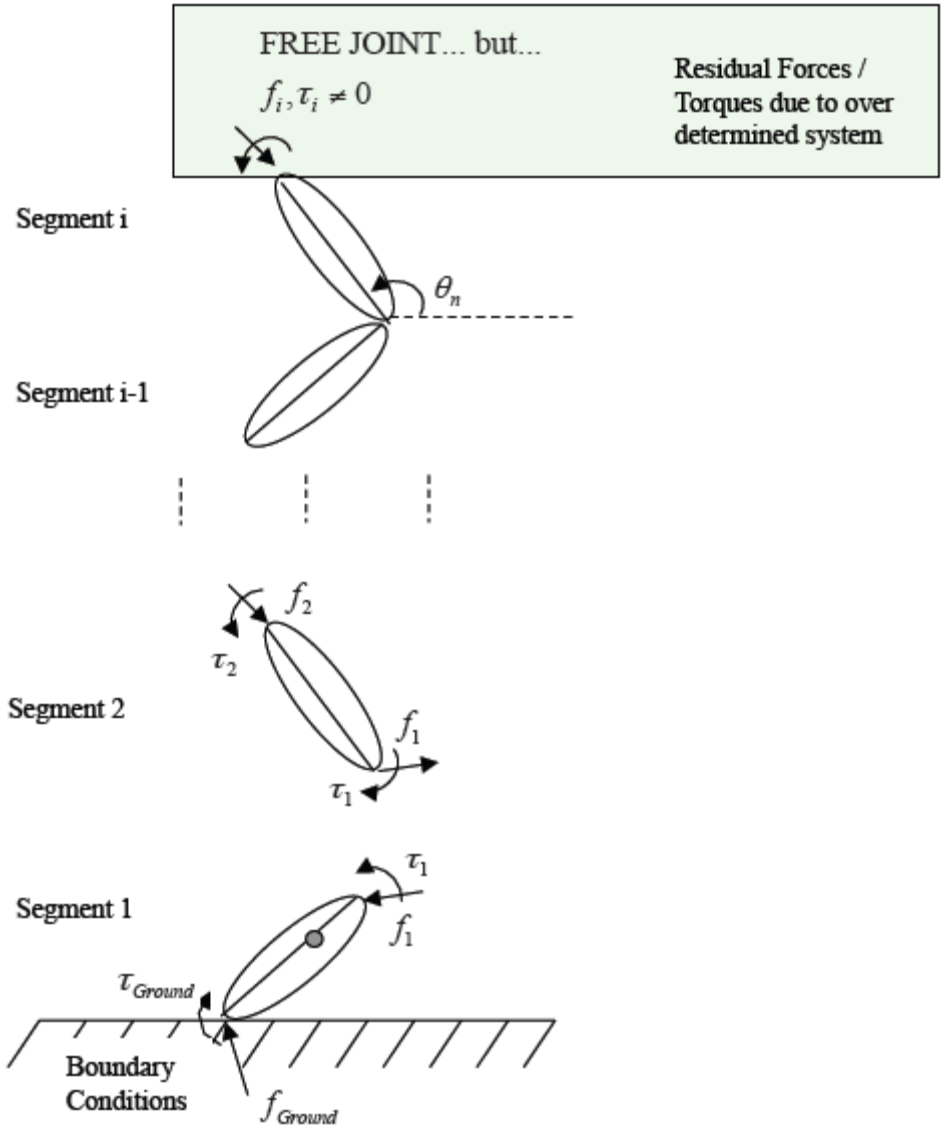
Solved algebraically from the ground up

$x,\ \dot{x},\ \ddot{x} \qquad \Sigma F_x = m\ddot{x}$

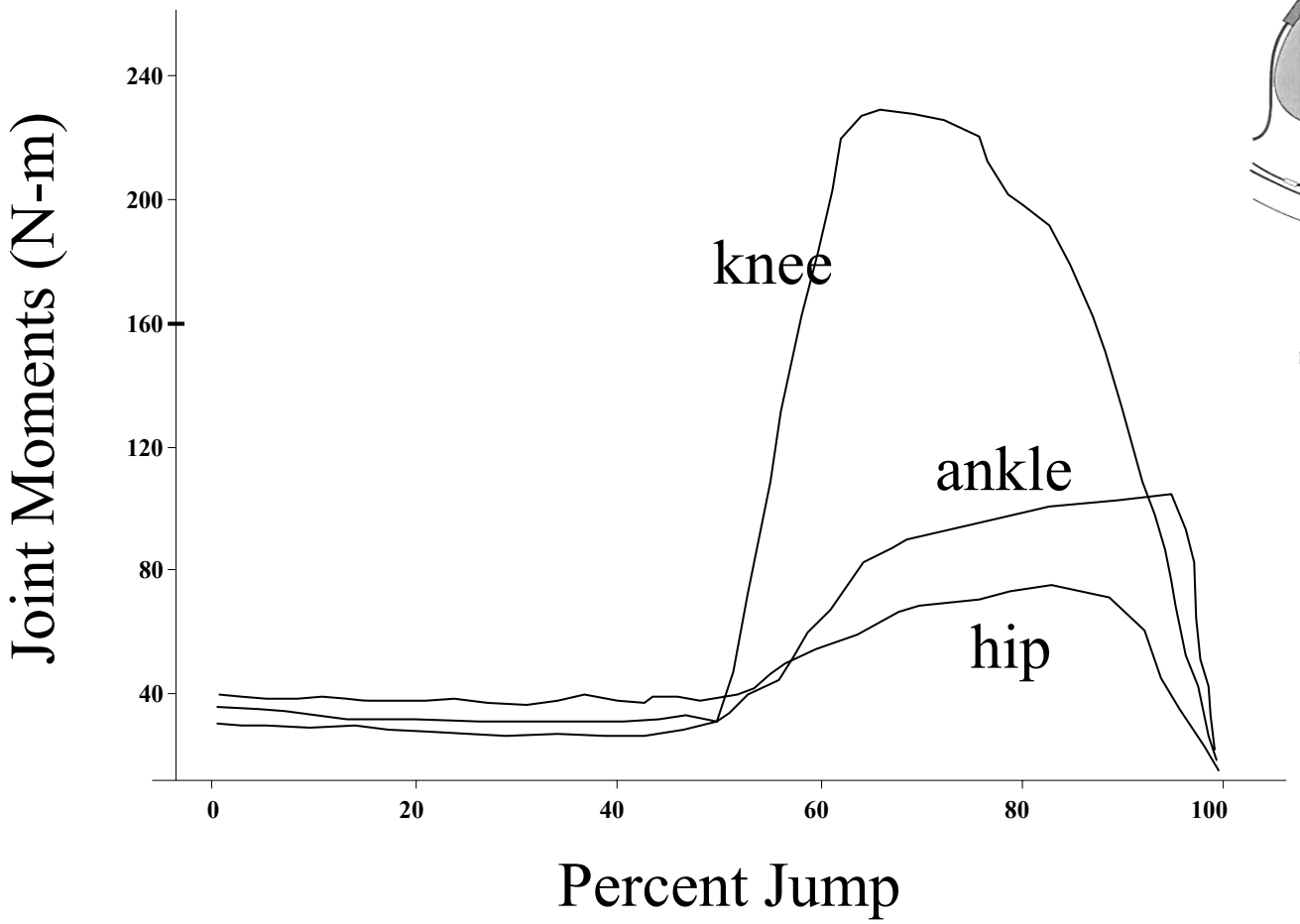
$y,\ \dot{y},\ \ddot{y} \rightarrow \Sigma F_y = m\ddot{y}$

$\theta,\ \dot{\theta},\ \ddot{\theta} \qquad \Sigma T = I\ddot{\theta}$

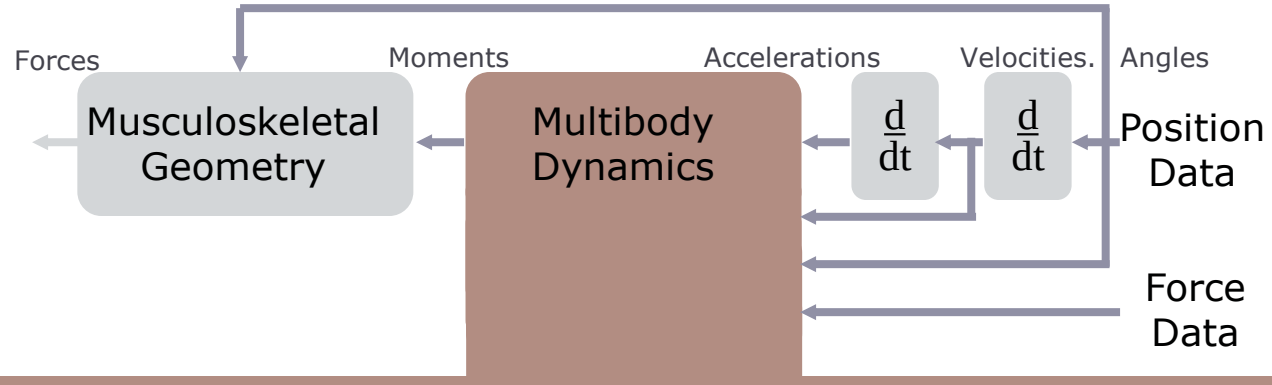
Joint Moments that generate the motion



Inverse Dynamics Output: Net Joint Moments



The Inverse Problem

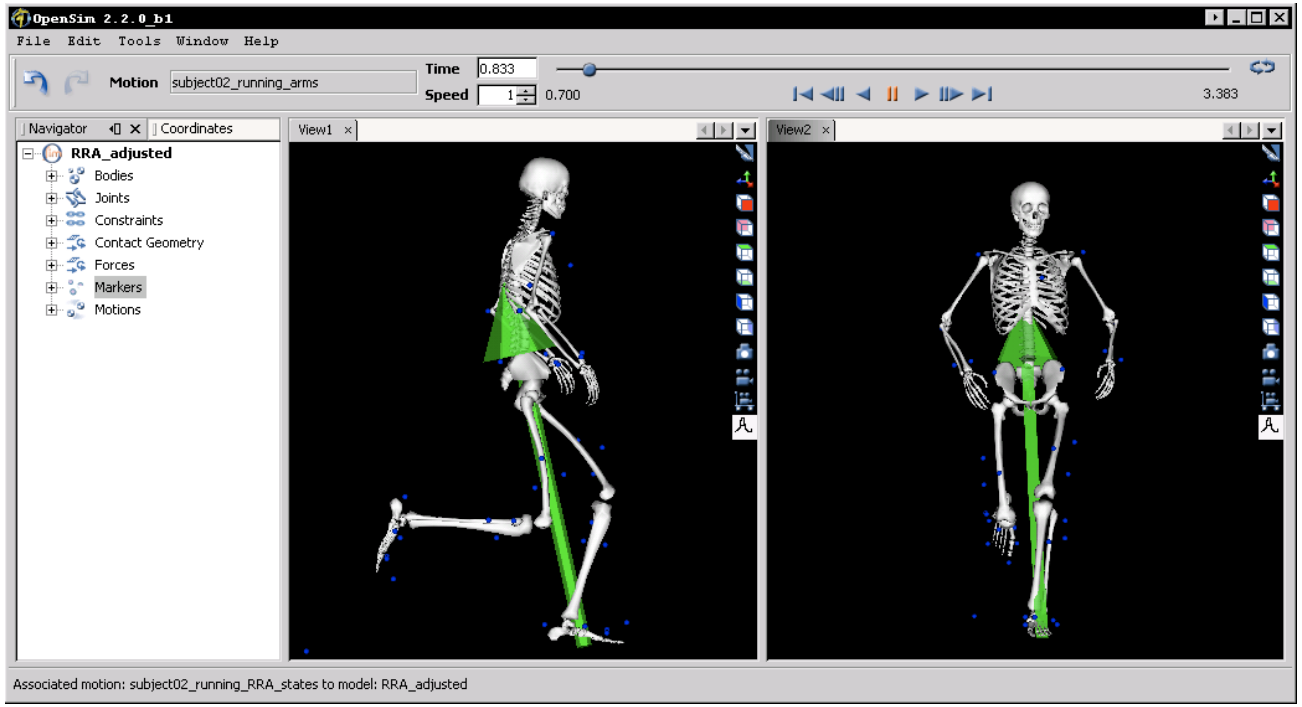


Inverse Dynamics

Inverse Kinematics

- ✓ Derived equations of motion defining the model
- ✓ Solved equations of motion for joint moments

Inverse Dynamics



TIPS & TRICKS
Filter your raw coordinate data
Make sure GRFs were applied correctly and check residuals on the body connected to ground
Compare to previous literature data (if available)