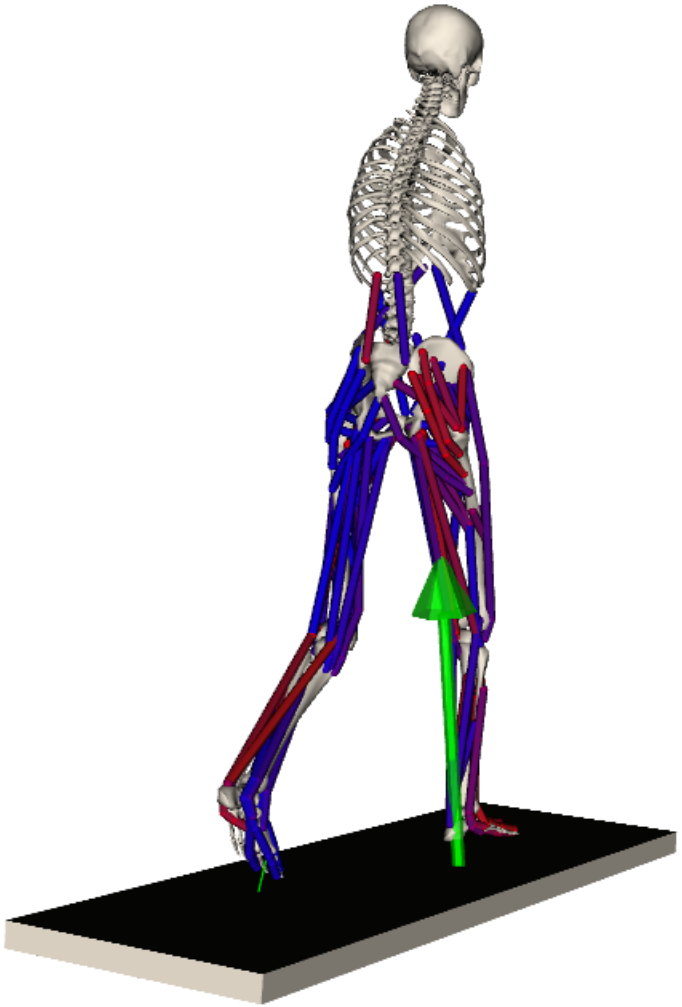


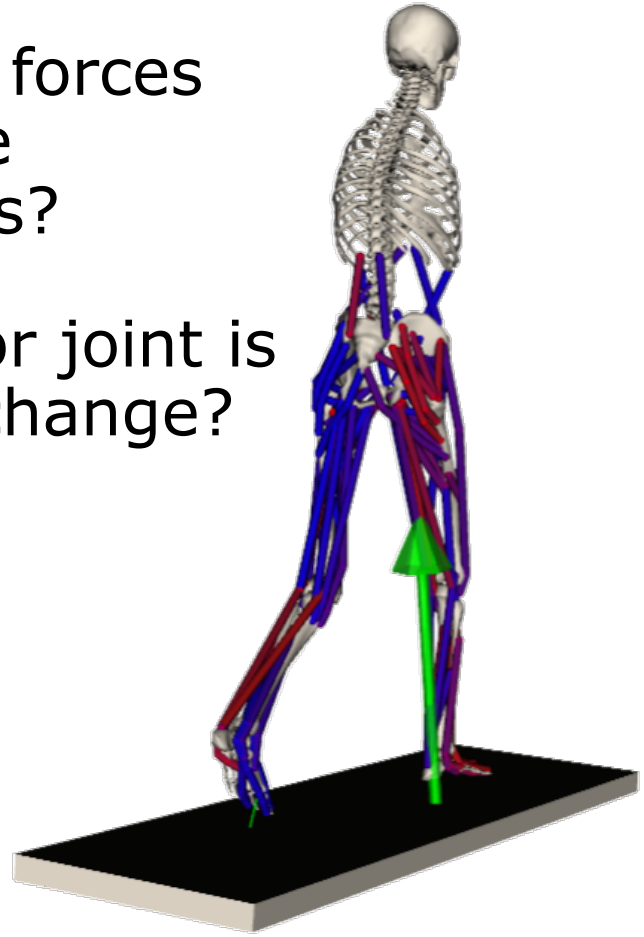
Forward Dynamics

Why Use Forward Dynamics Simulations?

1. Validation: do forces estimated from inverse dynamics reproduce the observed motion?

2. Understanding: how do muscle forces generate motion – what are the "cause and effect" relationships?

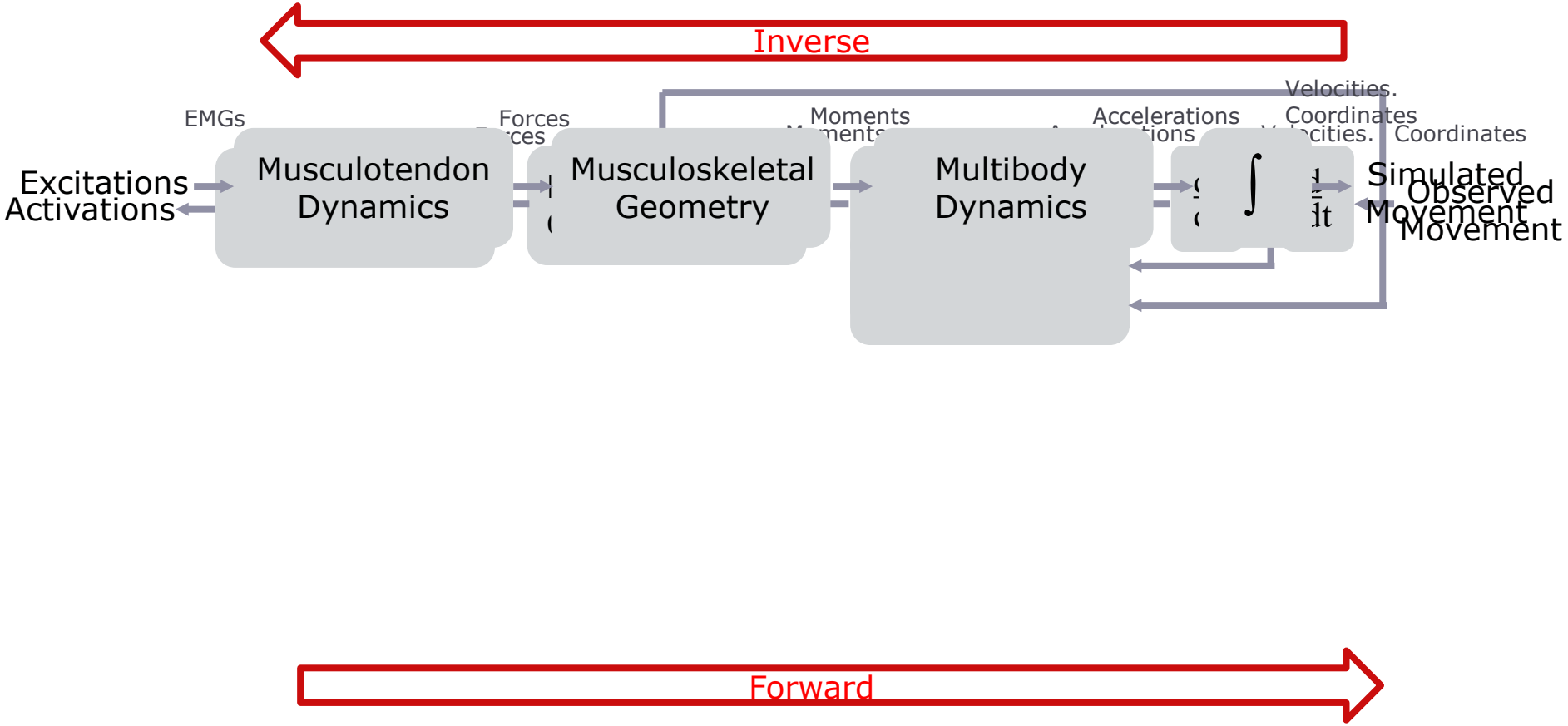
3. Prediction: "what if" a muscle or joint is altered, how will performance change?

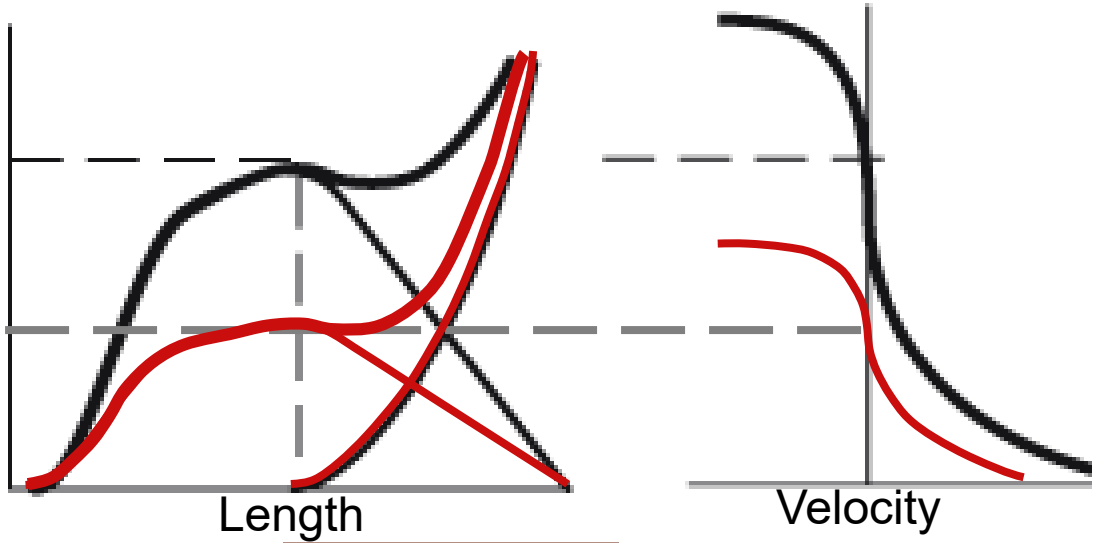


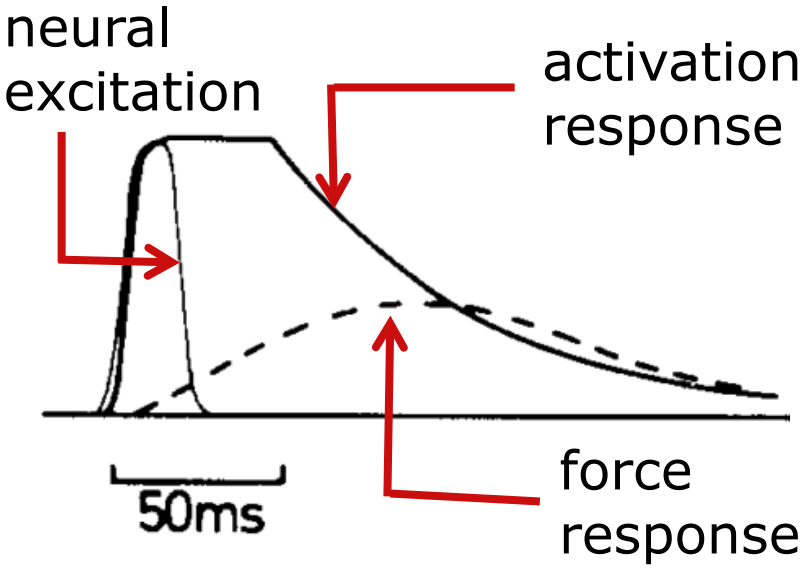
Key Concepts

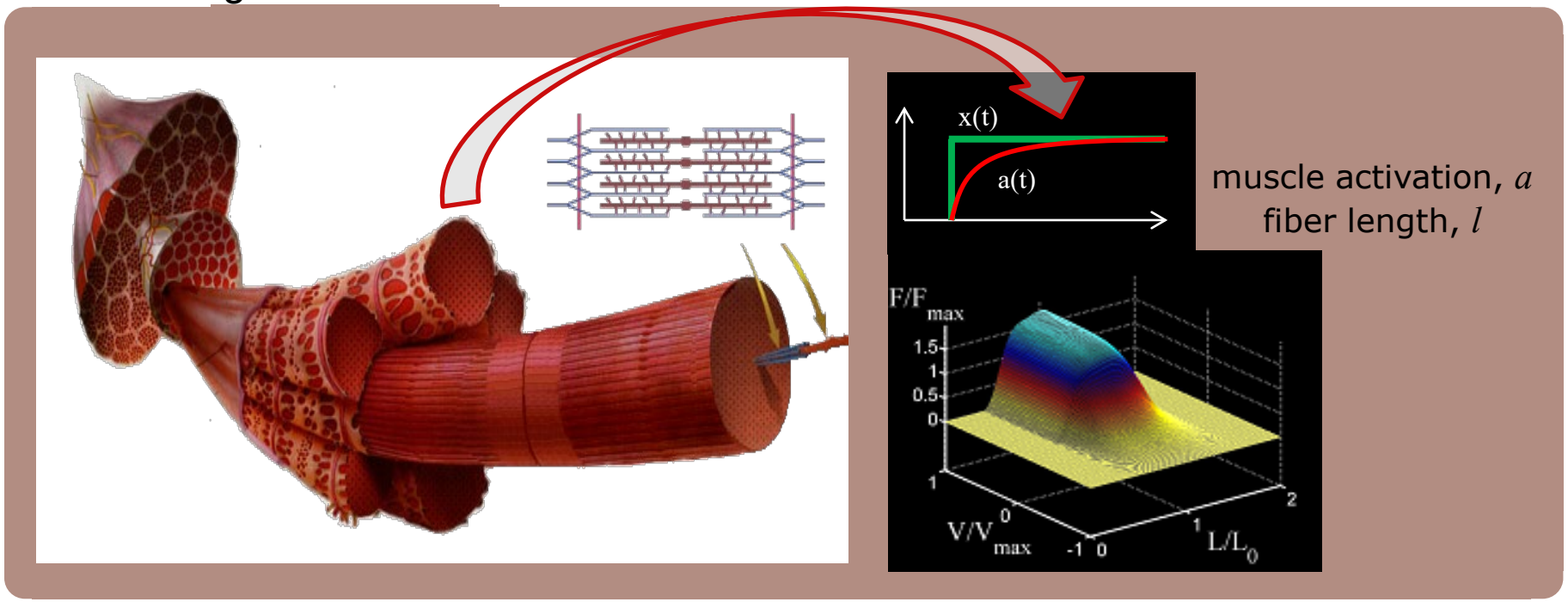
- Musculoskeletal model dynamics
- States of a musculoskeletal model
- Controls of a musculoskeletal simulation
- Numerical integration of dynamical equations

Overview of Forward Dynamics

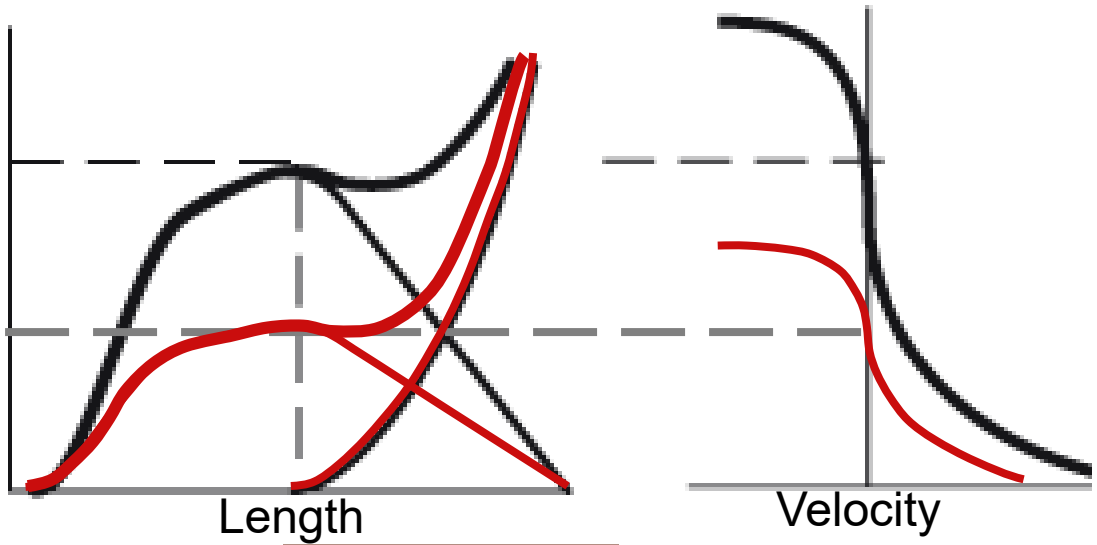


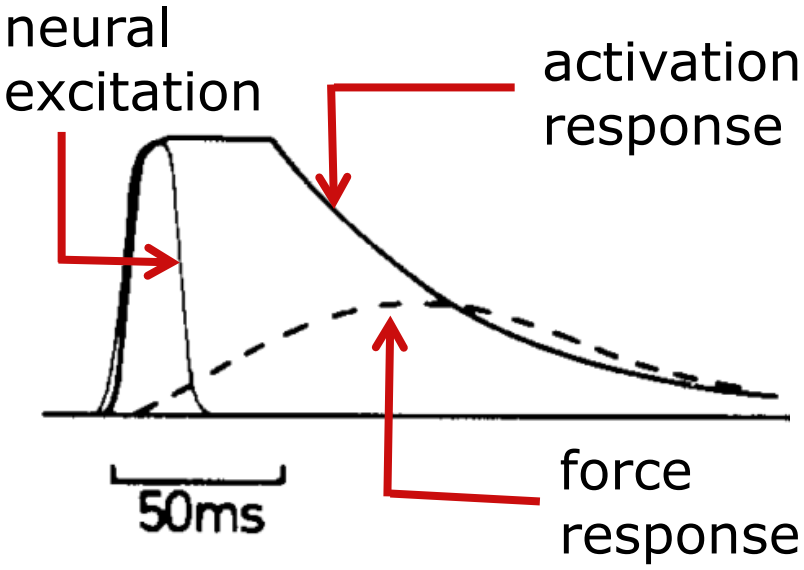

Length
Velocity

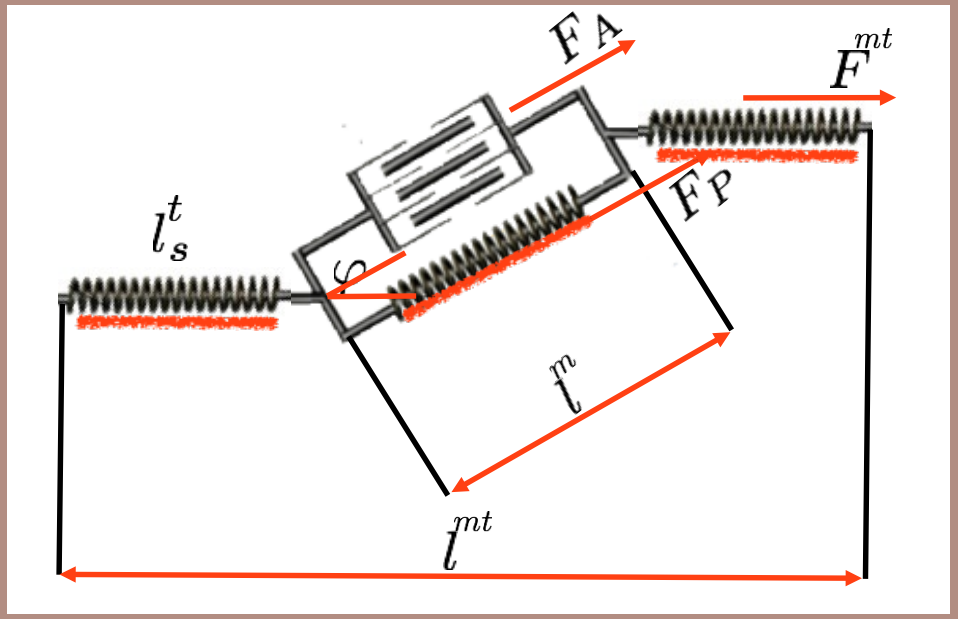

neural
excitation
activation
response
50ms
force
response

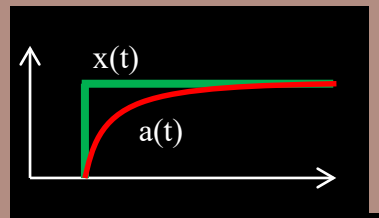

x(t)
a(t)
muscle activation, a
fiber length, l
F/F max
1.5
1
0.5
0
V/V max
-1
0
1
L/L0
2

Science

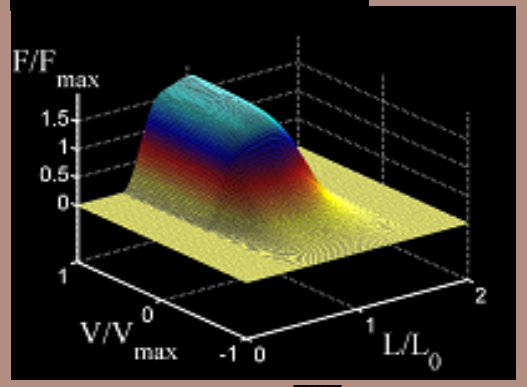








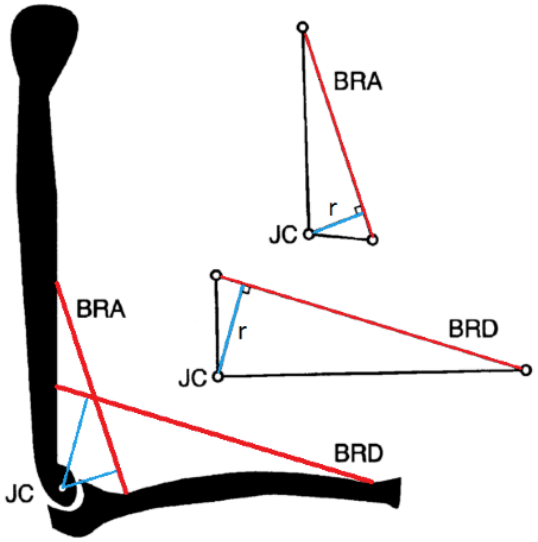
muscle activation, a
fiber length, l



$$F^m = (f_A(\tilde{l}^m) \cdot f_V(v^m) \cdot a(u) + f_P(\tilde{l}^m) + d^m \cdot \tilde{v}^m) \cdot F_0^m \cdot \delta$$

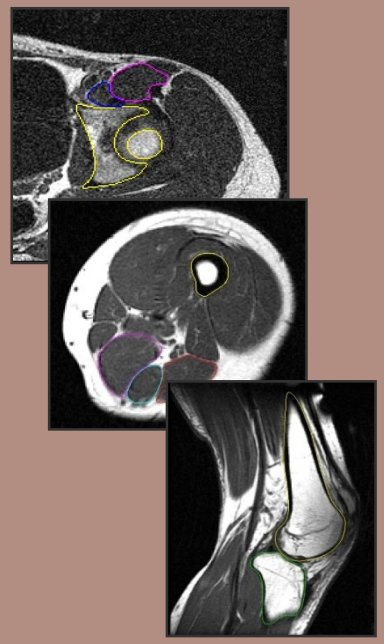
F_A F_P

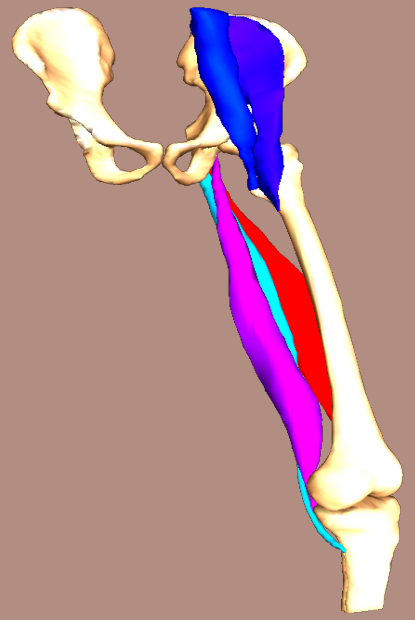
Musculoskeletal Model Dynamics

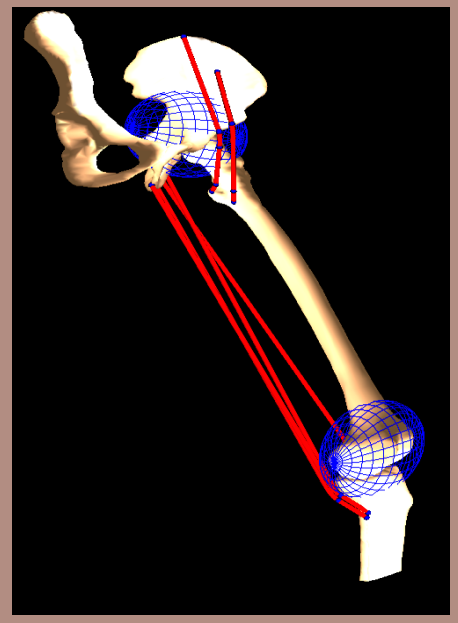


EMGs Forces Moments Accele

Neural Command → Musculotendon Dynamics → Musculoskeletal Geometry → Multibody Dynamics

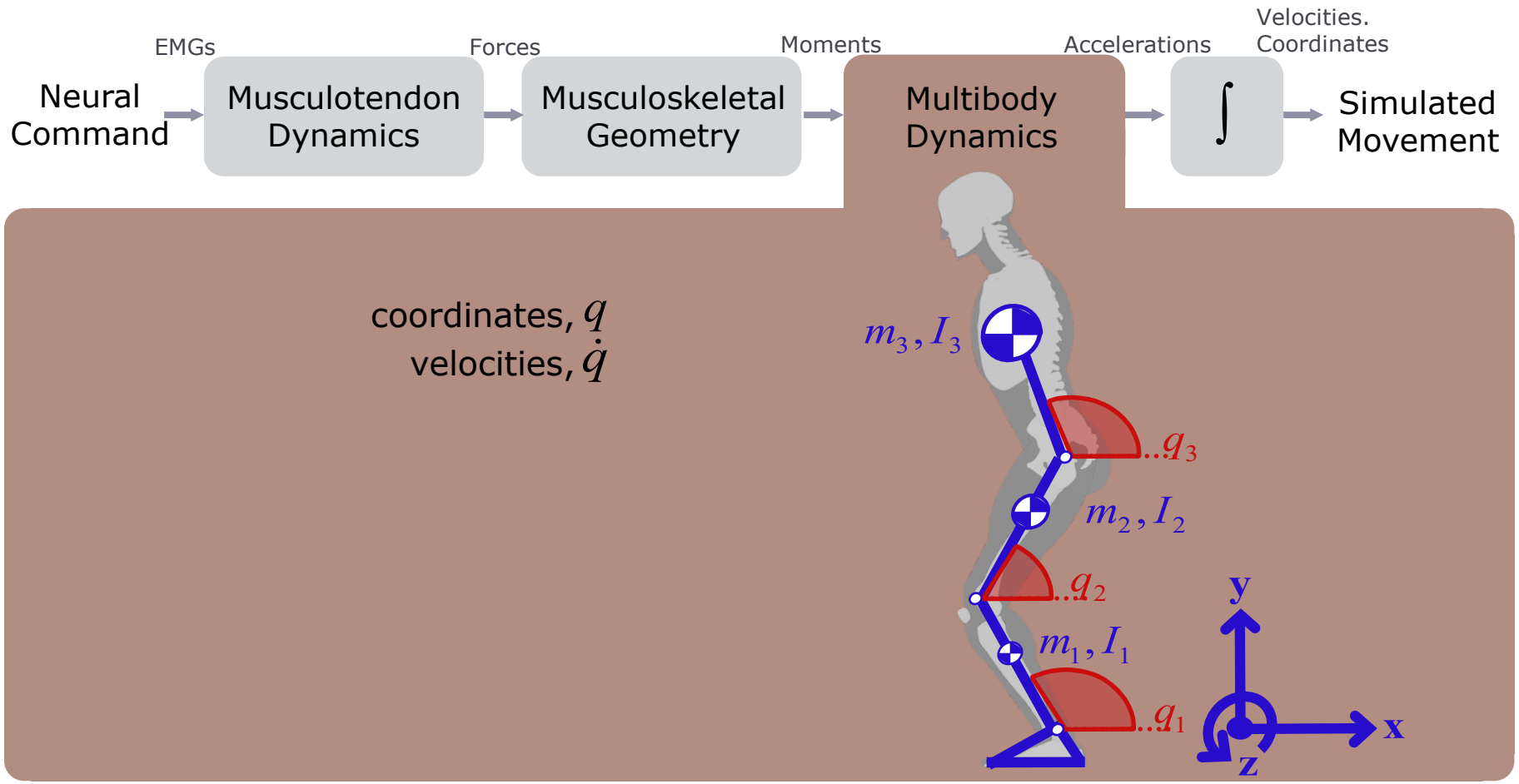




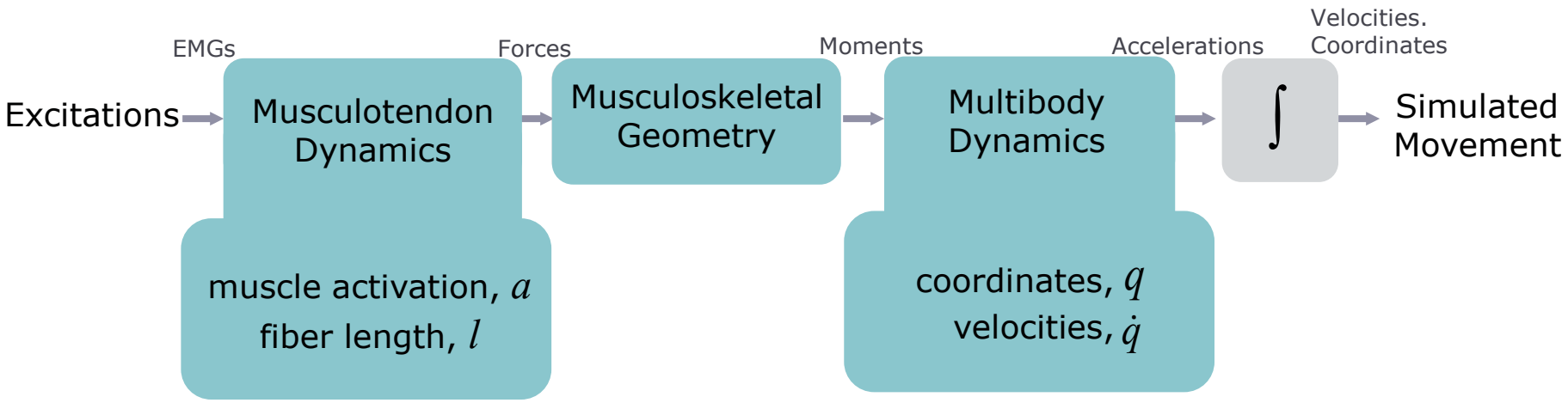


muscle lines of action
moment arms

Musculoskeletal Model Dynamics

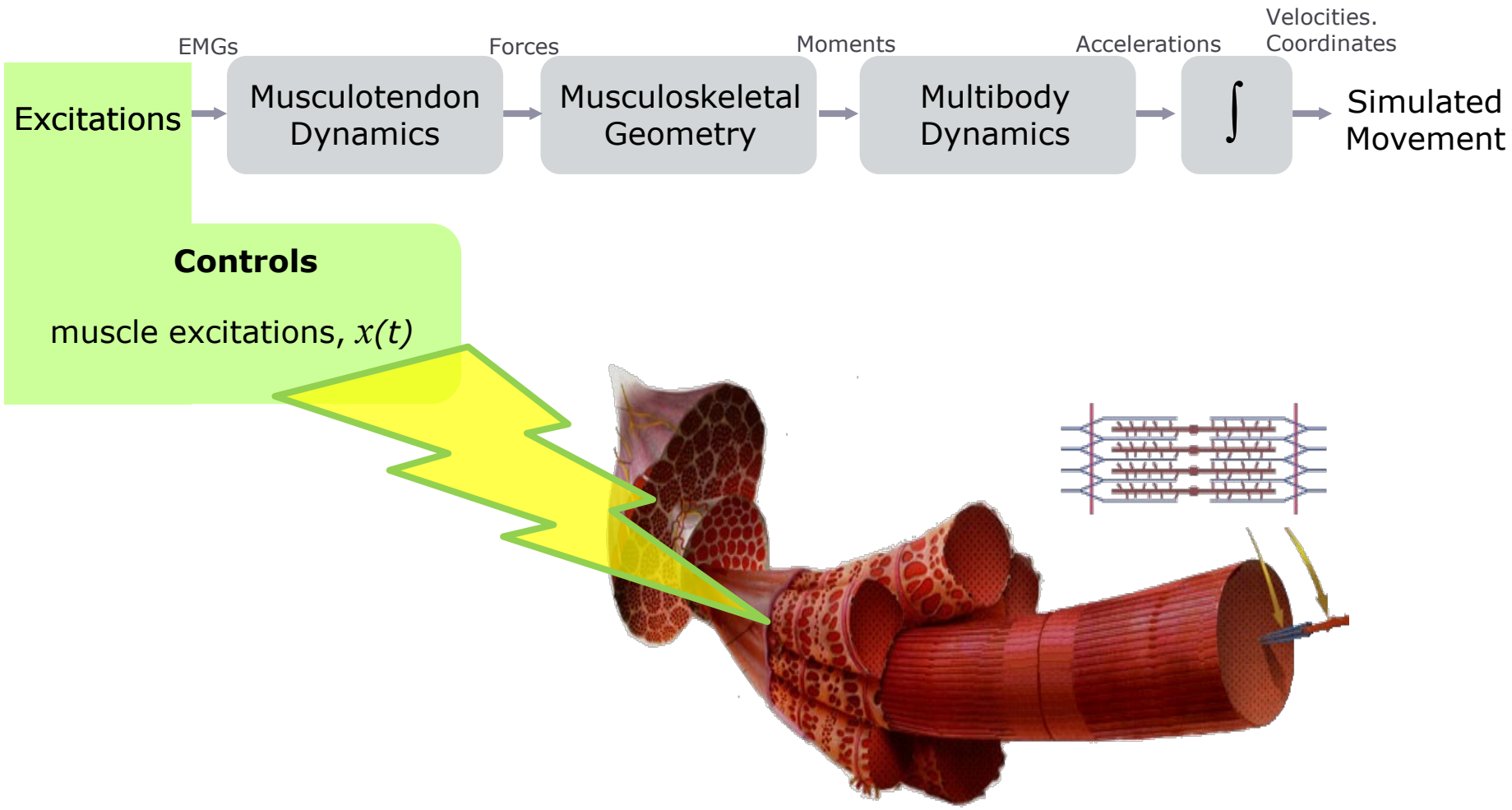


States of a Musculoskeletal Model

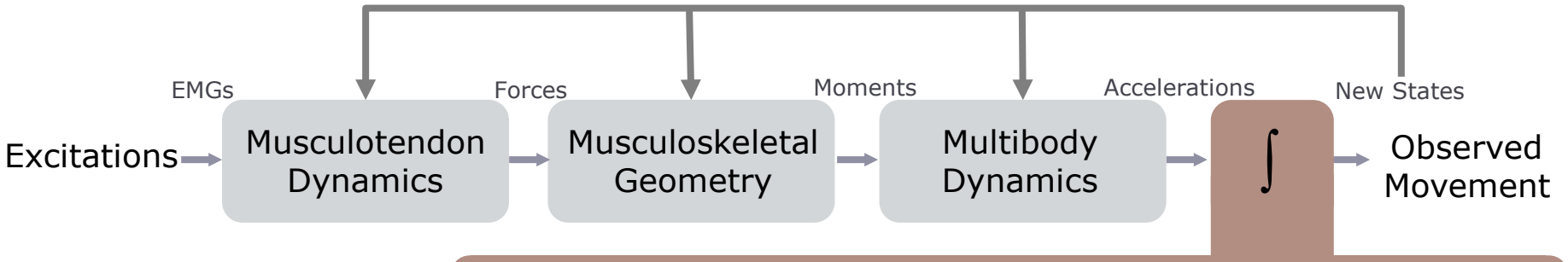


- States are model variables that are governed by the dynamics
- All measures of interest can be calculated from the states

Controls of a Musculoskeletal Model



Numerical Integration of Dynamical Equations



Controls

muscle excitations, $x(t)$

Initial States

joint coordinates, q
joint velocities, $\dot{q}$
muscle activation, a
fiber length, l

Model dynamical equations:

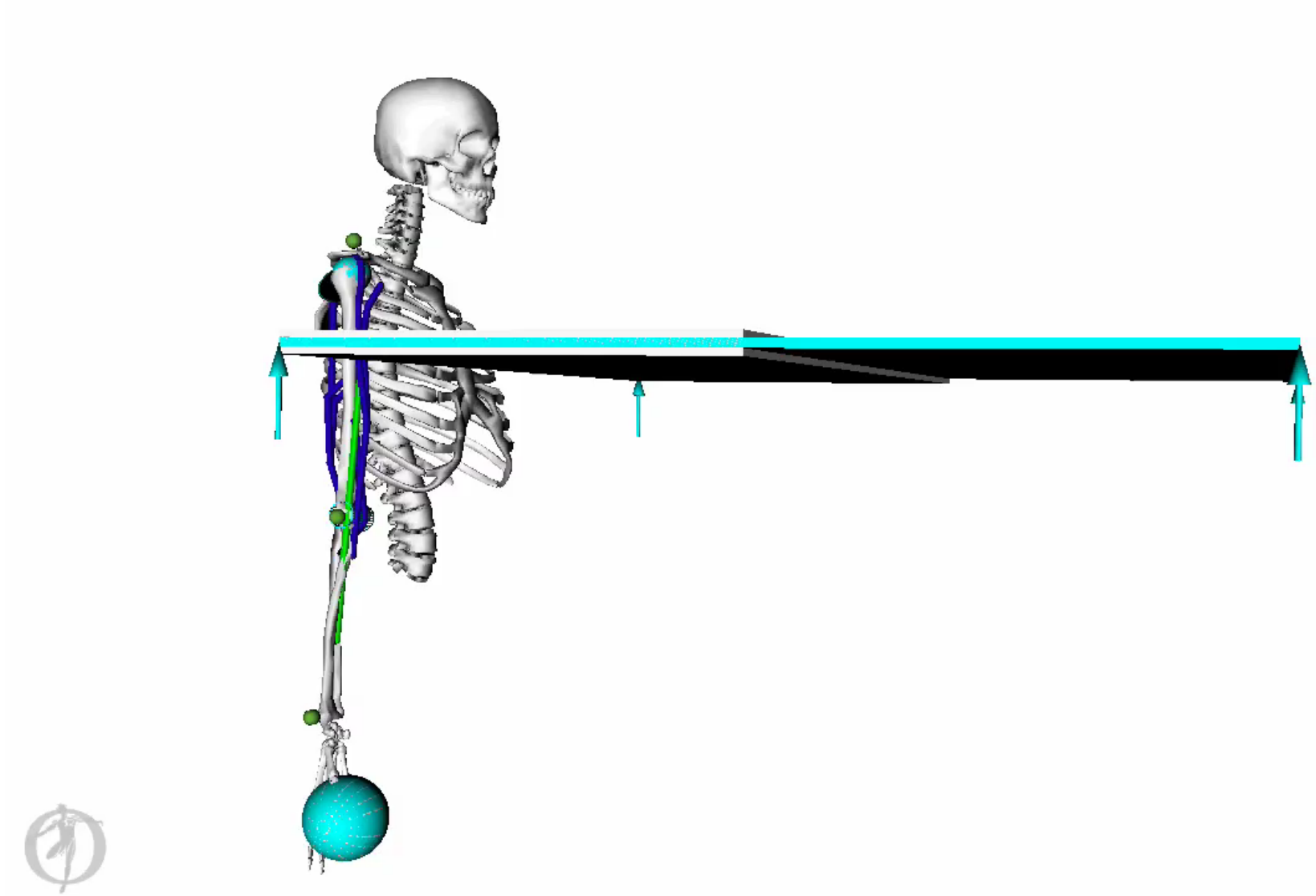
$$\ddot{q} = \left[\mathbf{M}(q)\right]^{-1}\left\{\boldsymbol{\tau}_m(a,l,\dot{l}) - \mathbf{C}(q,\dot{q}) + \mathbf{G}(q) + F\right\}$$

$$\dot{a} = \mathrm{A}(a,x)$$

$$\dot{l} = \Lambda(a,l,q)$$

Numerical Integrate from Initial States

Forward Dynamic Simulation



Exercise

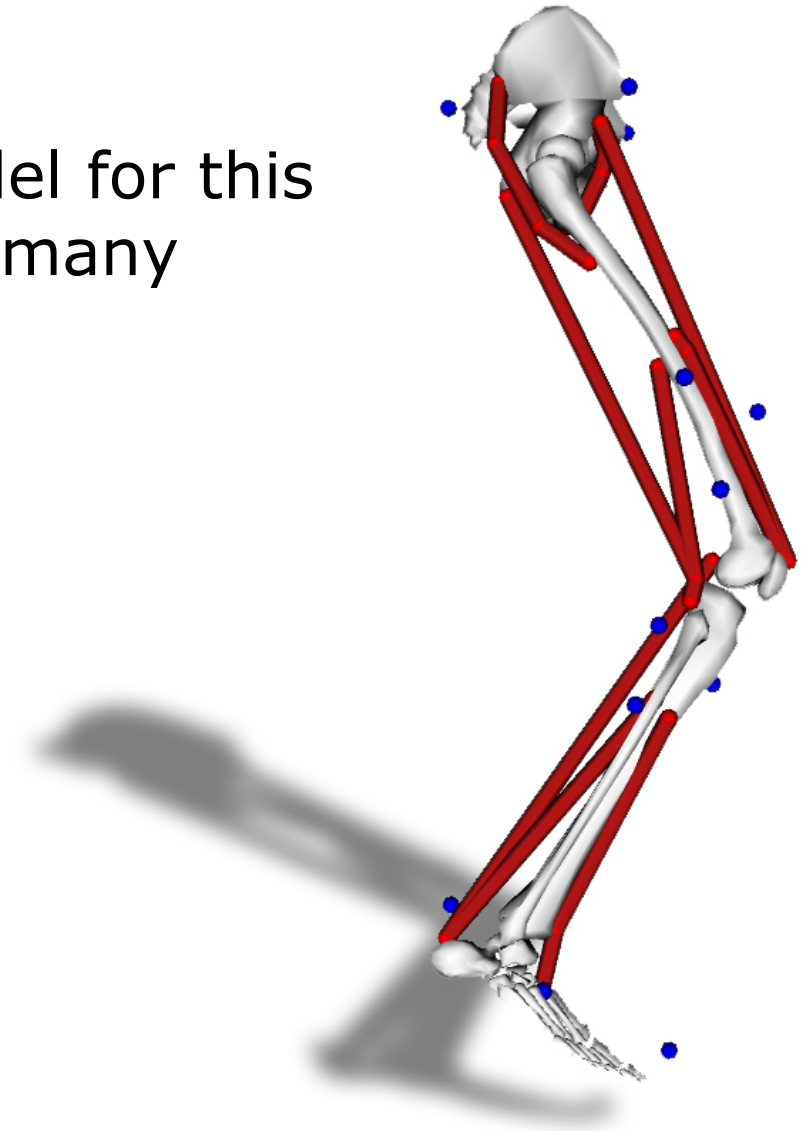
2. The musculoskeletal model for this tutorial (leg39) has how many states?

A. 3

B. 9

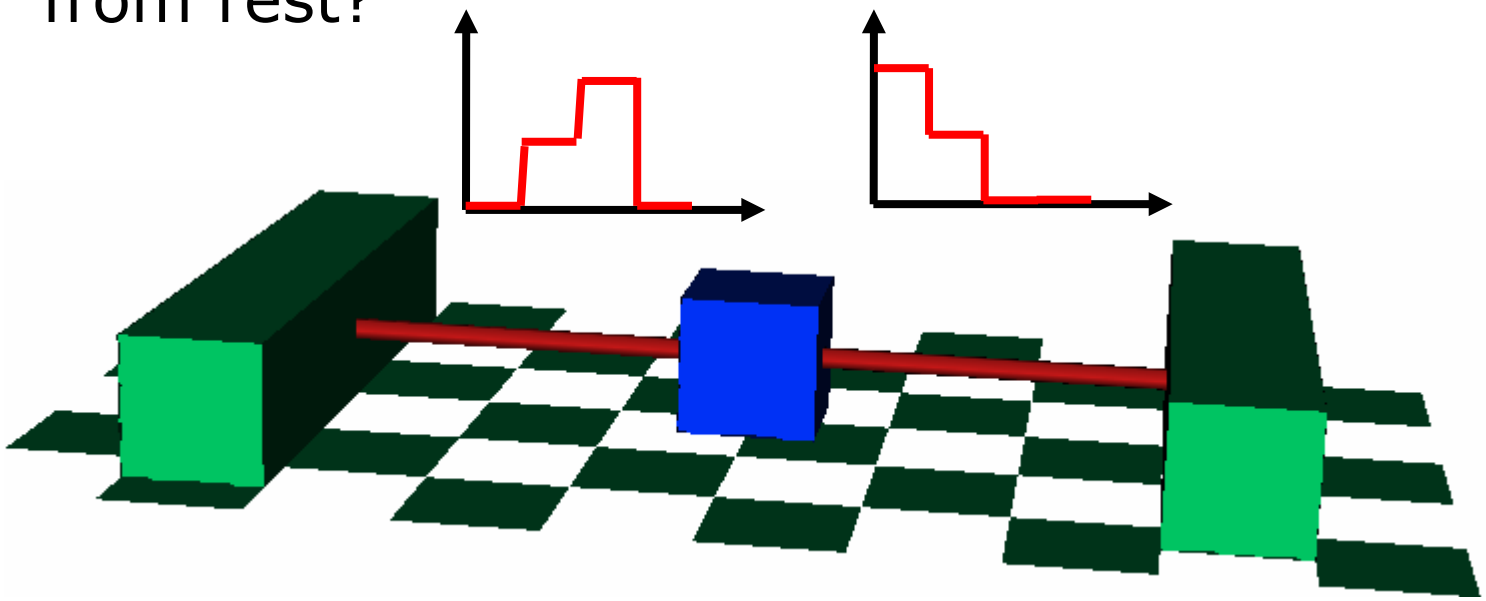
C. 12

D. 24



Exercise

3. Given the model below with two identical muscles and their levels of excitation plotted versus time, which way will the block initially move if starting from rest?



A. To the left
B. Does not move
B. To the right
D. Upward

Exercise

4. Given initial q and $\dot{q}$ and muscle a and l, how are these states determined at a small instant ahead in time?

A. Specify controls and compu $\dot{a}, \dot{l}$ l,ar $\ddot{q}$ q from model dynamics

B. Numerically integrate forces and controls from model differential equations

C. Numerically integra $\dot{a}, \dot{l}$ ar $\ddot{q}$ q

D. Numerically differentiate forces and controls from the dynamical equations

E. A & C

Exercise

1. A forward dynamics simulation is

   A. a musculoskeletal model
   B. muscle-driven
   C. a simulation that uses feedback
   D. the integration of dynamical equations