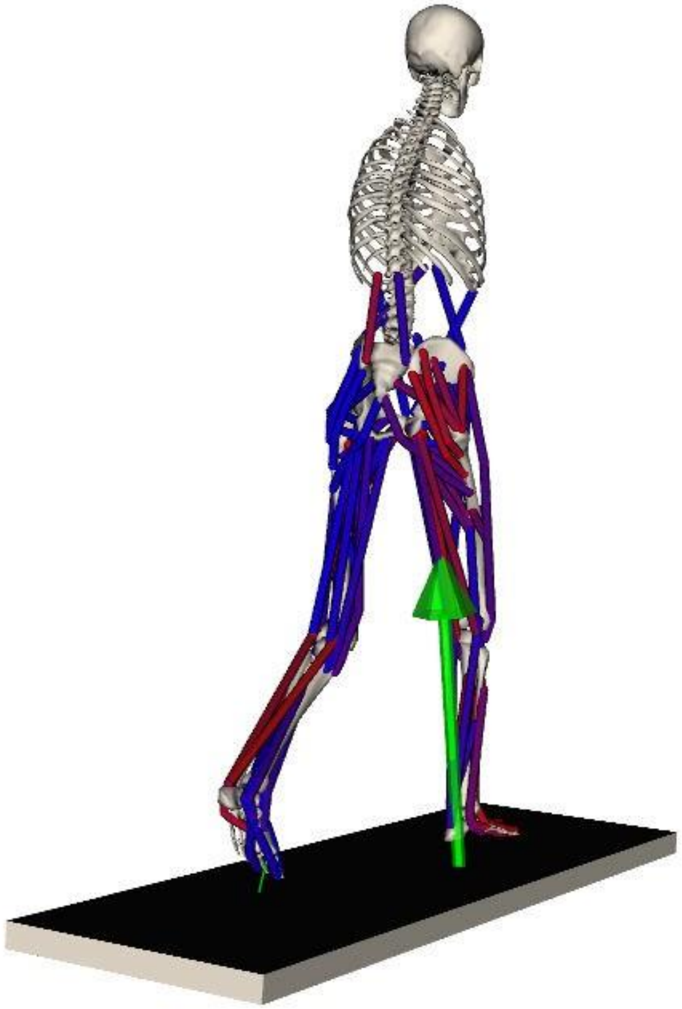
Forward Simulation

Forward Dynamics

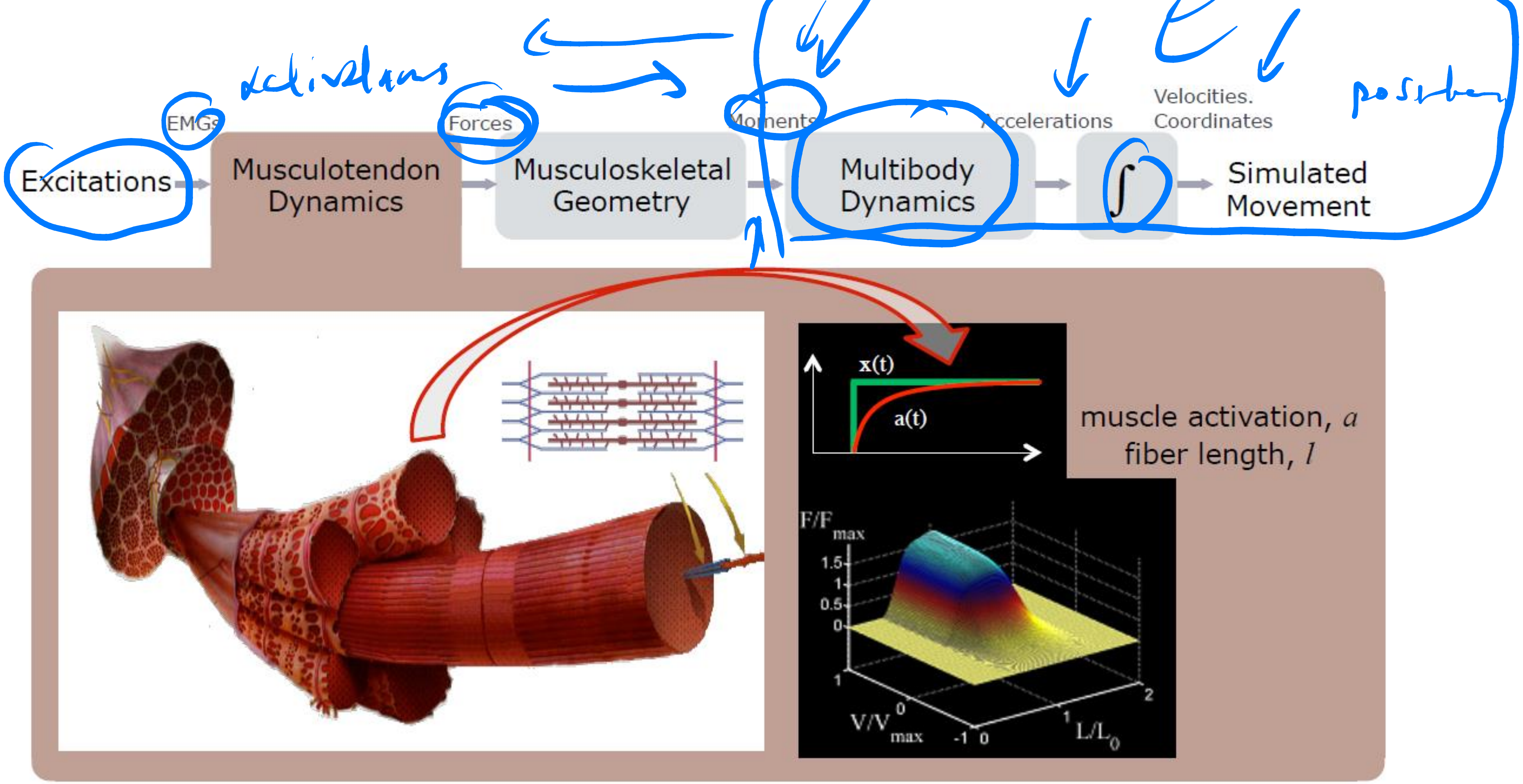
- Validation: do forces estimated from inverse dynamics reproduce the observed motion?
- Understanding: how do muscle forces generate motion – what are the “cause and effect” relationships?
- Prediction: “what if” a muscle or joint is altered, how will performance change?



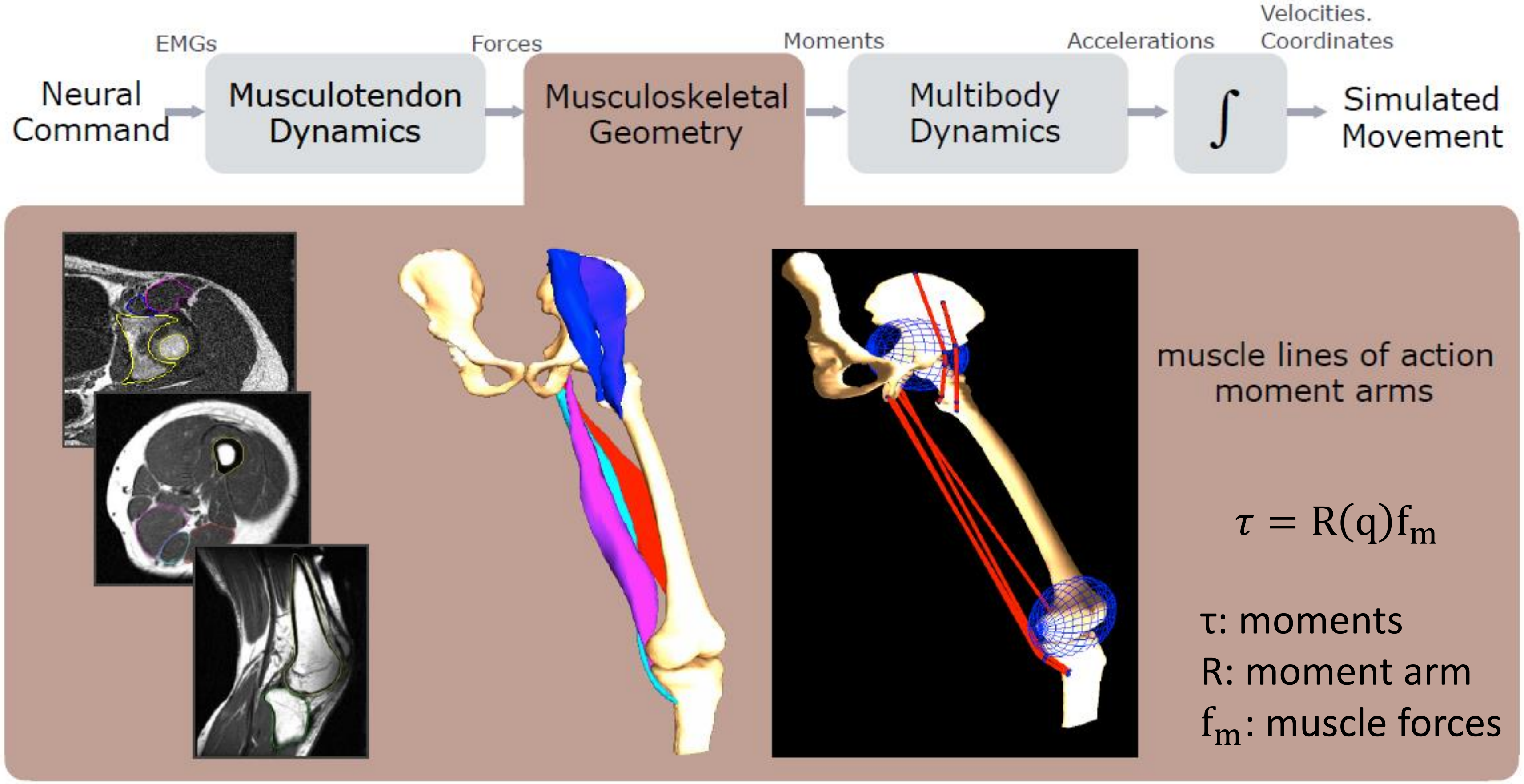
Key Concepts

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

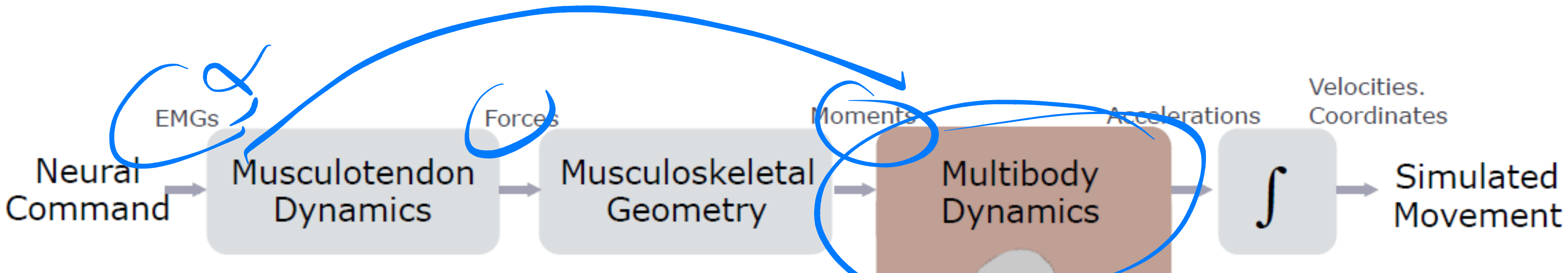
Musculoskeletal Dynamics



Musculoskeletal Geometry



Multibody Dynamics



coordinates, q

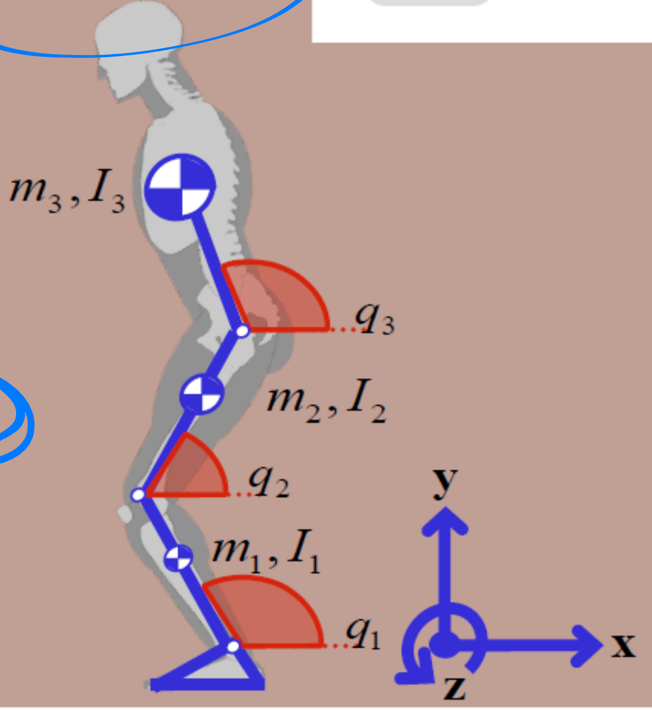
velocities, $\dot{q}$

$$\ddot{q} = M^{-1}(q)\big(R(q)f_m + C(q,\dot{q}) + G(q)\big)$$

M: inertial matrix

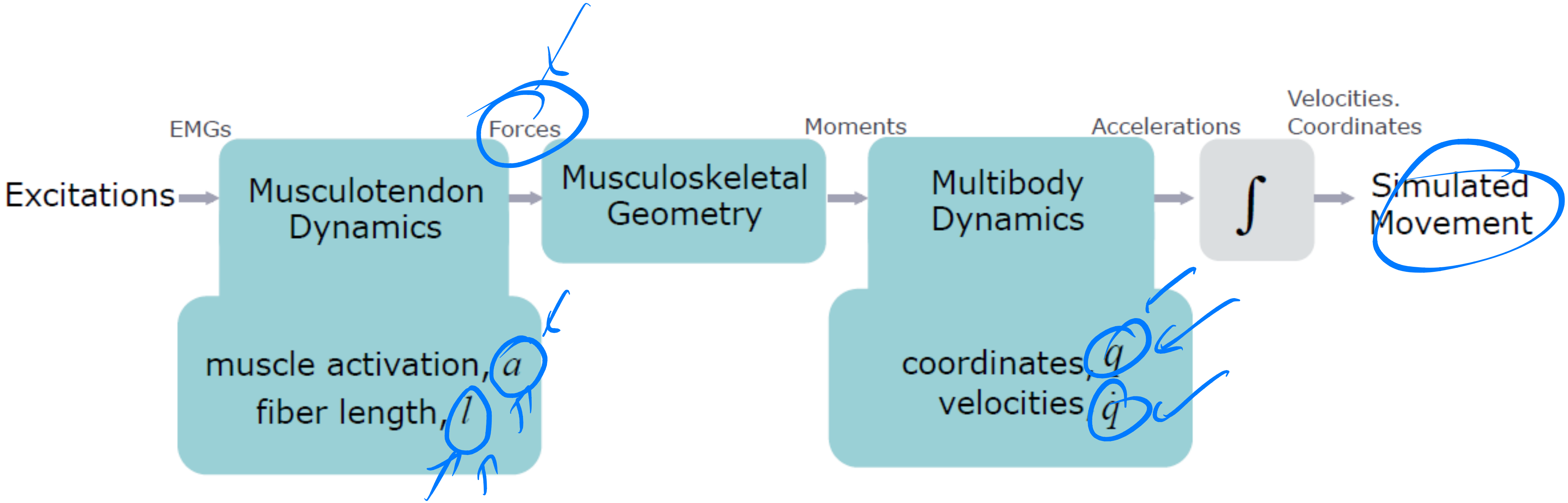
C: Coriolis, centrifugal and other forces

G: Gravitational forces

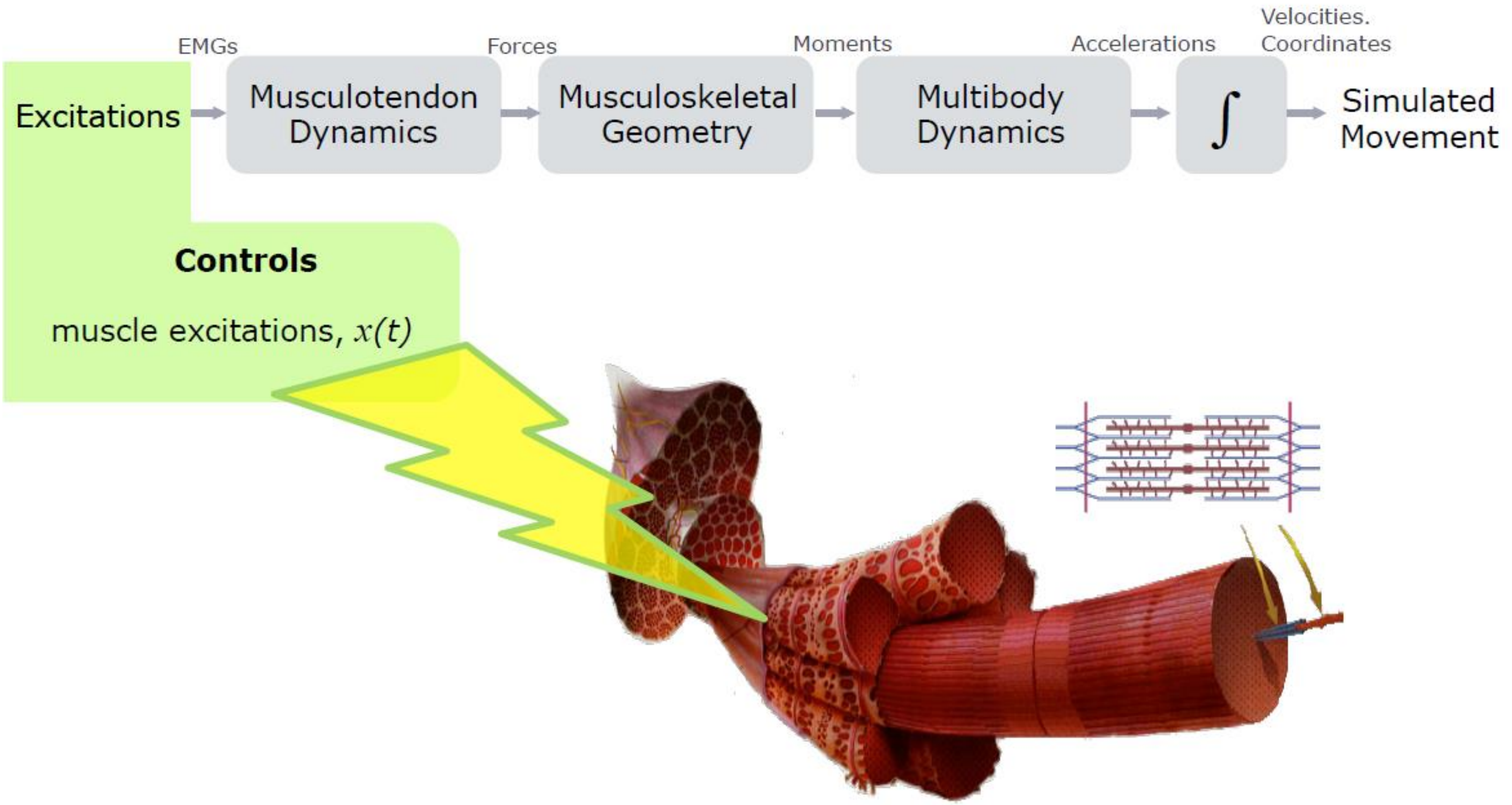


States of a Musculoskeletal Model

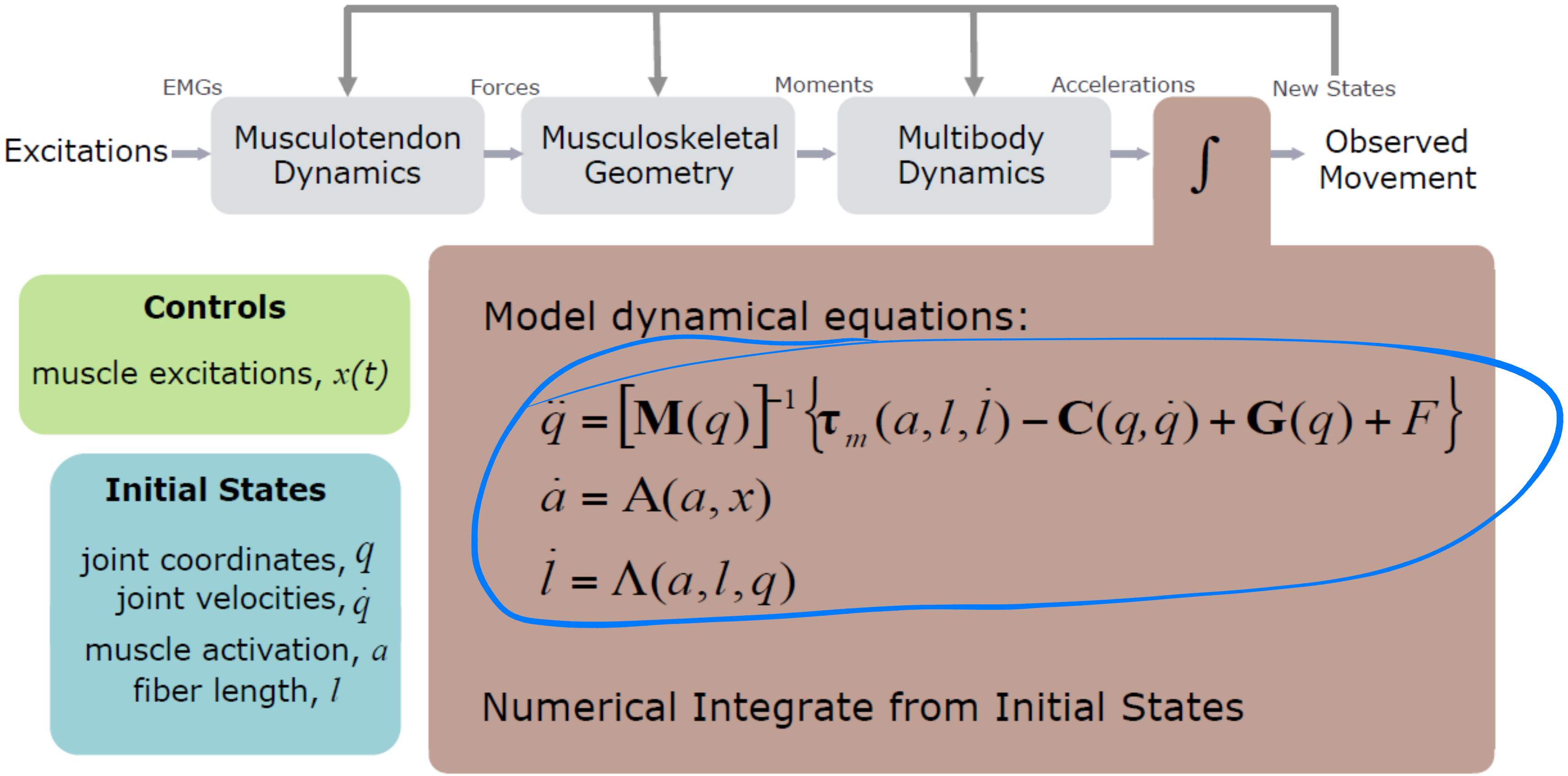
- States are model variables that are governed by the dynamics
- All measures of interest can be calculated from the states



Controls of a Musculoskeletal Model

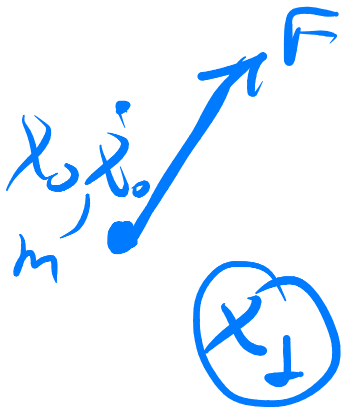


Numerical Integration of Dynamical Equations



Forward Dynamics Exercise

A forward dynamics simulation is



$$\dot{x}_1 = \dot{x}_0 + \alpha \cdot dt$$

$$x_1 = x_0 + \dot{x}_0 \cdot dt$$

A. a musculoskeletal model

B. muscle-driven

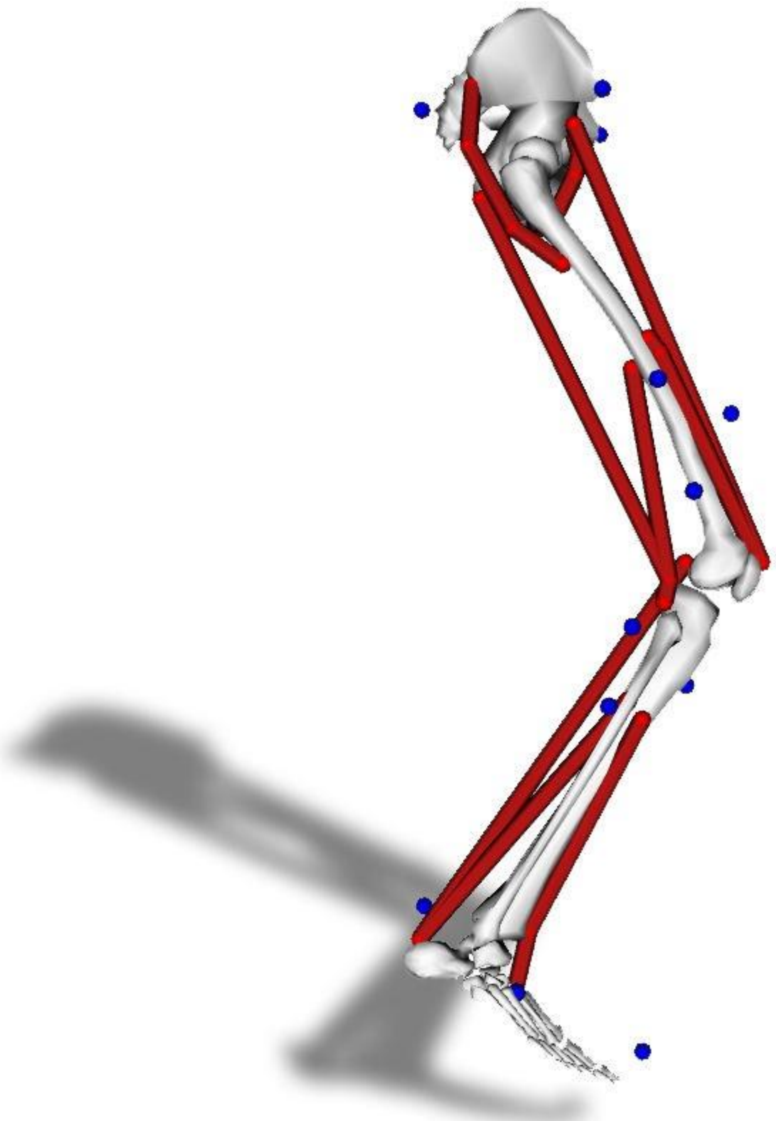
C. a simulation that uses feedback

D. the integration of dynamical equations

Forward Dynamics Exercise

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

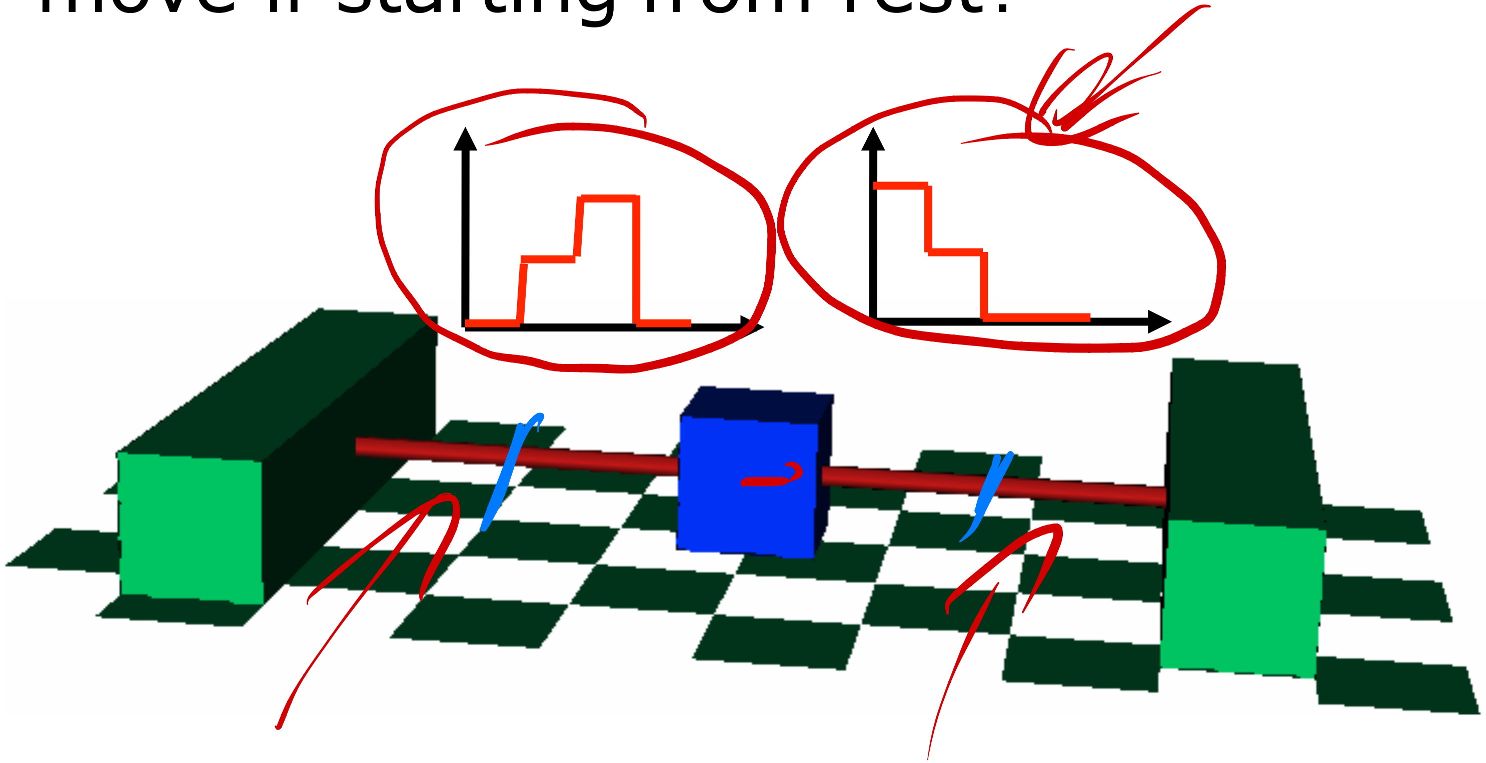
A. 3
B. 9
C. 12
D. 24



Forward Dynamics Exercise

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
C. To the right
D. Upward

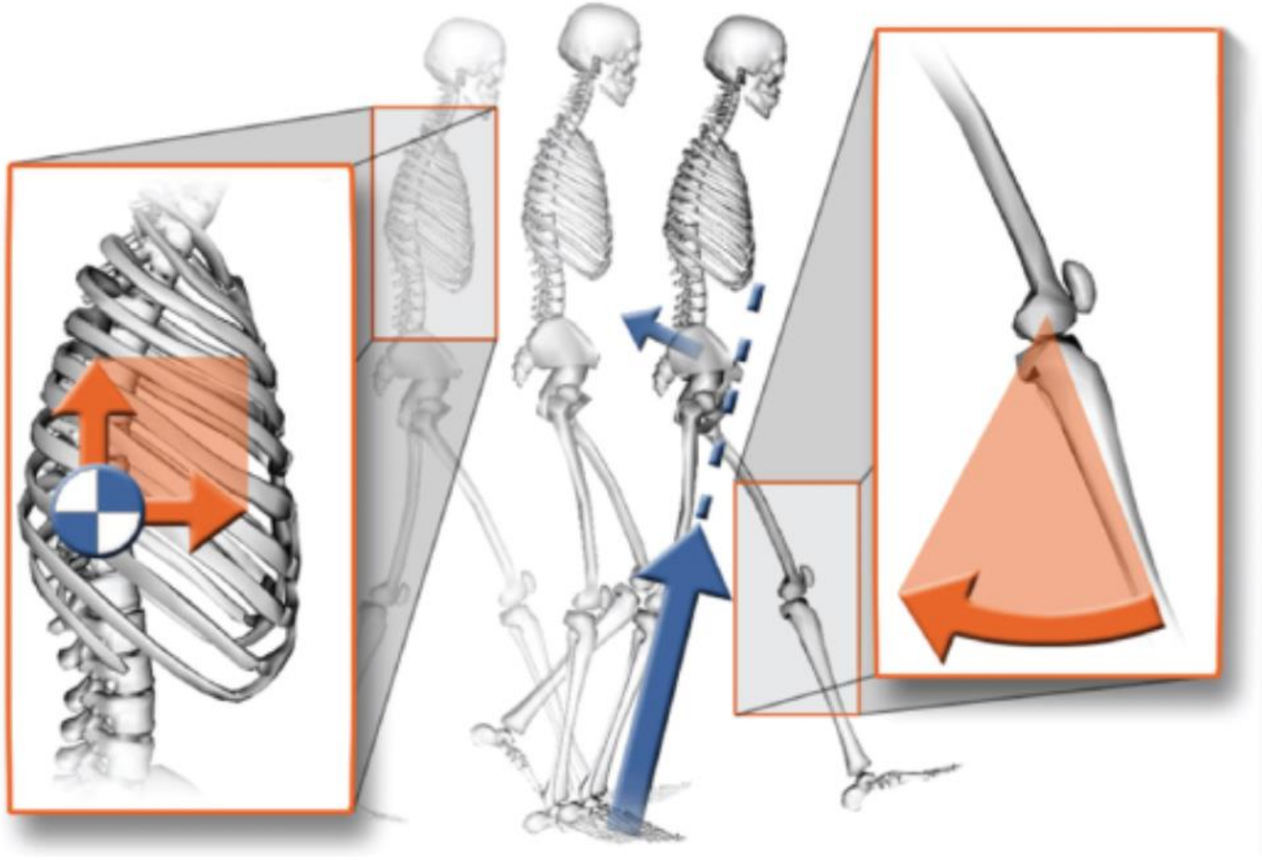


Forward Dynamics Exercise

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 compute $\dot{a}$, $\dot{l}$, and $\ddot{q}$ from model dynamics
B. Numerically integrate forces and controls from model differential equations
C. Numerically integrate $\dot{a}$, $\dot{l}$, and $\ddot{q}$
D. Numerically differentiate forces and controls from the dynamical equations
E. A & C

Reducing Residuals



What are residuals?

Non-physical forces that account for inconsistencies between experimental GRFs and joint accelerations estimated from experimental markers.

$$F = ma + R$$

Inconsistencies due to:

1. noise in marker and joint angle data (differentiating angles for accelerations)

2. inaccuracies in model geometry and mass distribution

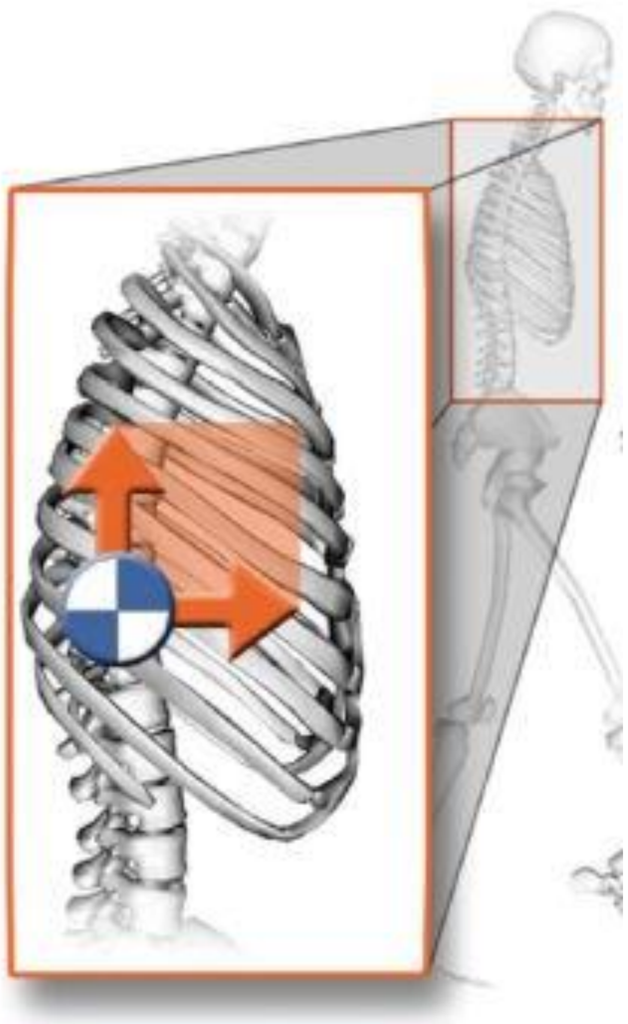
Why reduce residuals?

1. Residuals are non-physical and necessary only to account for errors
2. Want muscles to account for all movement
3. To have confidence in muscle contributions

How can you reduce residuals?

- Torso is most massive and error prone to estimate
- Location of Torso mass center also difficult to estimate

1. Adjust mass distribution including Torso COM location

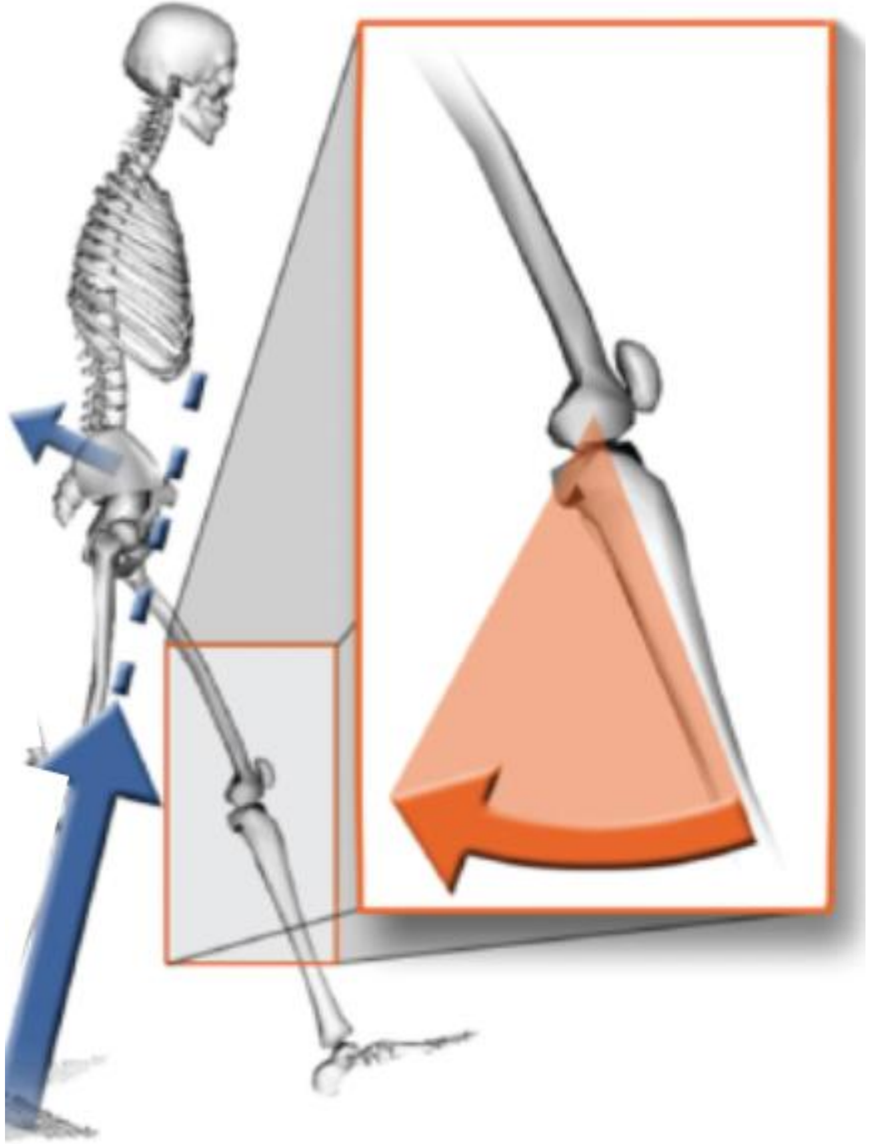


How can you reduce residuals?

- Joint kinematics estimated from marker position has inaccuracies
- Differentiation of kinematics can yield non-physical accelerations

1. Adjust mass distribution including Torso COM location
2. Adjust kinematics slightly while satisfying equations of motion

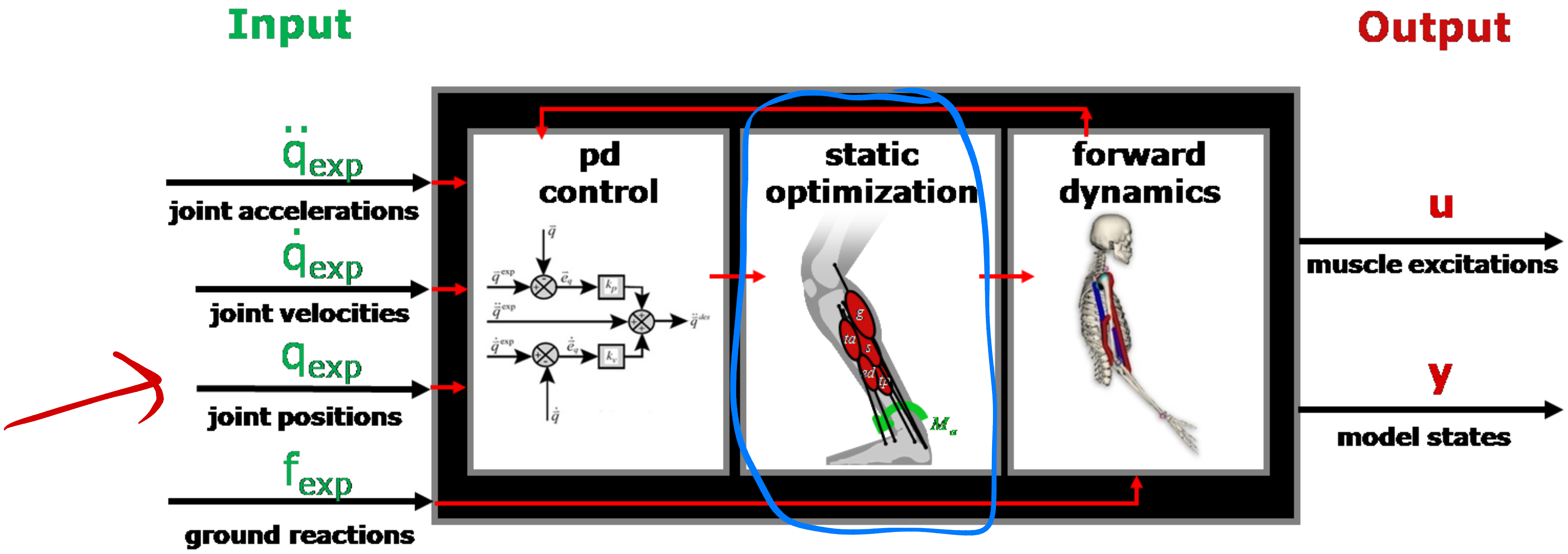
RRA tracks kinematics in a forward dynamics simulation



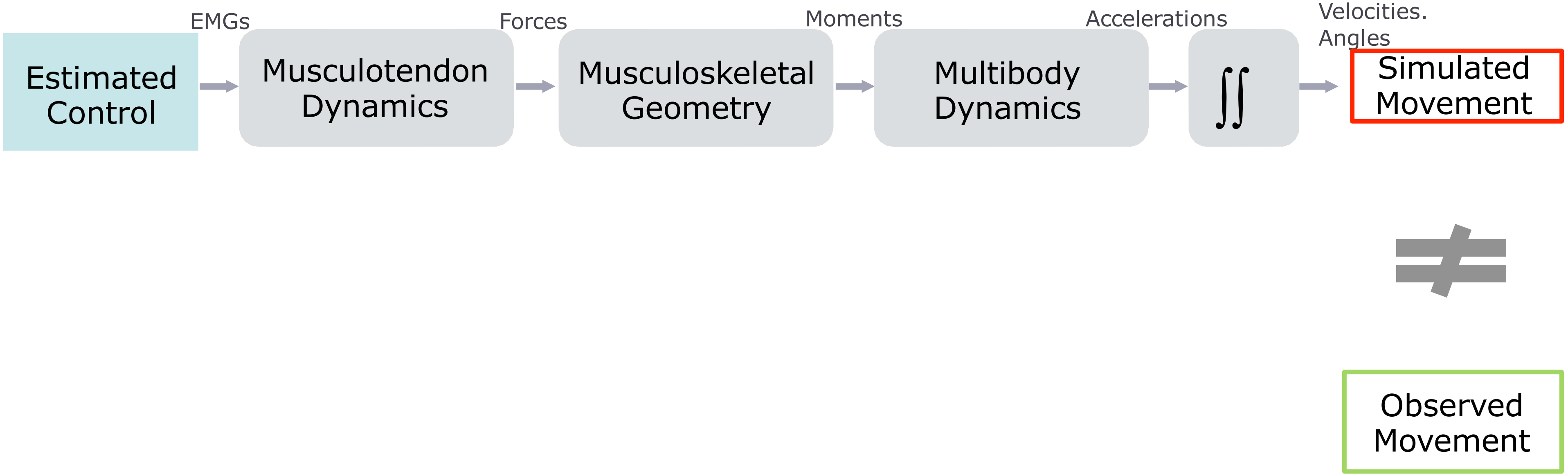
Tips and Tricks

- Keep optimal forces for residuals low (increase control bounds if necessary)
- Lower weight on kinematics that track closely or have low con!dence in measurement
- Make mass adjustments and run RRA again - repeat until residuals no longer change

Computed Muscle Control

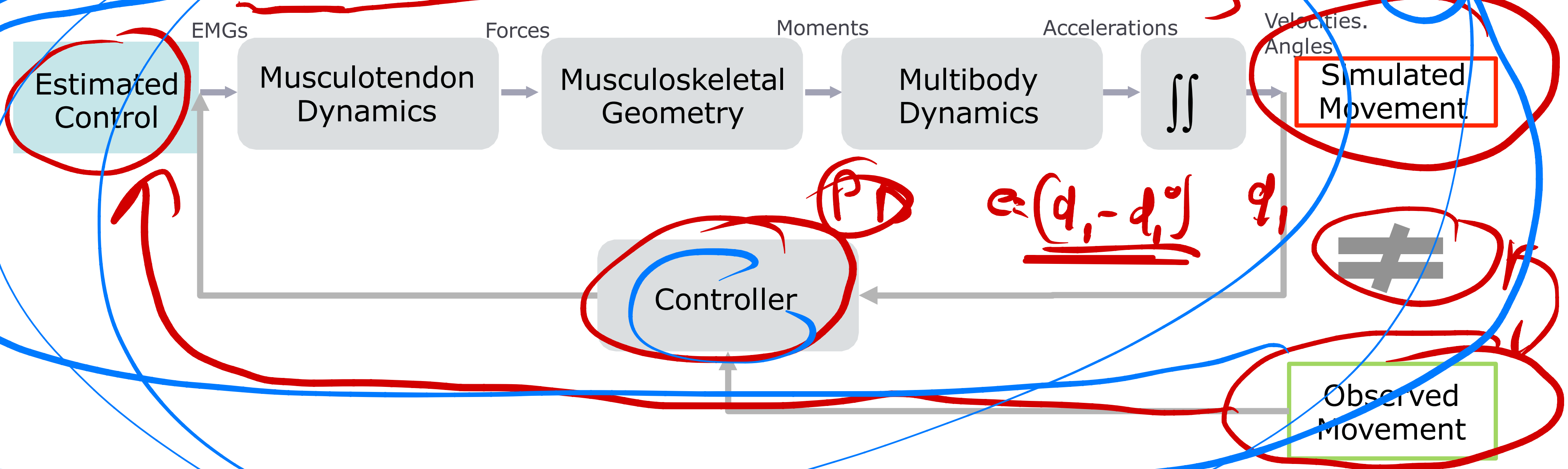


Muscle Driven Forward Simulation



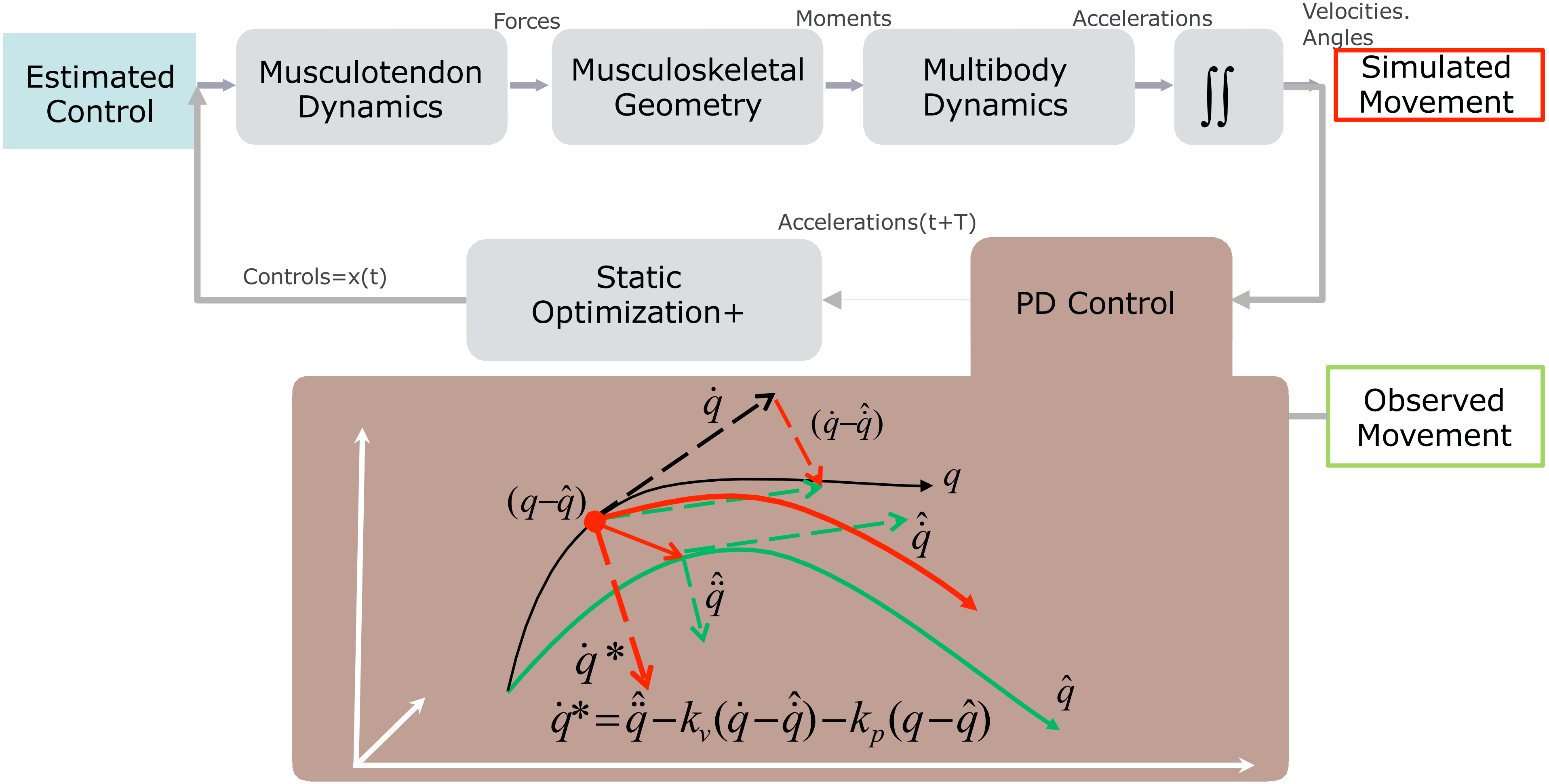
- Static optimization muscle model differs from dynamical model in forward simulation
- Acceleration data is discrete and noisy
- A nonlinear dynamical systems can be chaotic

Muscle Driven Forward Simulation

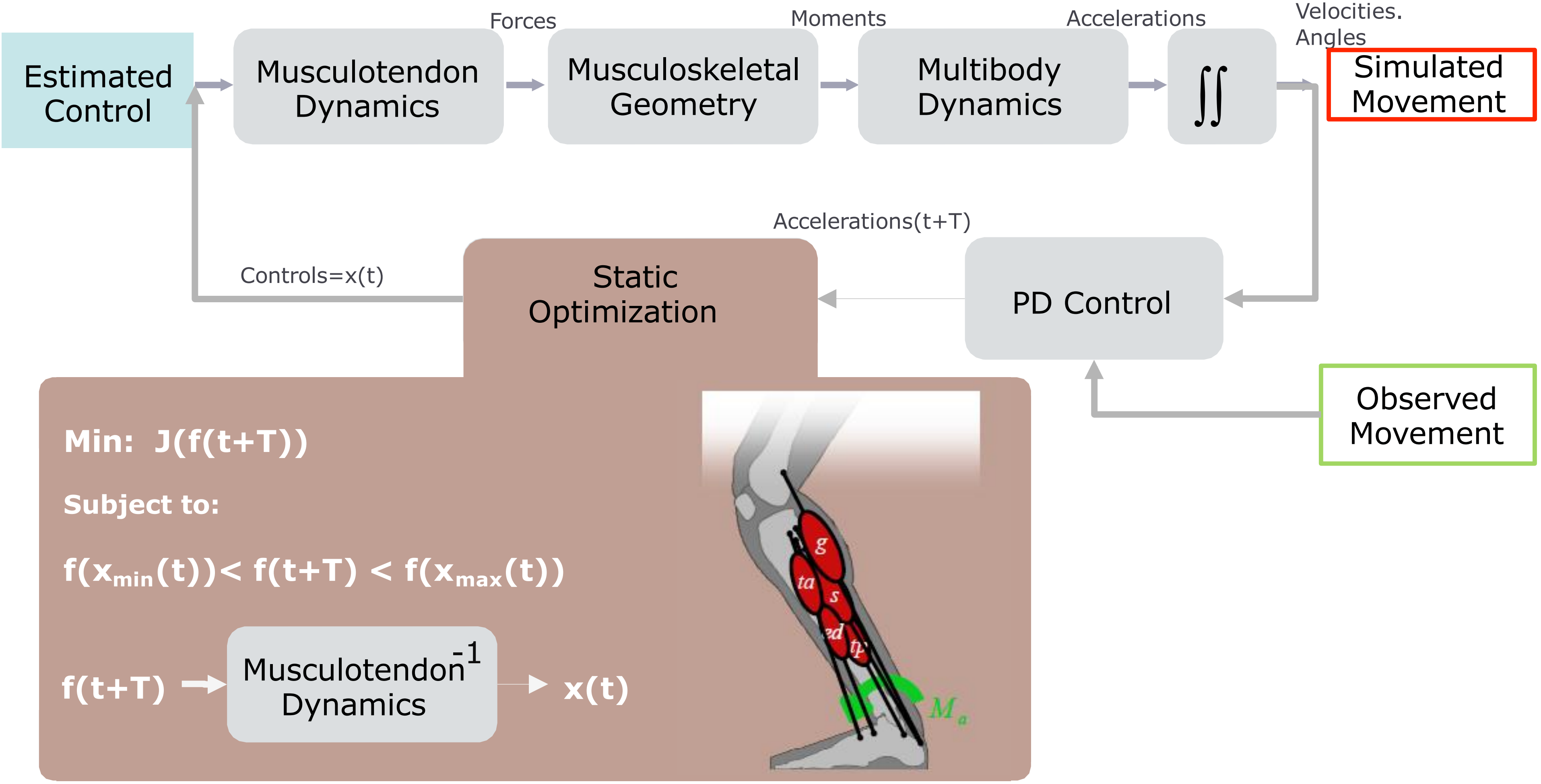


- Close the loop and try to track the observed movement in a forward dynamic manner: Computed muscle control

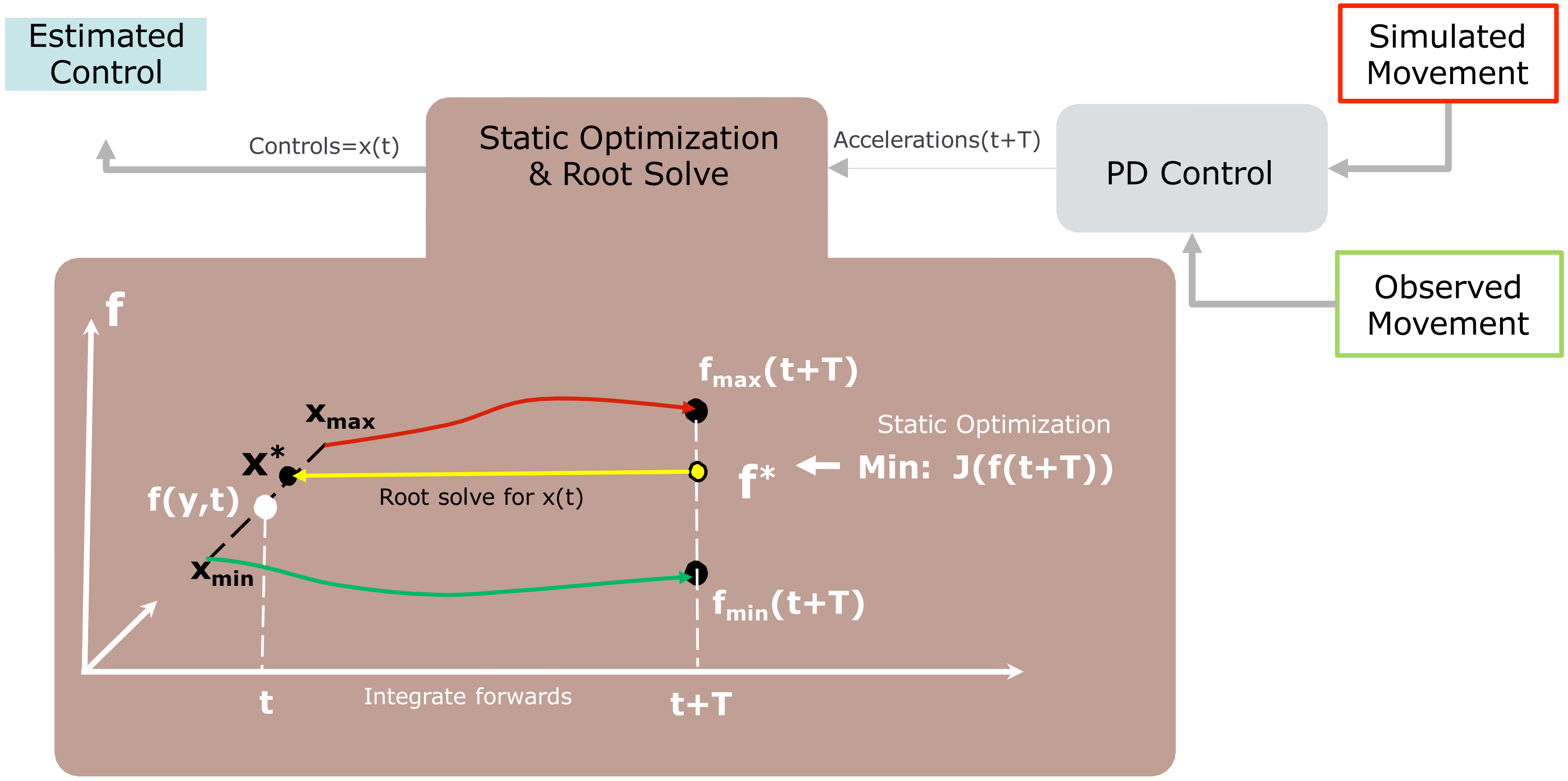
Computed Muscle Control (CMC)



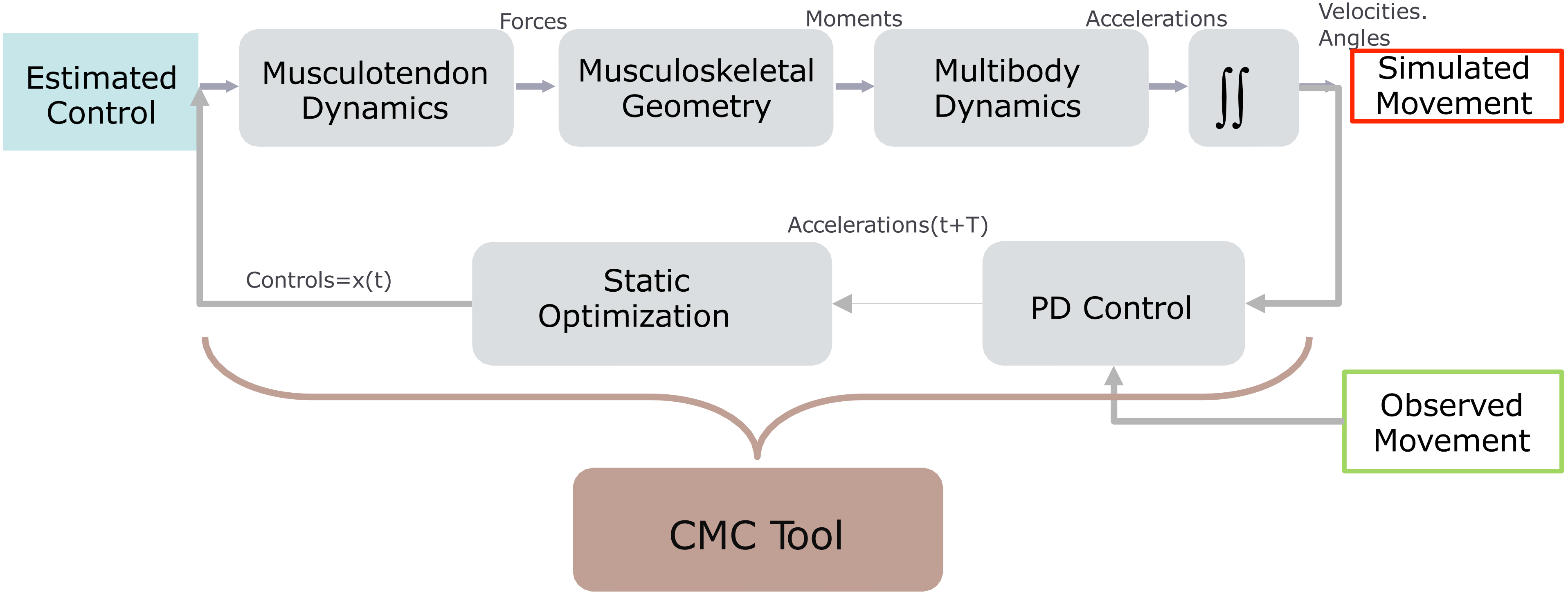
Computed Muscle Control (CMC)



Inside the CMC Algorithm



Computed Muscle Control Tool



Tips and Tricks

- You can use results from IK or RRA. For best results, track RRA output not IK
- Increase max excitation of reserves if CMC is failing
- Compare to EMG and constrain excitations where there is a mismatch
- Command Line: cmc –S cmc_setup_!le.xml

Other Types of Analyses

- Kinematics
- BodyKinematics
- Actuation
- JointReaction