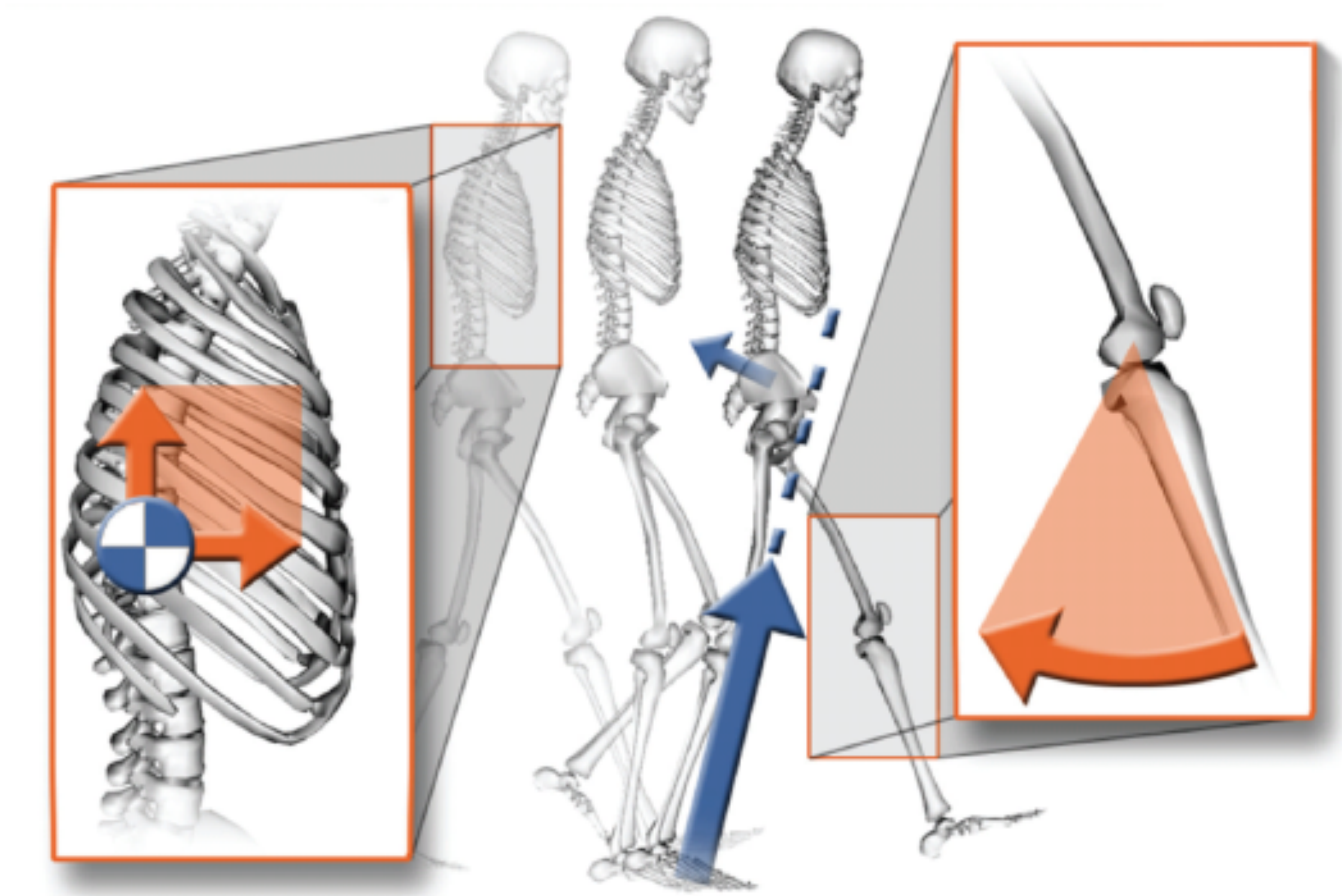


Reducing Residuals

What are residuals?

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

$$F = ma + R$$

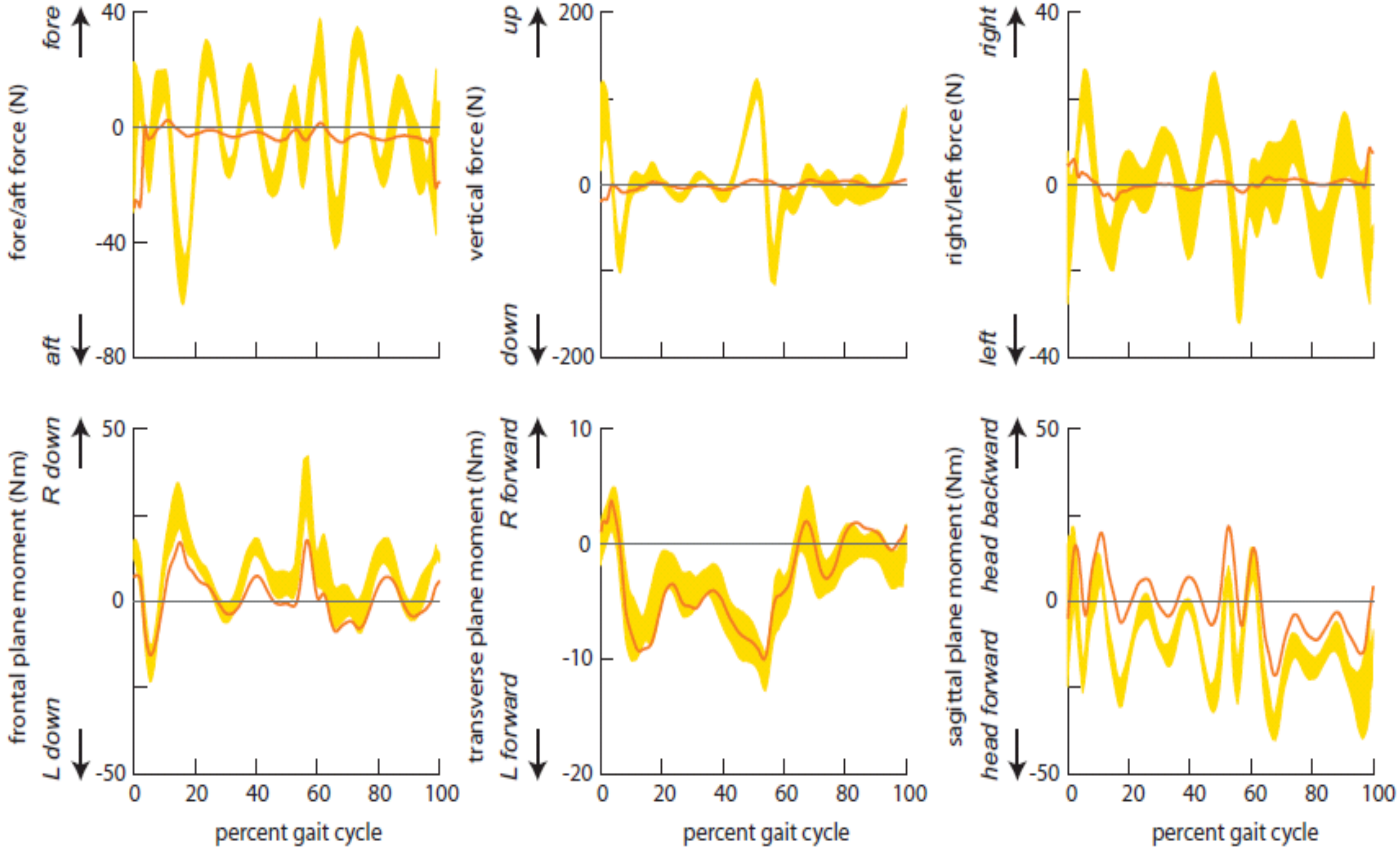
Inconsistencies due to:

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

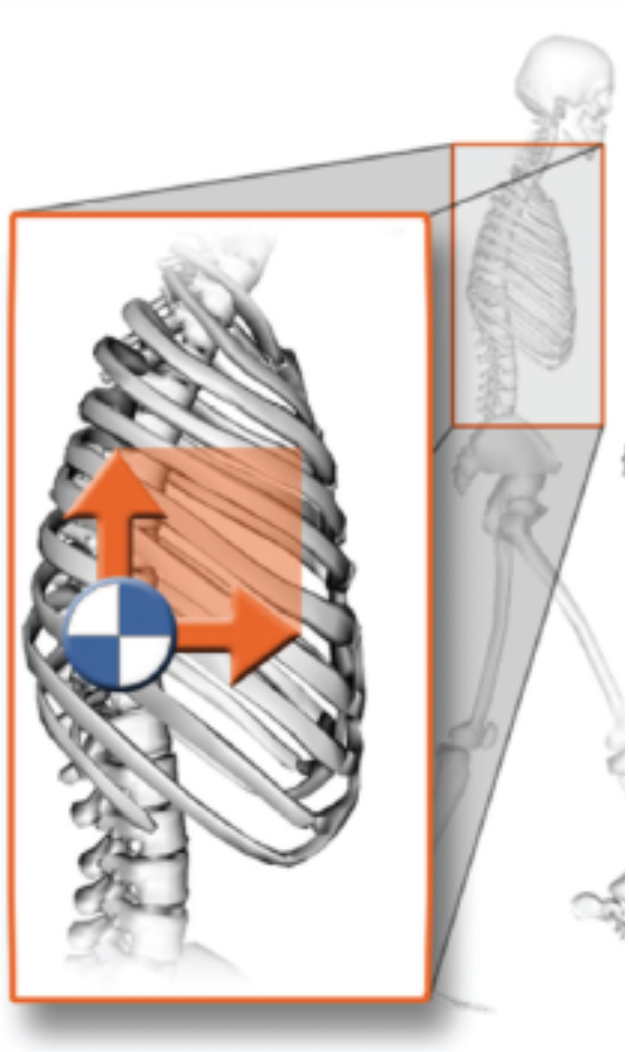
Sample residual reduction during gait



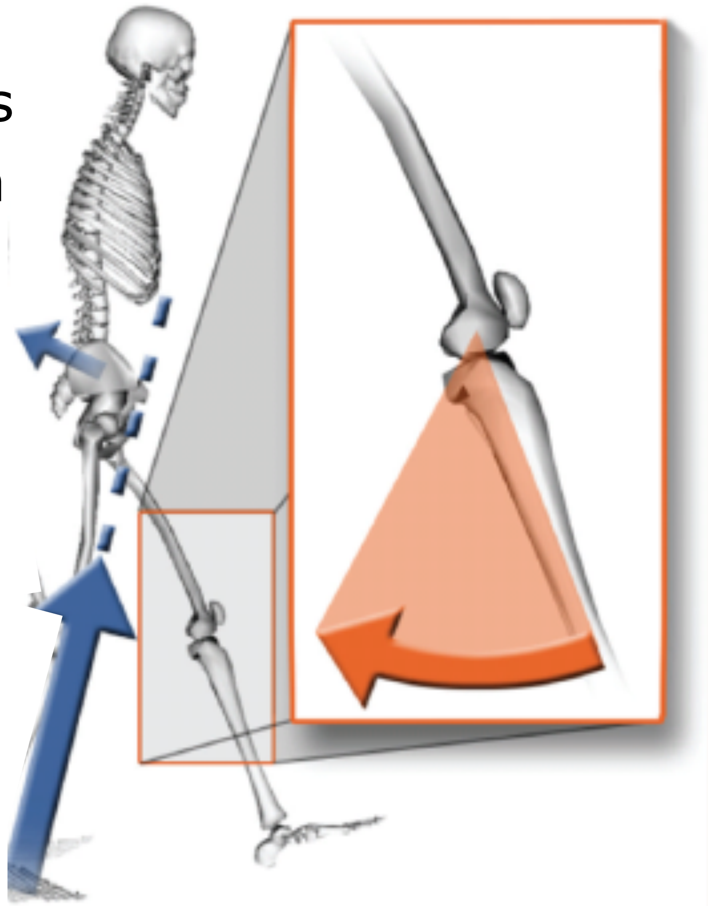
How can you reduce residuals?

- 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?



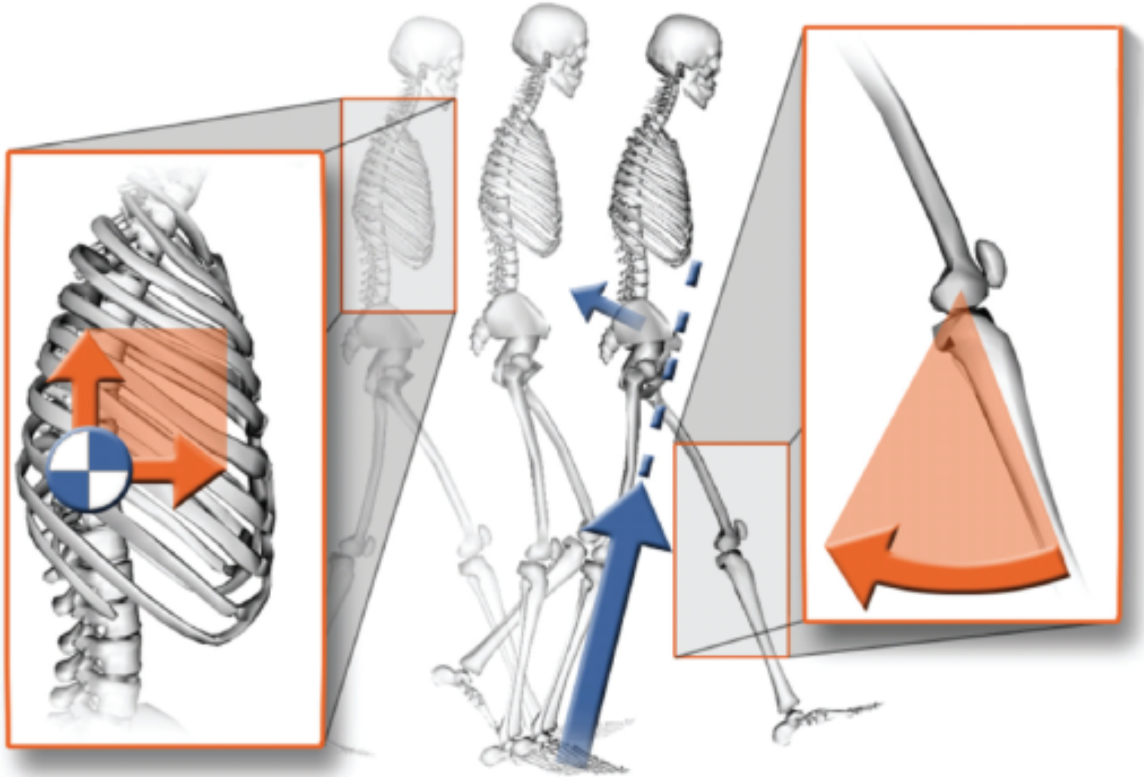
- Joint kinematics estimated from marker position has inaccuracies
- Differentiation of kinematics can yield non-physical accelerations

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

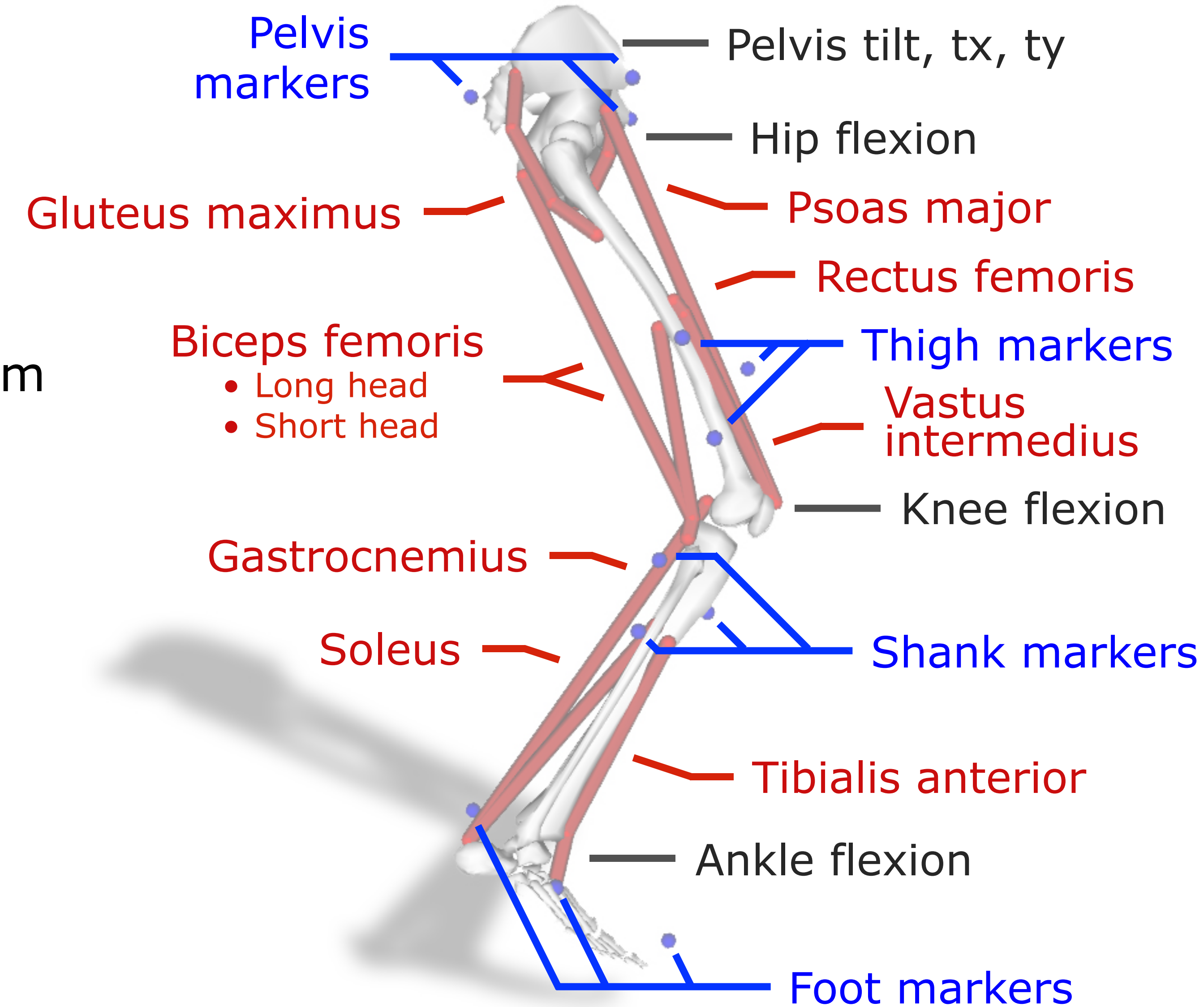
Residual Reduction Algorithm (RRA)



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

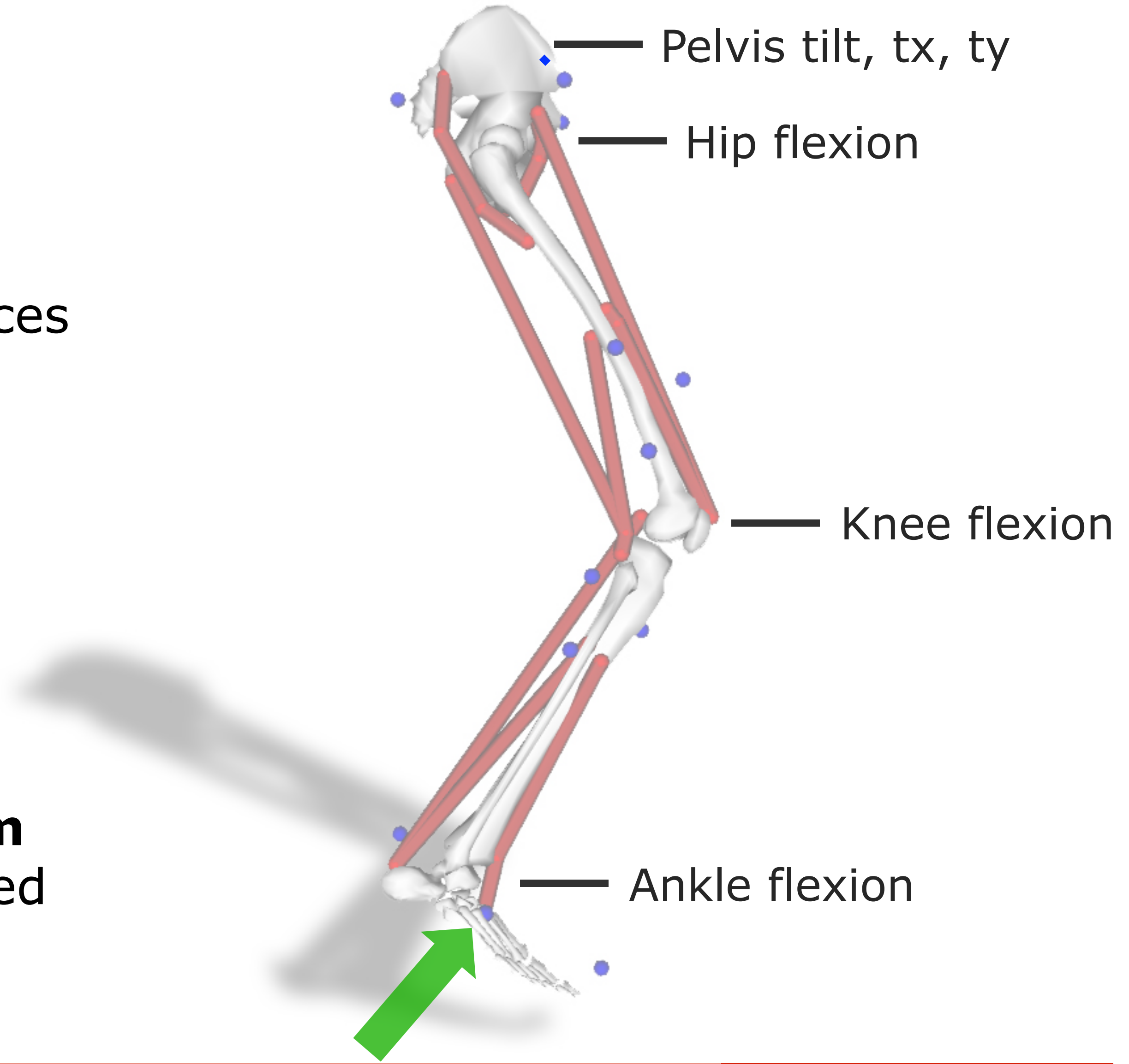
Exercise: Forward Simulation of Stance

Leg Model:
6 Degrees of Freedom
9 Muscles



Part 1: Dynamically Consistent Model & Data

Leg Dynamics
3 Residual pelvis forces
3 Joint motors
GRF on foot



Launch OpenSim
Handout for detailed instructions

Work with your Group: Viewing the Data and Inverse Dynamics

10 mins to complete Parts A & B

1. What type of data is available?

2. What time range were GRFs measured for the leg of interest?

3. Why are the residual forces so large?

4. Which force is the largest? Why?

Work with your Group: Residual Reduction

5 mins to complete Part C: Steps 1-14

1. Why does the model initially “float” up and down?

2. Are all of the forces being applied correctly?

3. Thinking about this model and motion, what time range of the gait should you restrict your RRA analysis?

Work with your Group: Residual Reduction

3 mins to complete Part C: Steps 15-16

1. Does the model still "float" up or down? If so, what else could be causing this?

2. What is the recommended mass adjustment?

3. Why would the mass adjustment be so large?

Work with your Group: Residual Reduction

7 mins to complete Part C: Steps 17-20

1. Is the mass adjustment suggested by RRA smaller than before?

2. How do the residual forces compare to the forces acting on the pelvis from your ID results?

3. Which coordinates have large tracking errors? Which coordinates tracked well?

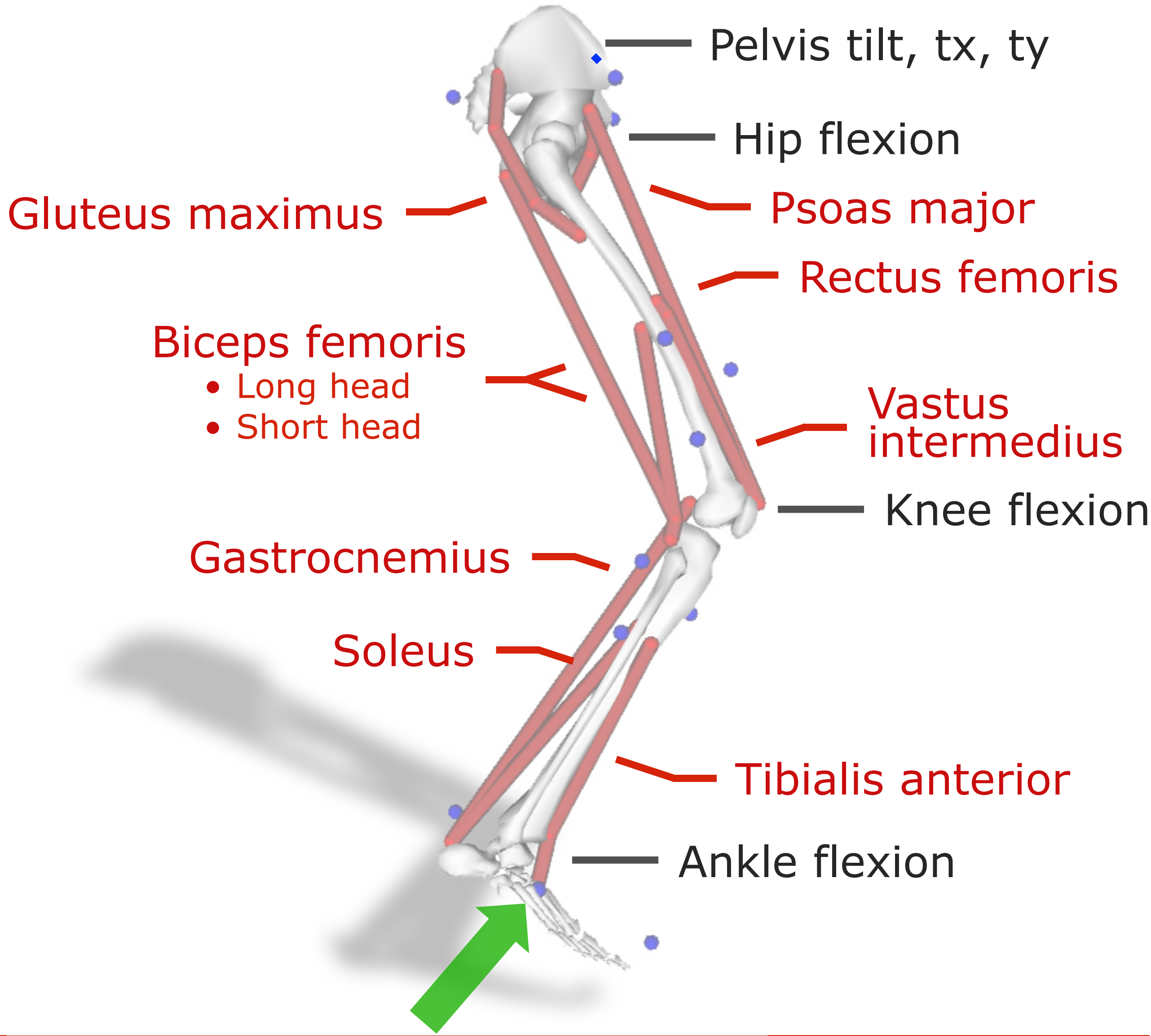
Work with your Group:
Residual Reduction

5 mins to complete Part C: Steps 21-22

1. Are the residual forces and tracking improved?

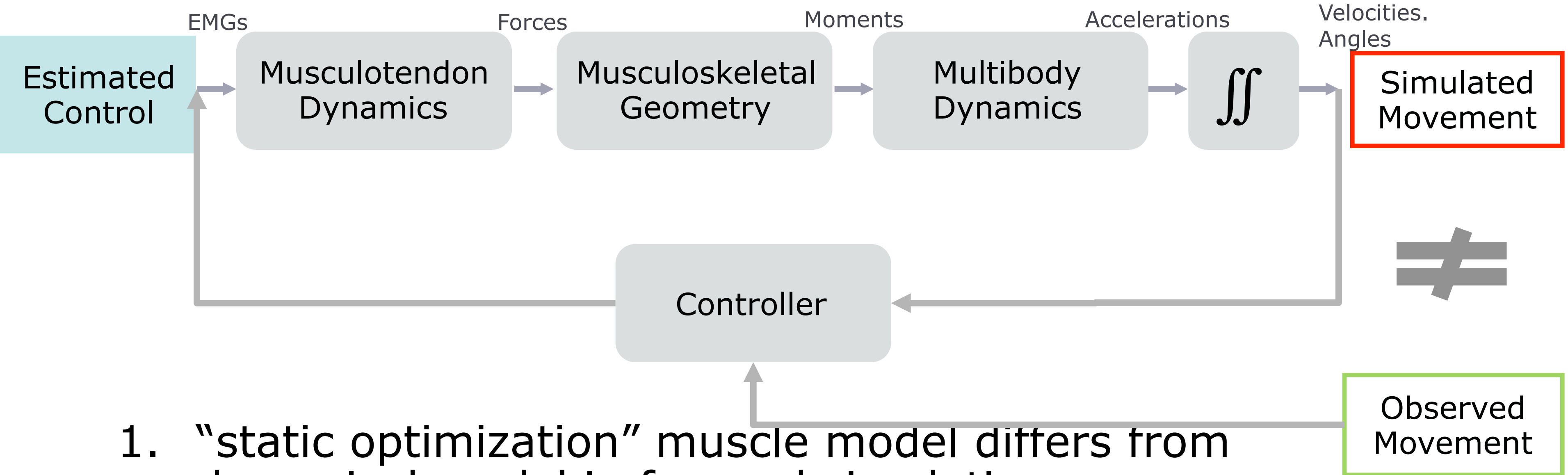
Part II: Muscle-driven Forward Simulation

Leg Dynamics
3 Residual forces
3 Joint motors
9 Muscles
GRF on the foot



Behind Computed Muscle Control

Muscle-Driven Forward Simulation



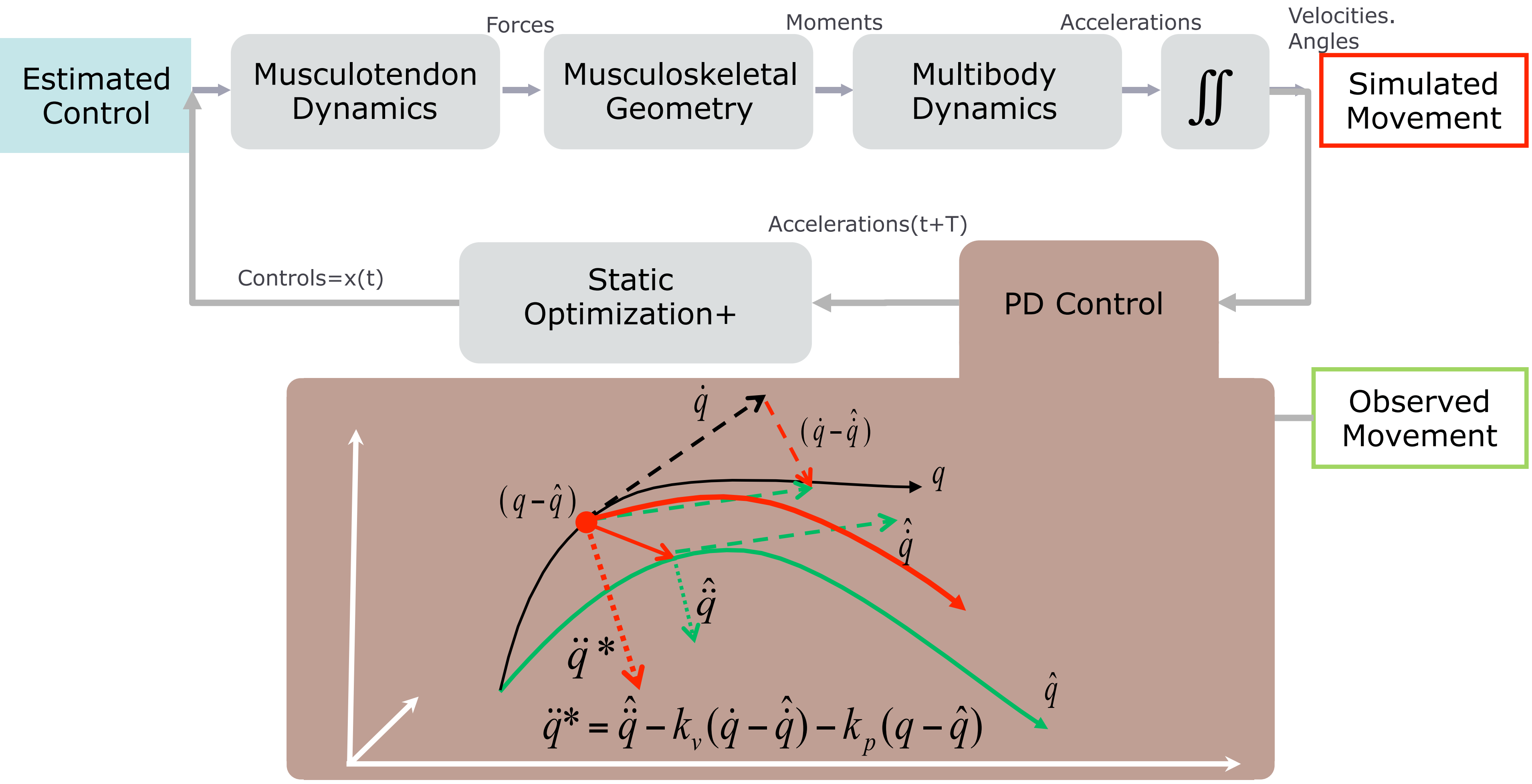
1. "static optimization" muscle model differs from dynamical model in forward simulation.

2. Acceleration data is discrete and noisy.

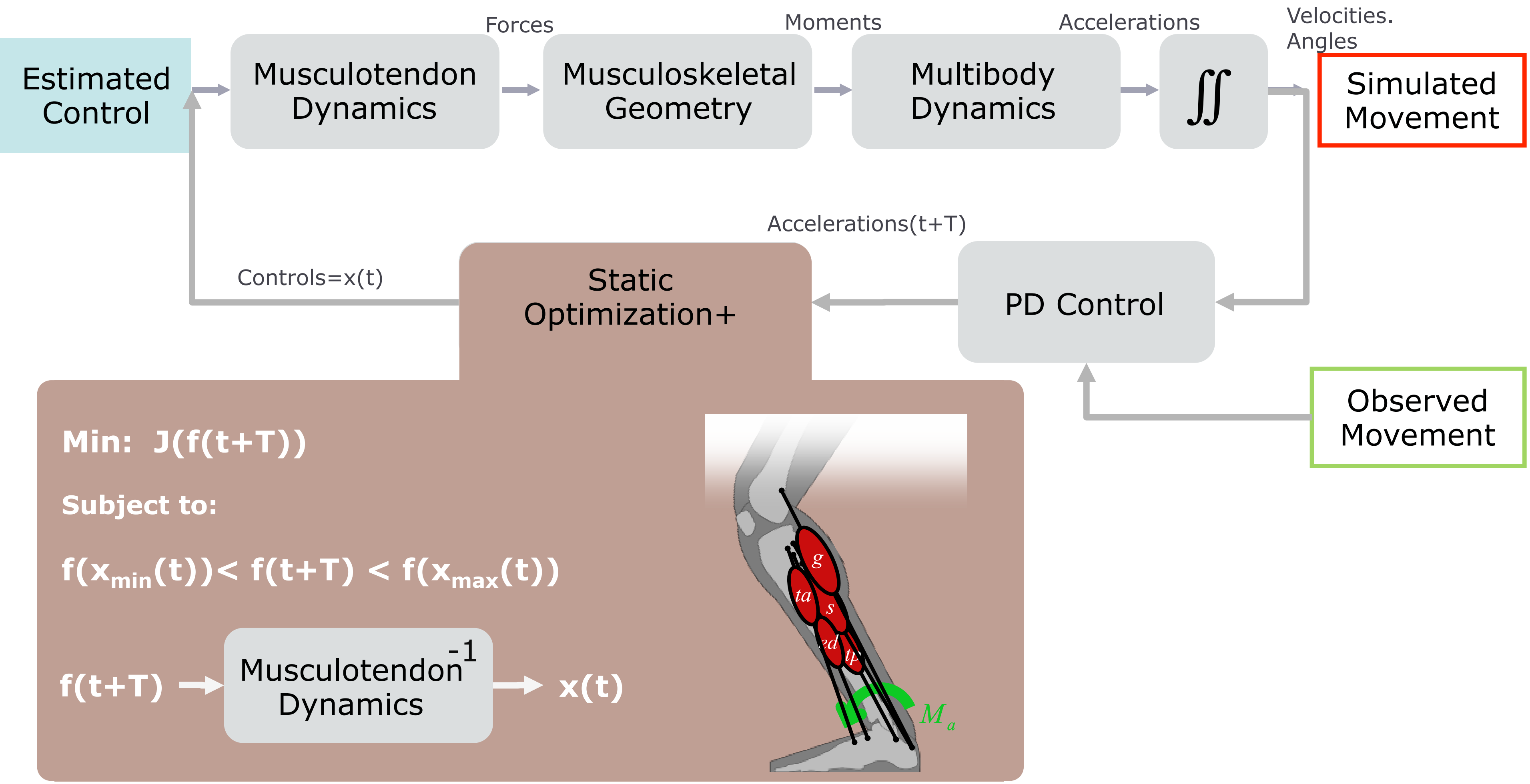
Solution: Close the loop!

3. A nonlinear dynamical systems can be chaotic.

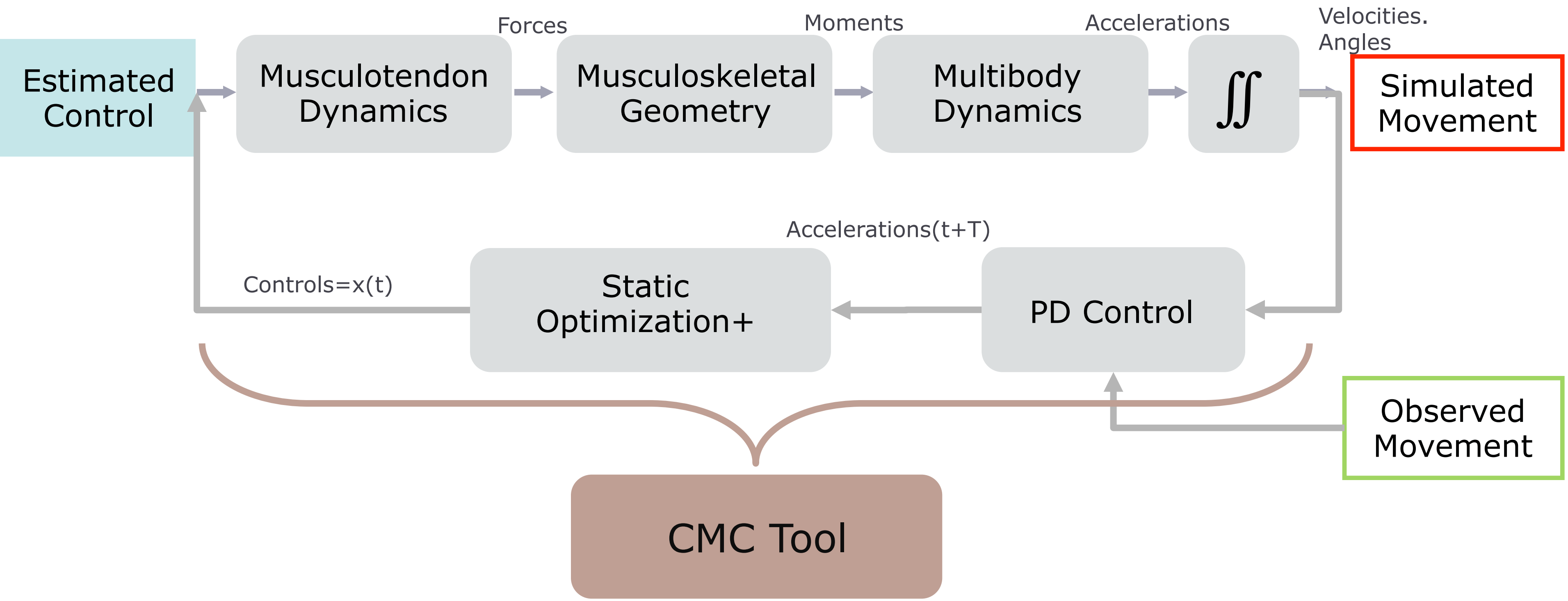
Computed Muscle Control (CMC)



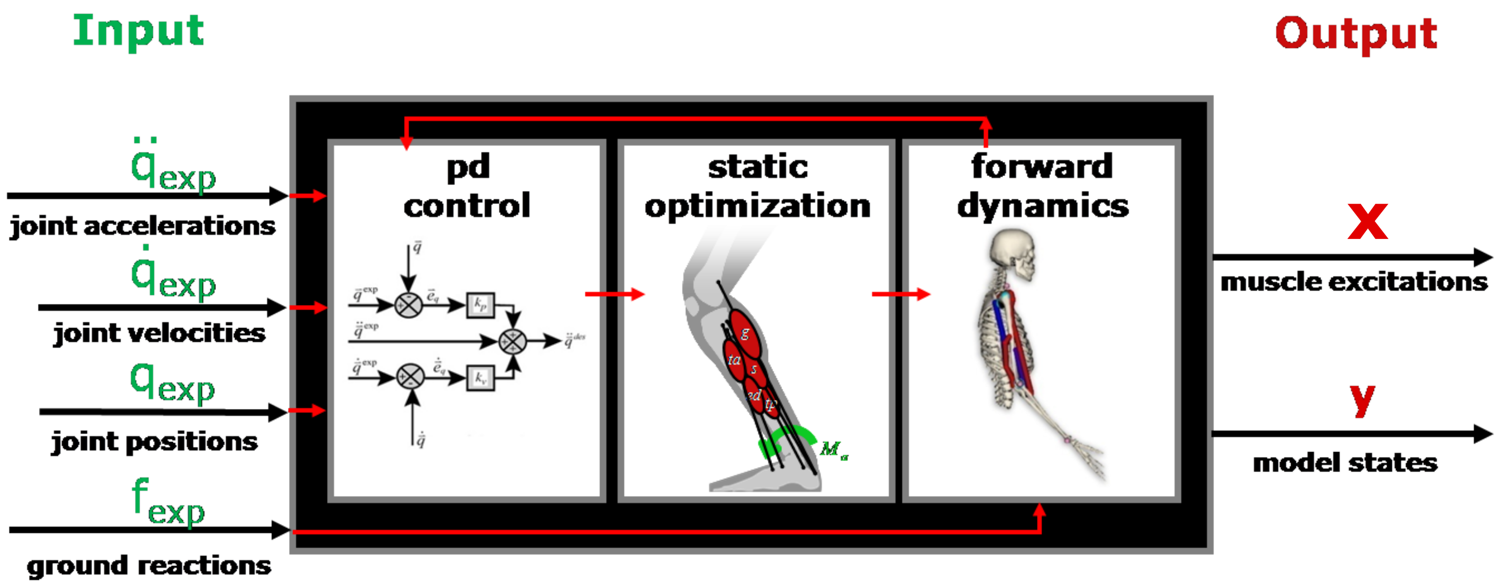
Computed Muscle Control (CMC)



Computed Muscle Control Tool:



Computed Muscle Control



TIPS & 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_file.xml