BME 271
Biomechanics of Movement

Jeff Reinbolt

October 3, 2012

Question of the Day: Who has run here?

Outline for Today

- Objectives of the lecture and assignment
- Why study movement?
- Production and measurement of movement
- What tools are used?
- What can you do with this stuff?
- Prerequisites for movement biomechanics
- Example research topic
- A little different homework assignment
- Answer your questions!

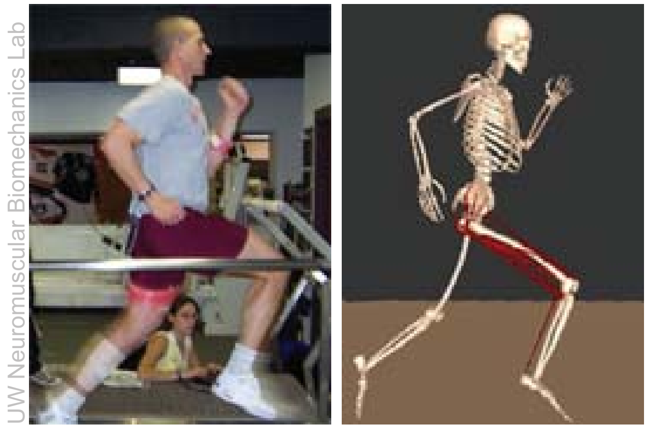
Objectives of the Lecture and Assignment

- Overview of key challenges in movement biomechanics
- Background in biology needed to understand production of movement
- Experience with engineering tools used to study movement
- Framework for self teaching and research

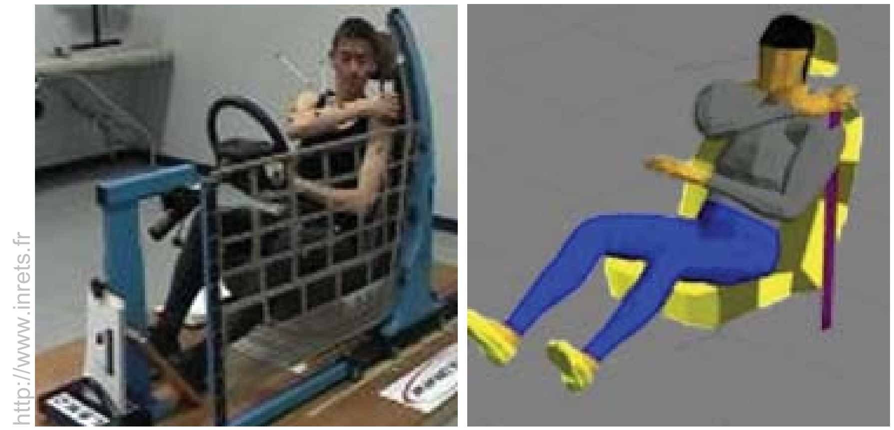
Other Stuff About the Lecture and Assignment

- This is some of the info I never had.
- You have a wide range of backgrounds. We would like to provide an assignment that stimulates every student without overwhelming anyone.
- You will need to dig beyond lecture notes for the assignment.
- Have fun! Be interactive!

Why Study Movement?



Analyze and optimize athletic performance

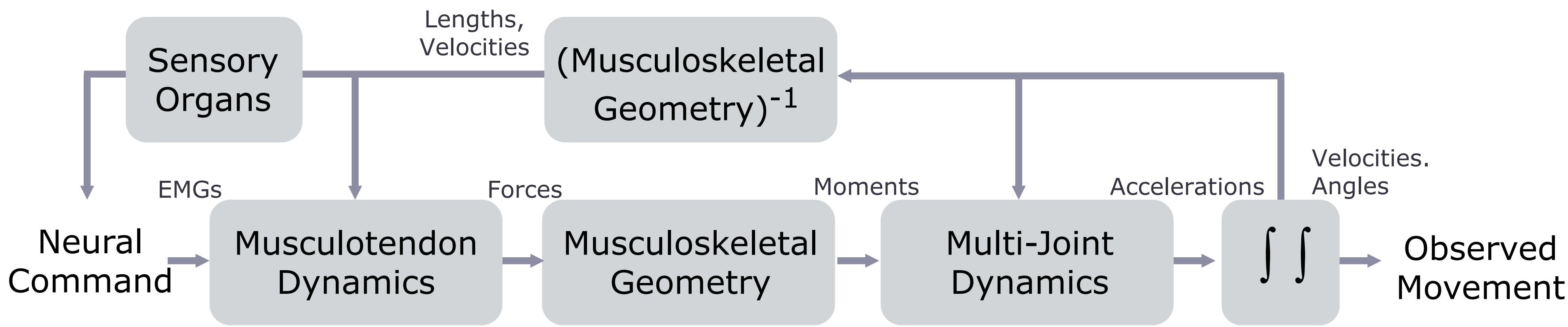


Design ergonomically safe environments

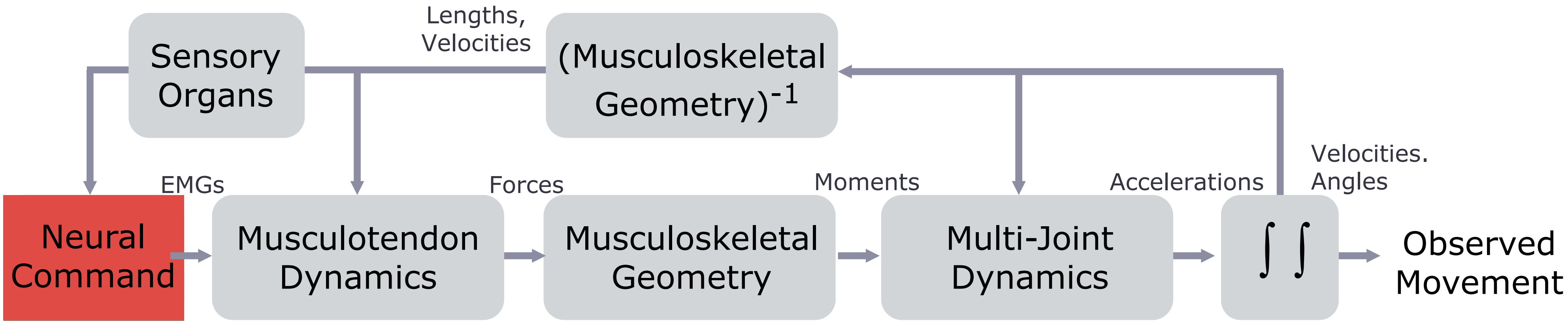
Create human and animal characters

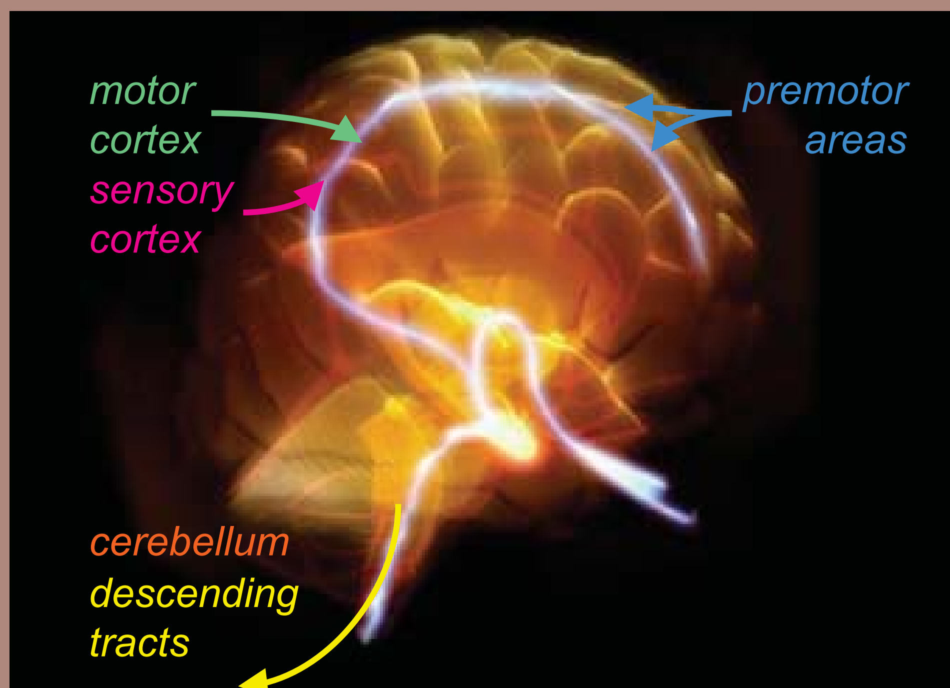
Understand and treat movement disorders

Production of Movement (forward dynamics)

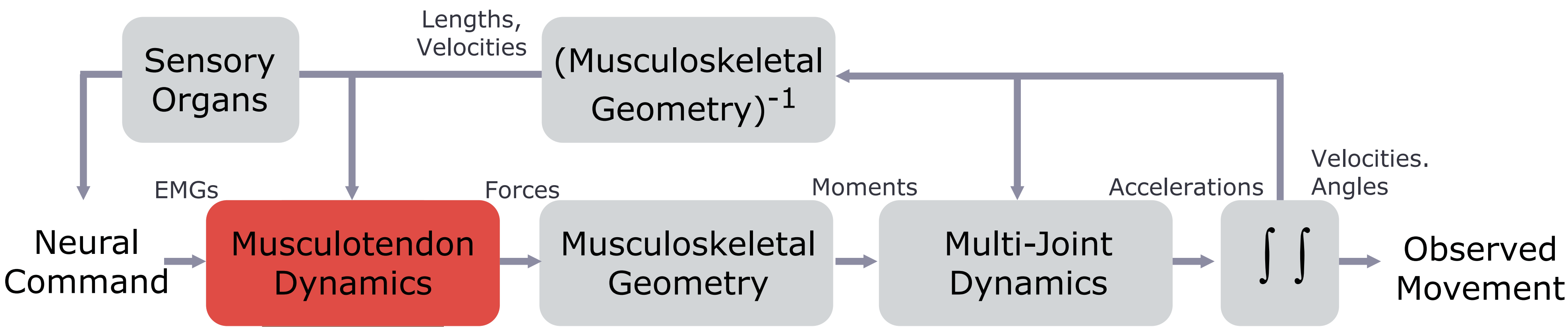


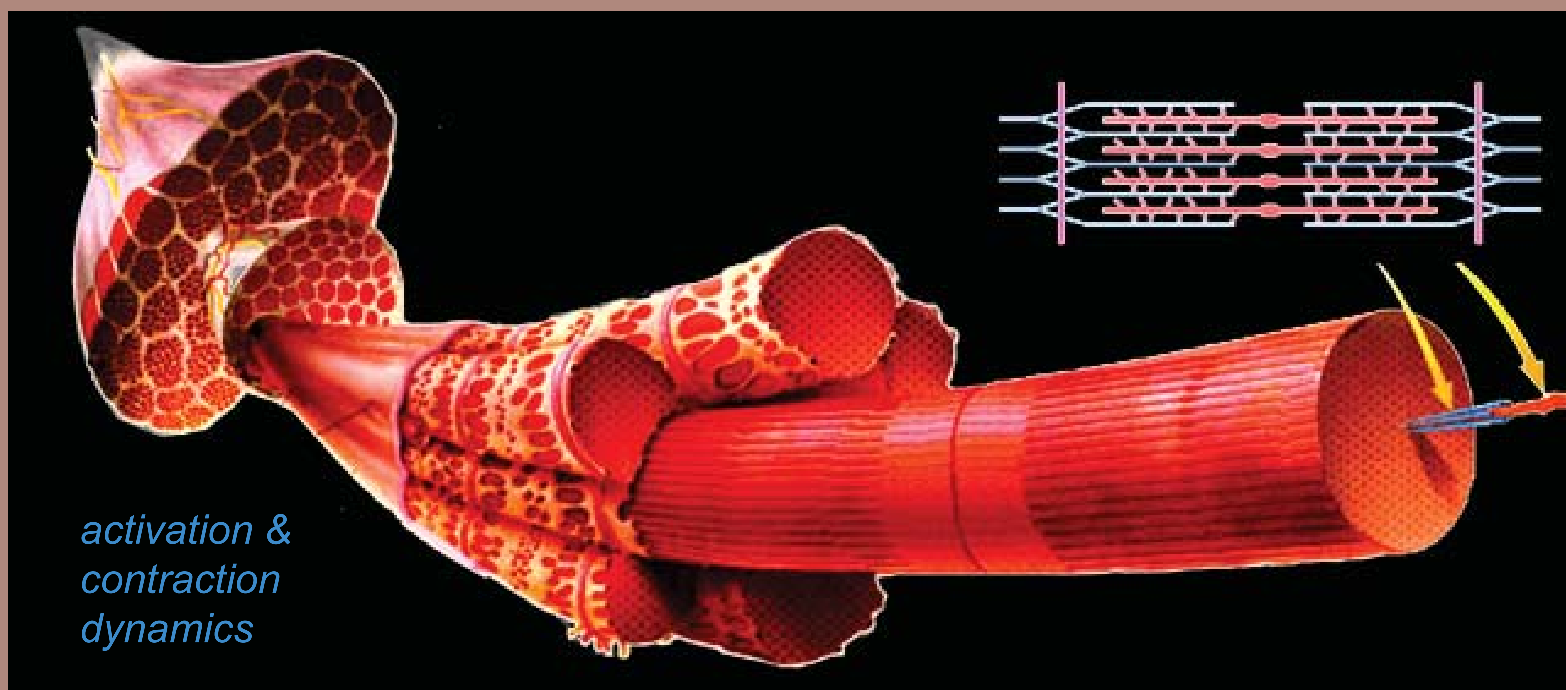
Movement Starts with a Neural Command



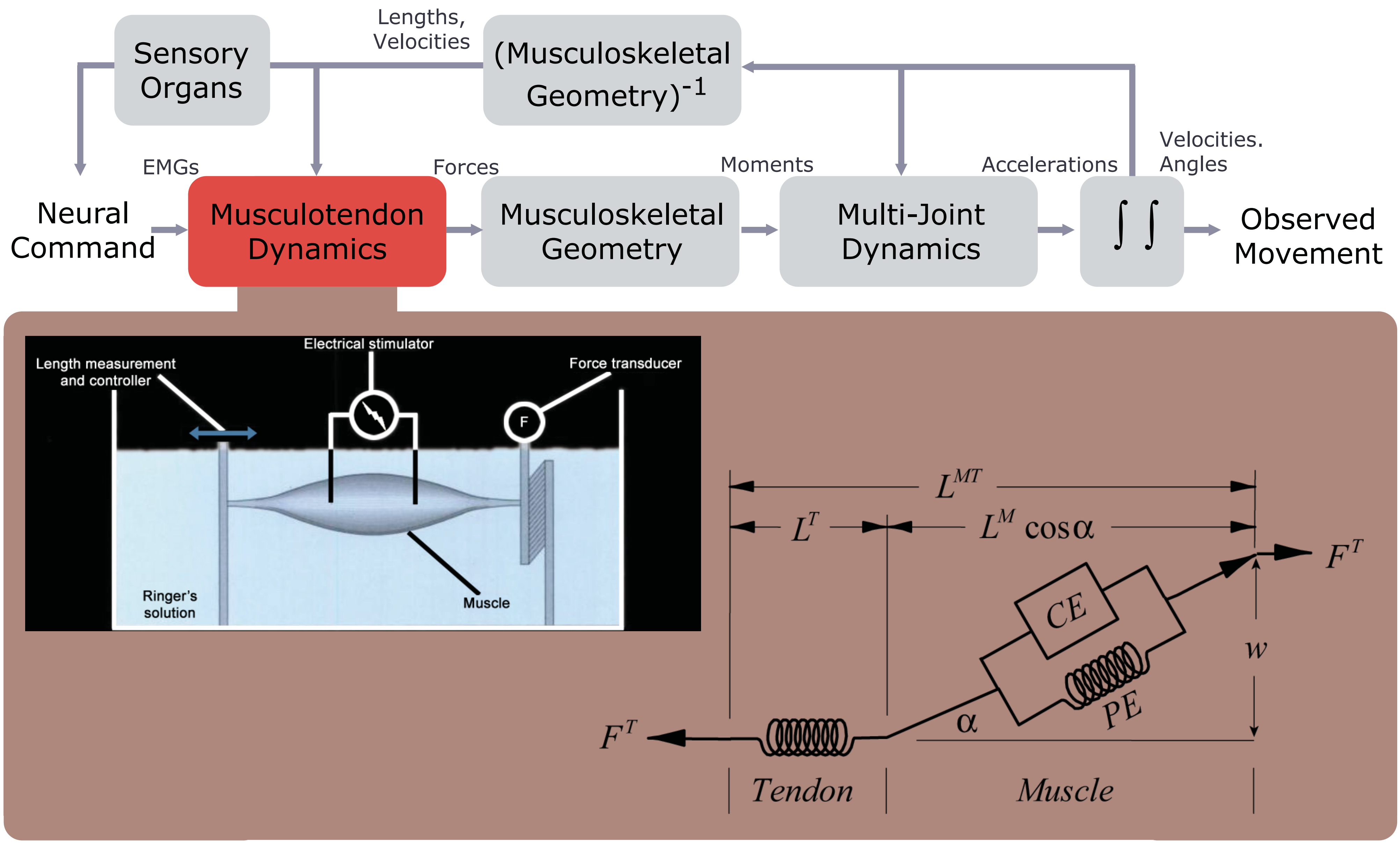


From EMGs to Forces

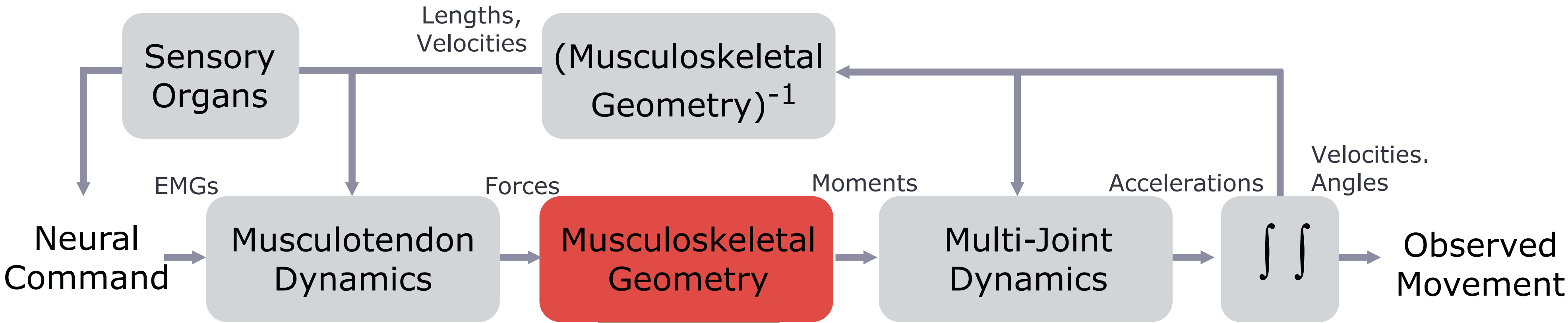


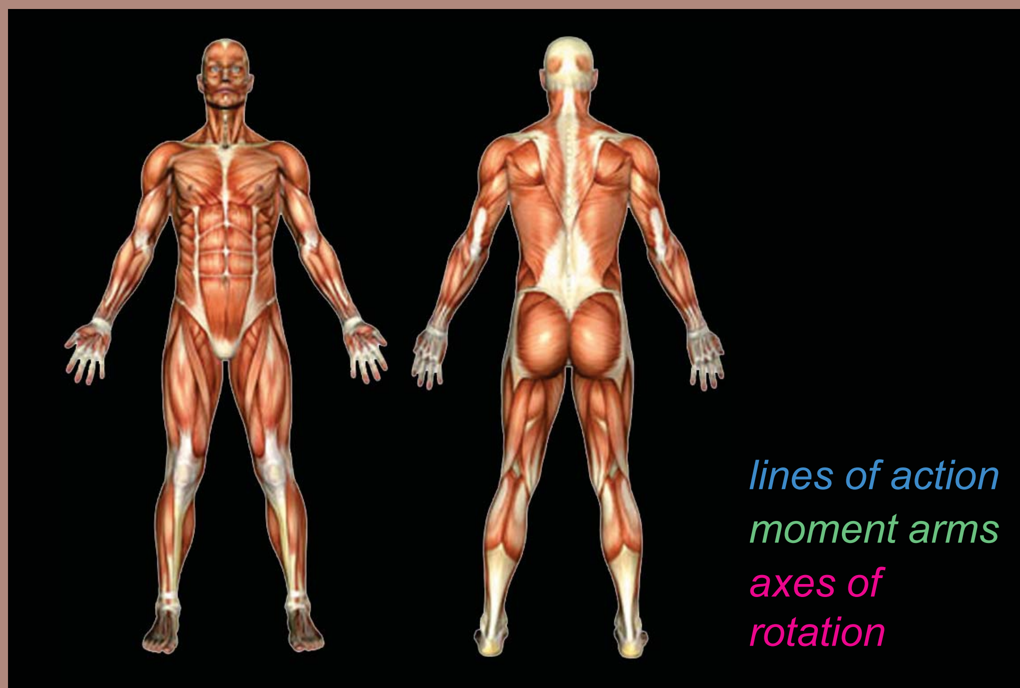


From EMGs to Forces

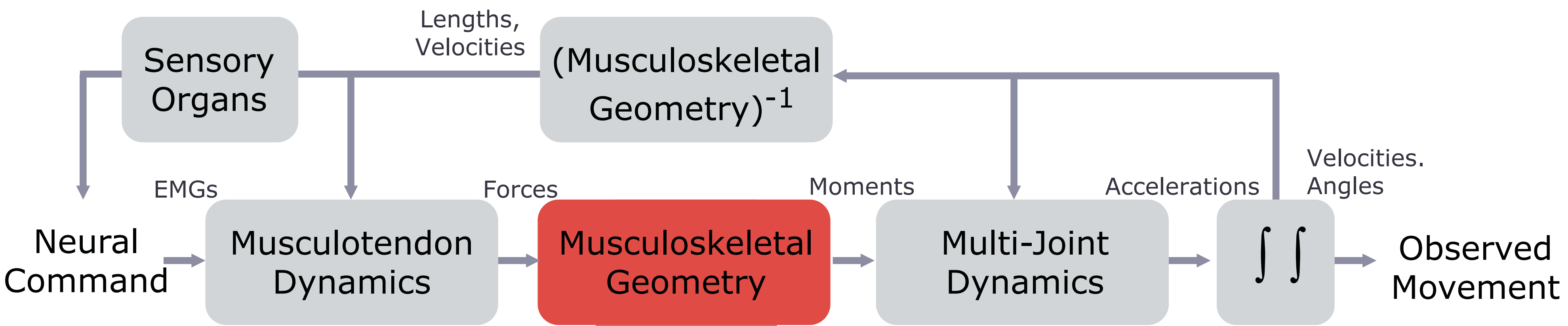


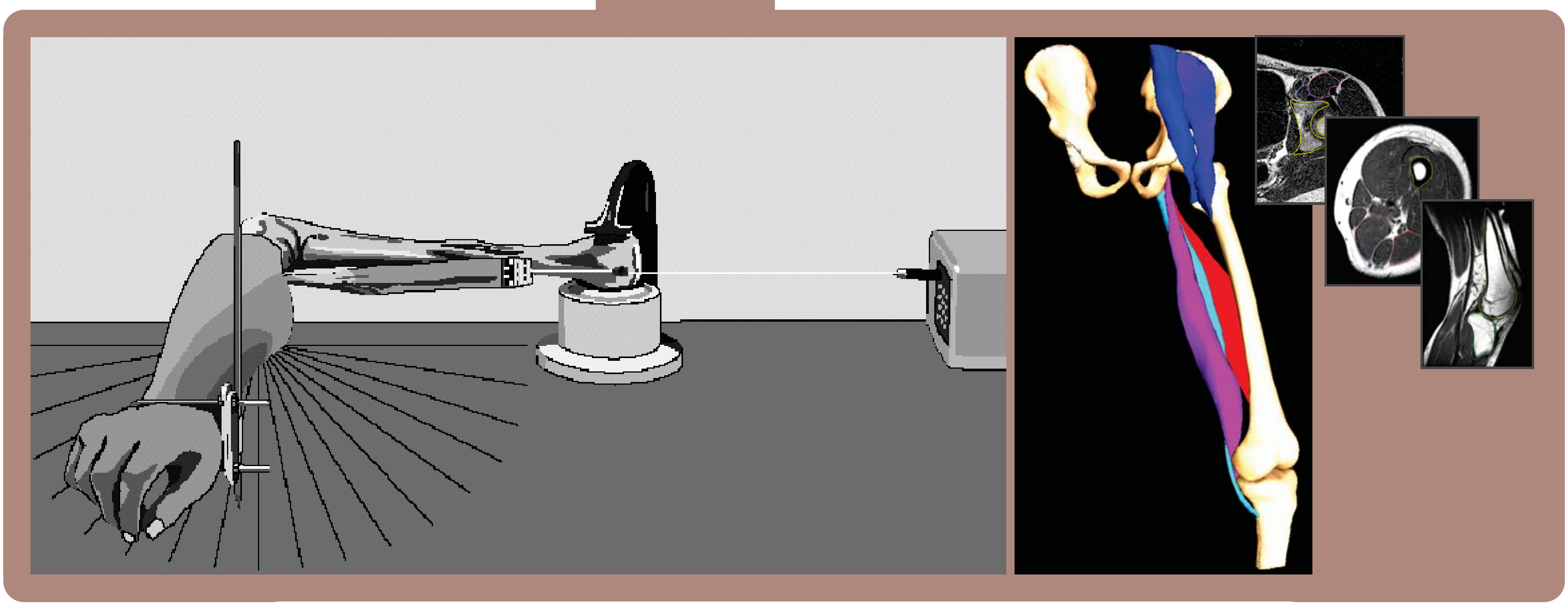
From Forces to Moments



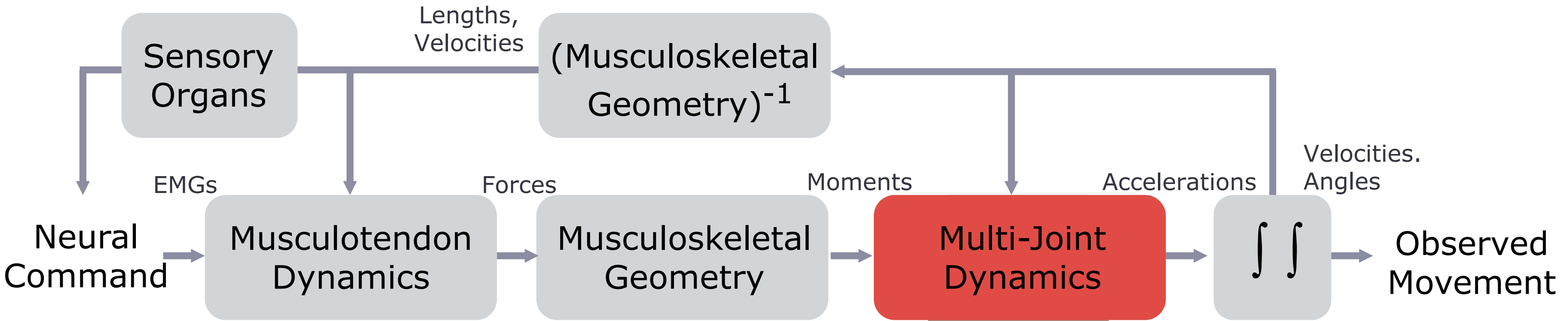


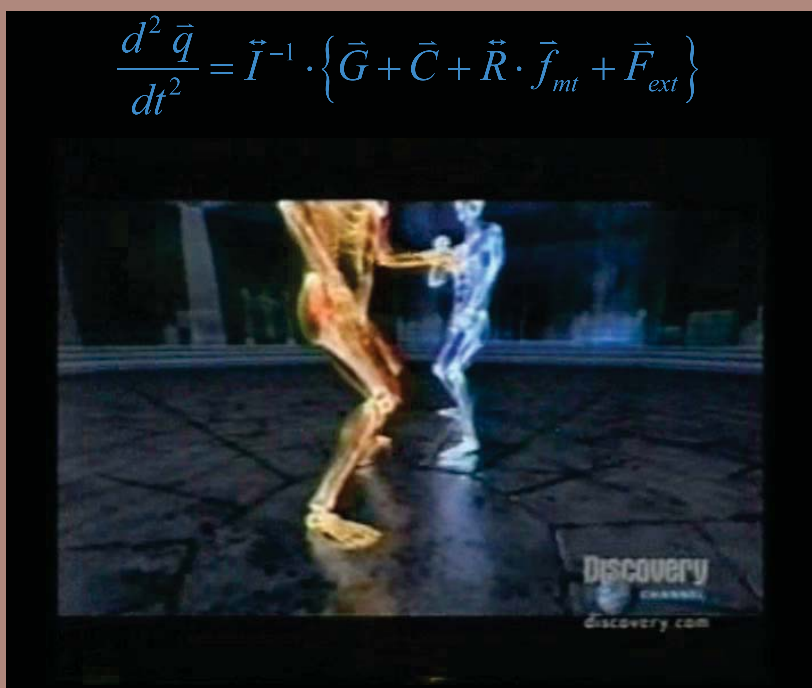
From Forces to Moments





From Moments to Accelerations





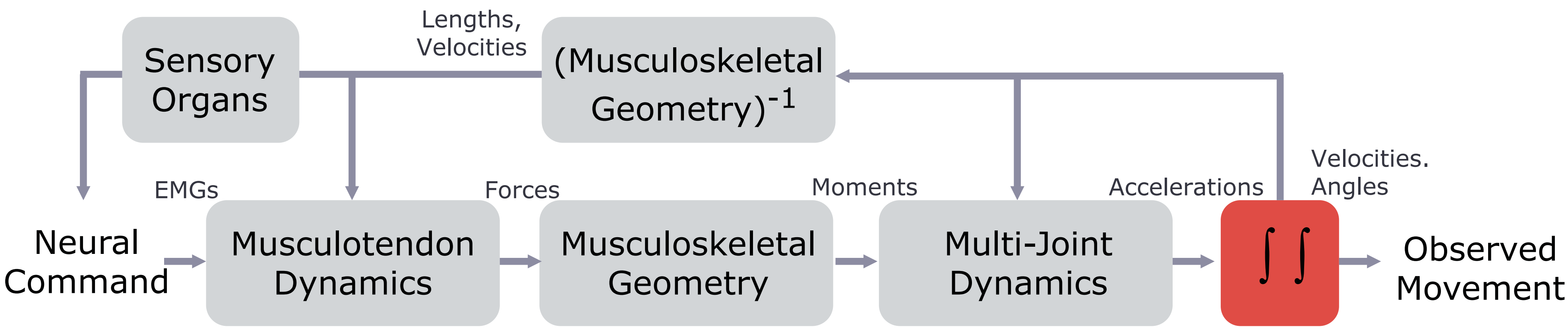
AXIOMATA
SIVE
LEGES MOTUS

Lex. I.

Lex. II.

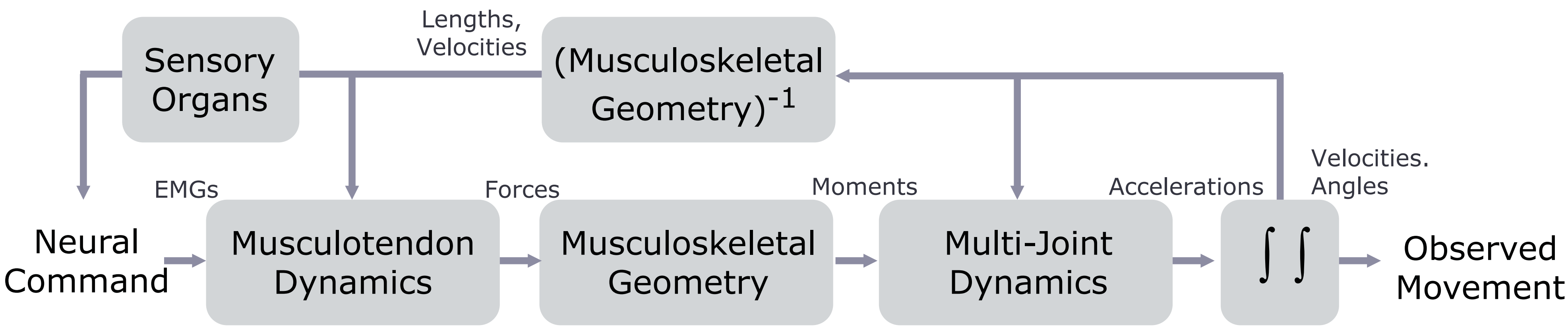
Lex. III.

From Accelerations to Positions (movement)

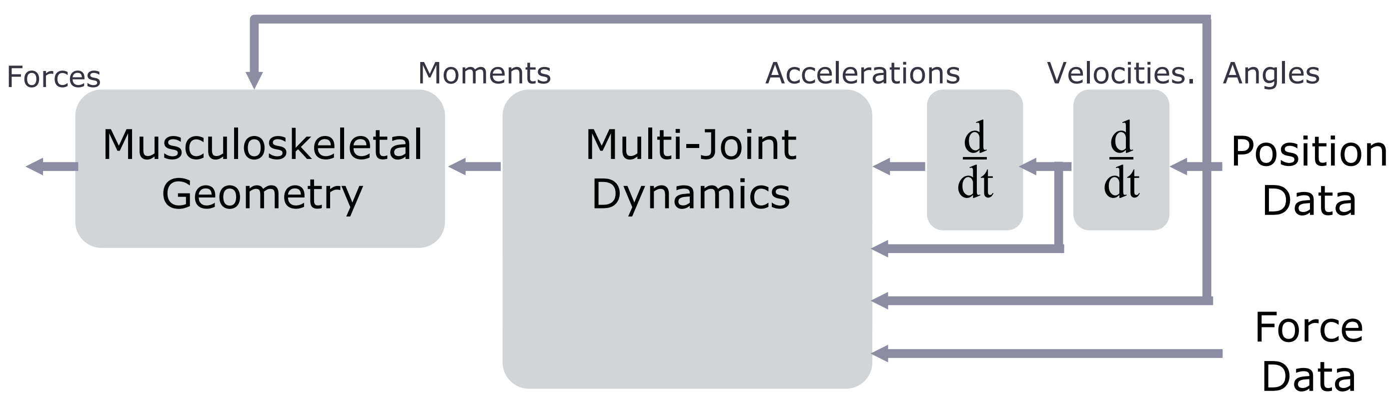


Integrating equations of motion is generally a straightforward procedure.

Production of Movement (forward dynamics)

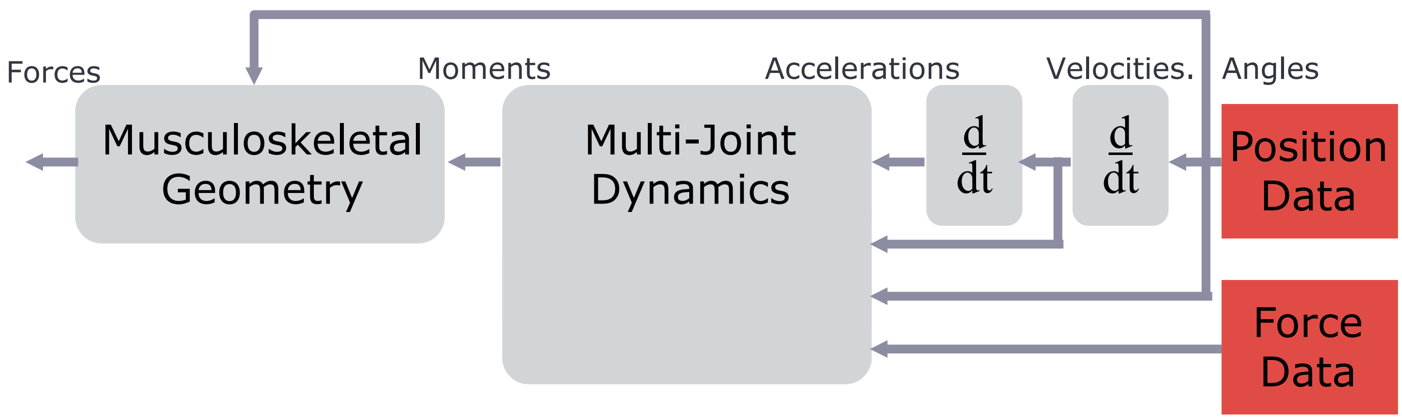


Measurement of Movement (inverse dynamics)



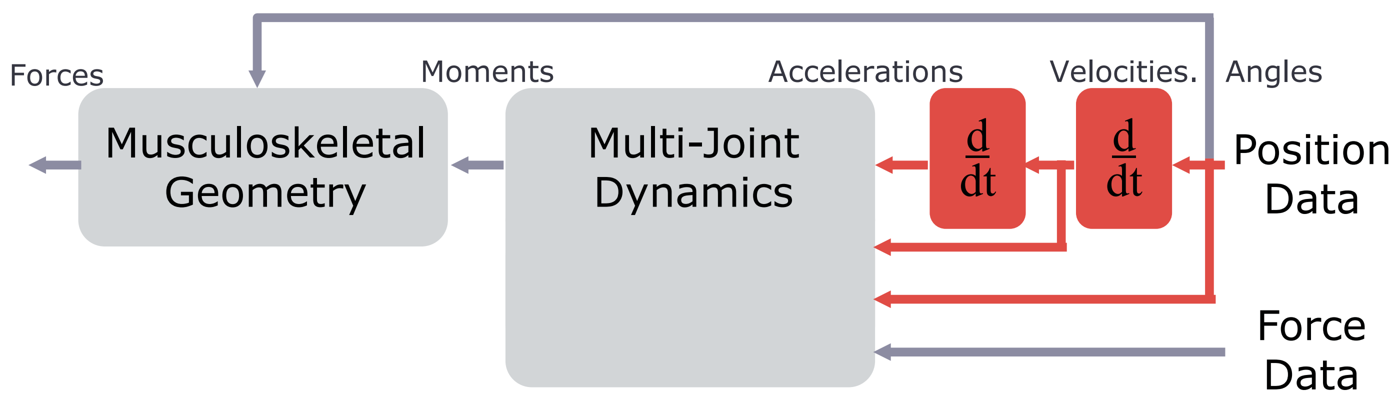
Motion and Force Measurements

The first step in an inverse dynamics approach is to measure positions and forces.



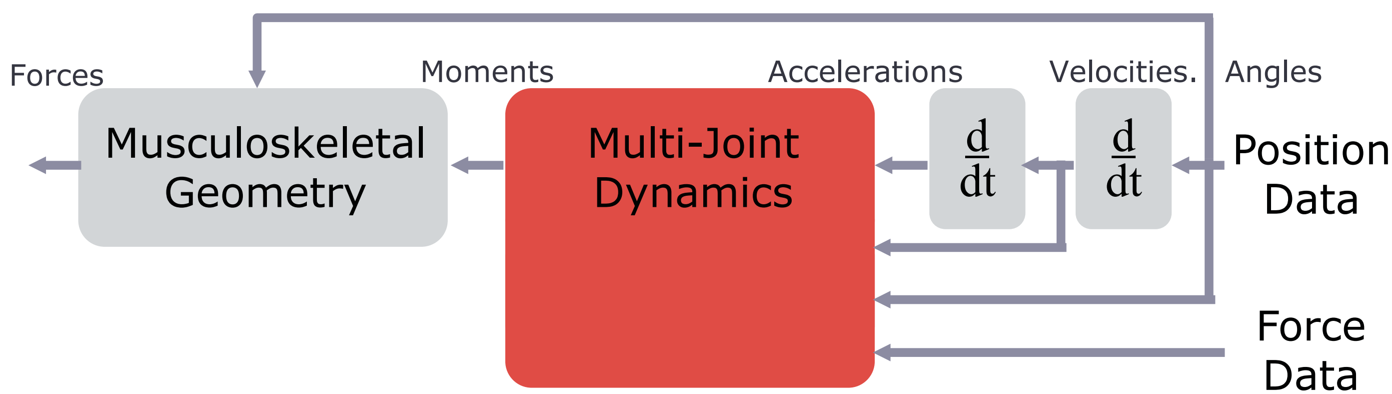
Filtering and Differentiation

This is an important practical step in experimental analysis.



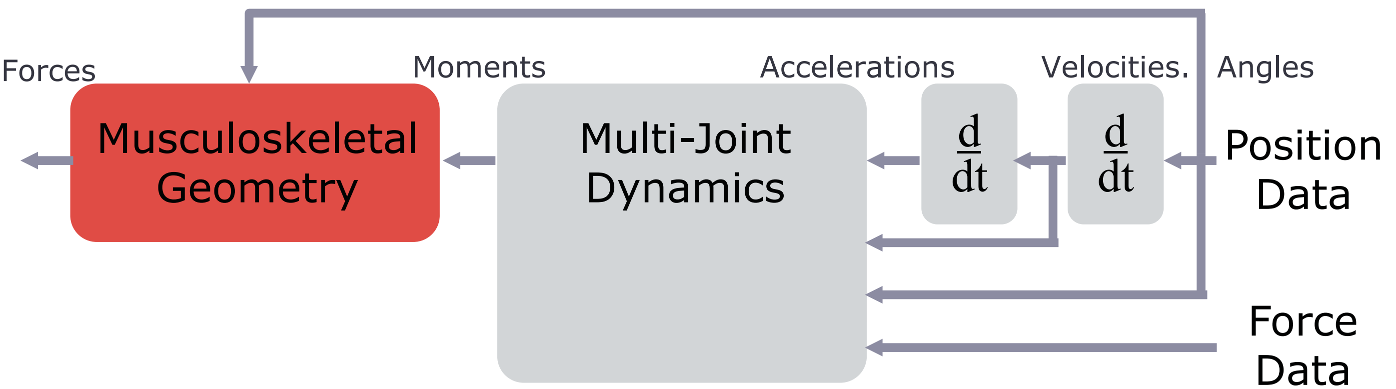
Multi-Joint Dynamics

Common to write equations of motion that solve the inverse dynamics problem.

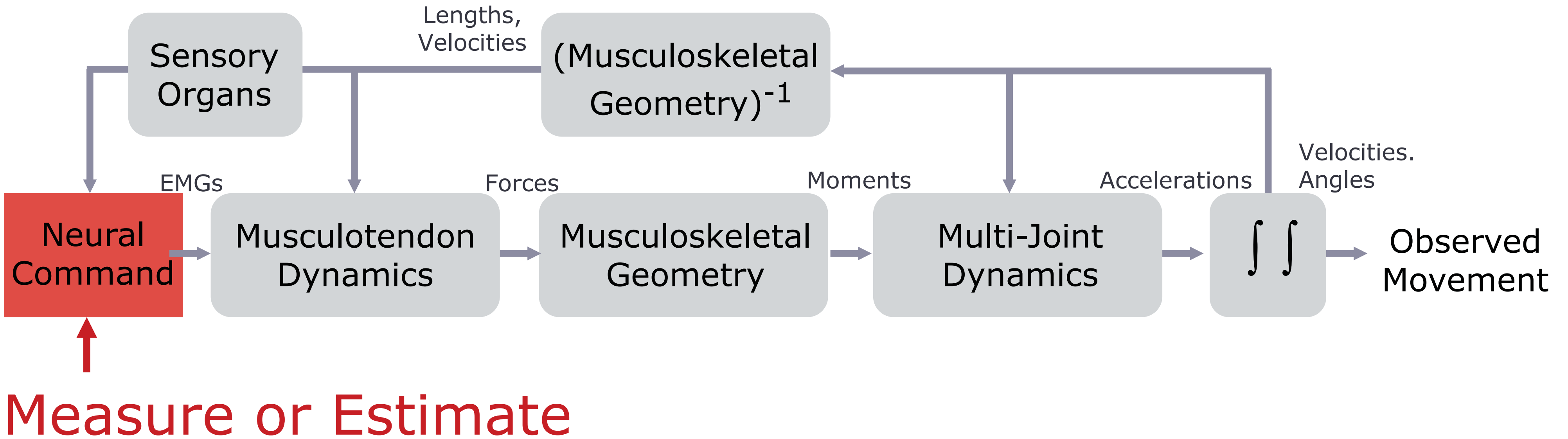


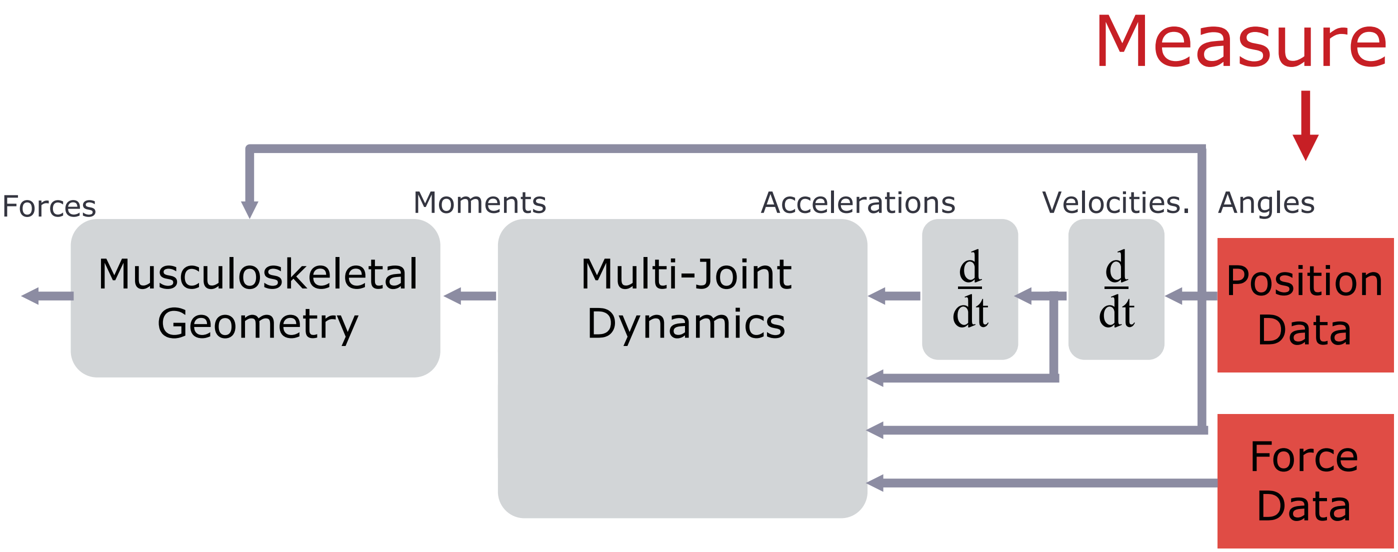
Estimating Muscle Forces

This is one of the basic problems in biomechanics; different methods to solve this problem.



Forward *vs* Inverse Dynamics





Tools to Study Movement

Name ‘em!

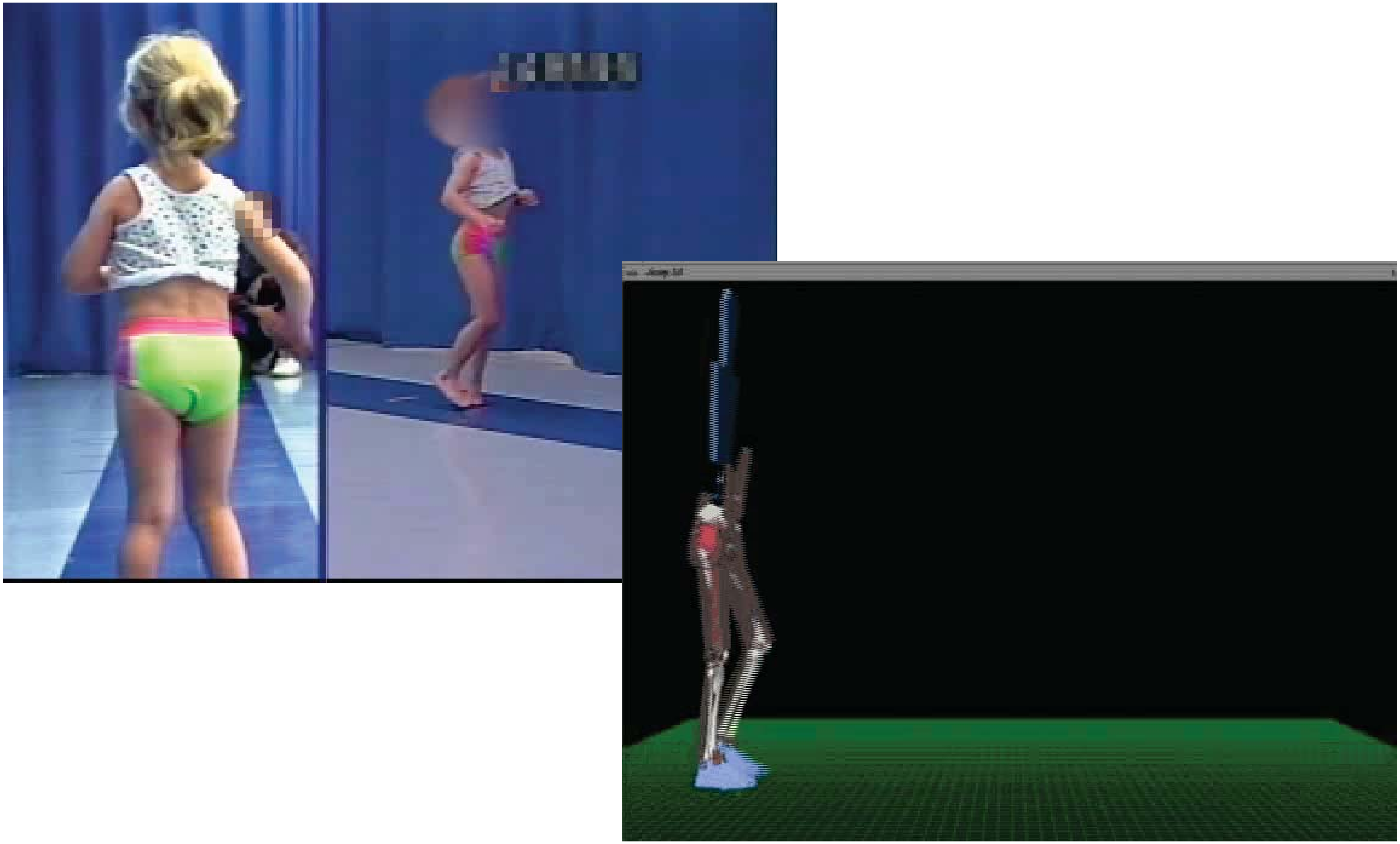
Tools to Study Movement

- Force plates
- Muscle experiments
- EMG
- Motion capture systems
- Kinematics and dynamics
- Optimal control theory, systems identification, animal studies…..

What can you do with this stuff?

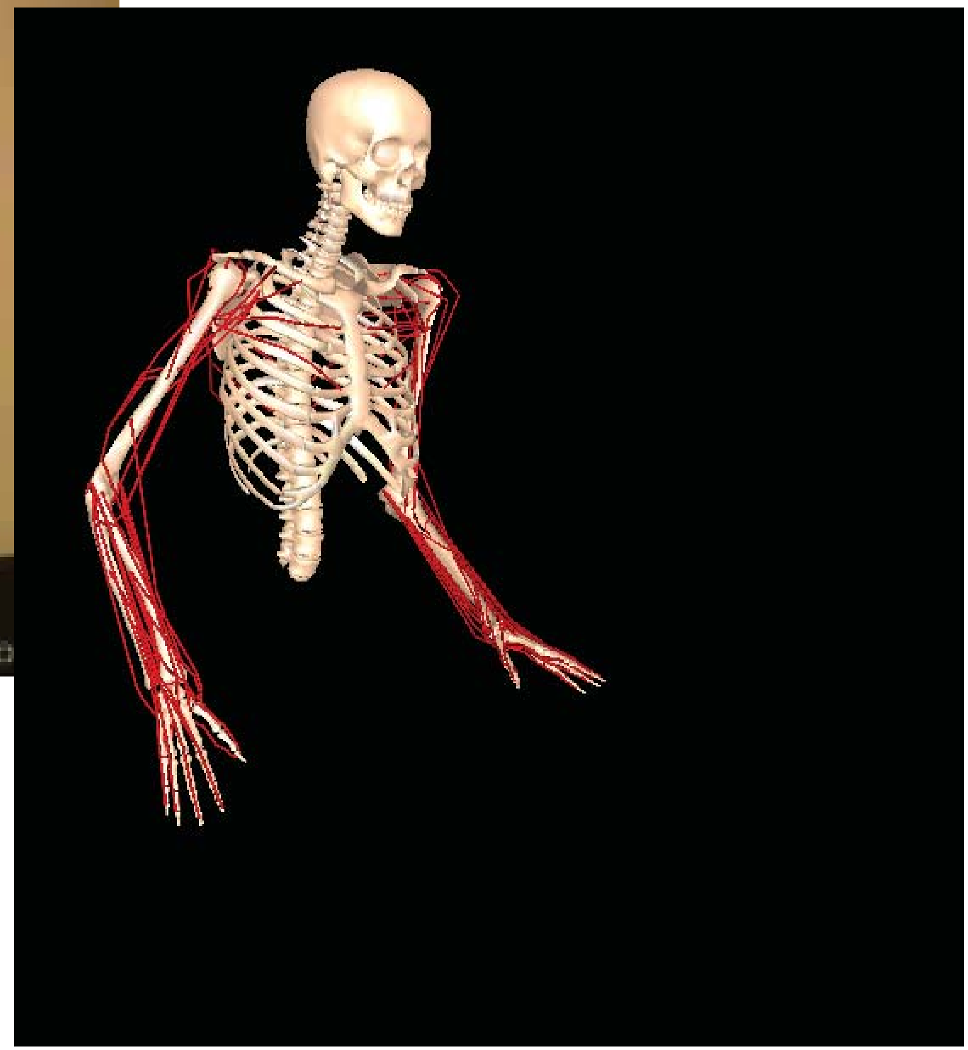
- Access the literature and scientific meetings
- Solve important problems in biomechanics
  - Movement disorders (CP, Parkinsons, stroke)
  - Musculoskeletal disease (arthritis, osteoporosis)
  - Sports performance and equipment
  - Ergonomics
  - Design of surgical procedures (tendon transfers, total joint replacement)
  - Realistic computer animations
- Think differently about the world
- Do some good

Biomechanics of Walking



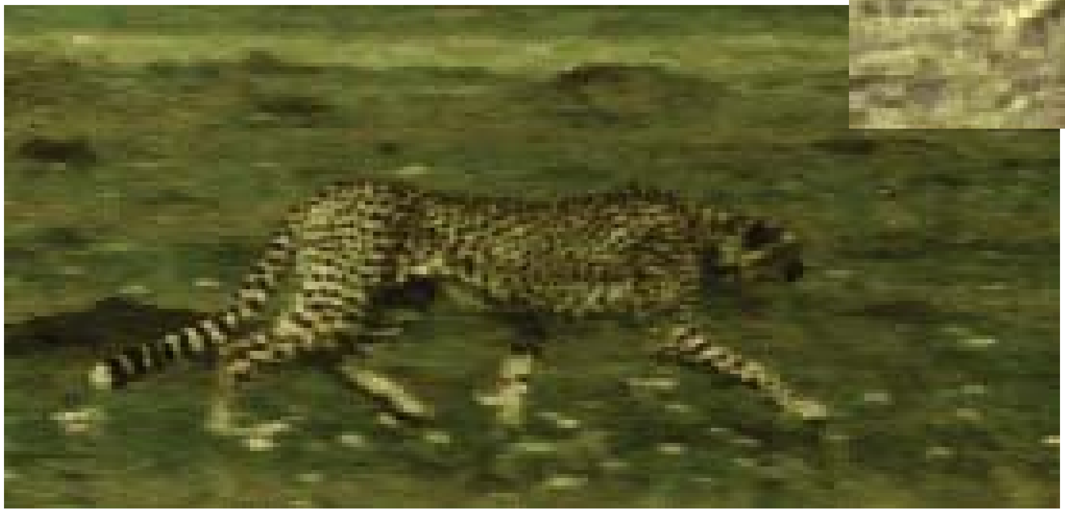
Movies: Gillette Children's Hospital, Chand John

Biomechanics of the Upper Extremity



Movies: Terry Sanger and Kate Holzbaur

Gait Transitions



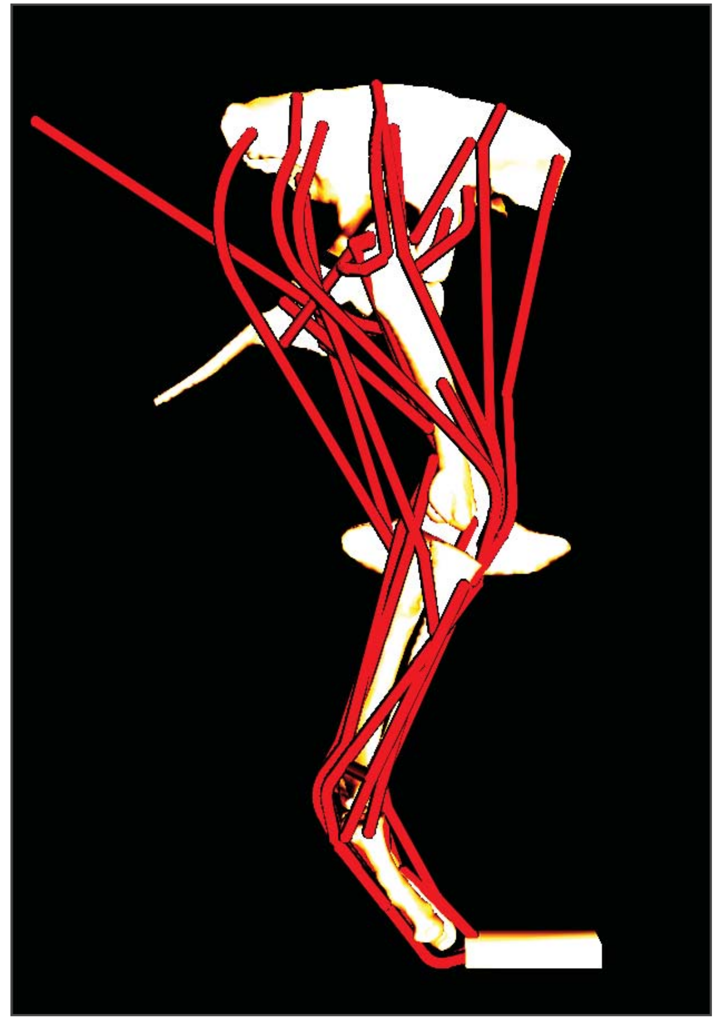
Movies: McNeill Alexander, How Animals Move

Elastic Mechanisms

Experience with biological, experimental, and mathematical tools to study movement.

Paleobiology

could the T-rex have run?



Hutchinson et al., 2005

Prerequisites for Movement Biomechanics

- Basic background in statics and dynamics
- Able to write equations of motion for multijoint systems (draw FBD, F=ma)
- Know basic linear algebra
- Able to solve 1st and 2nd order differential equations
- Read and process a large amounts of experimental and simulation data
- Programming experience (C++, Matlab)

Outline for Today

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- Prerequisites for movement biomechanics
- Example research topic
- A little different homework assignment
- Answer your questions!

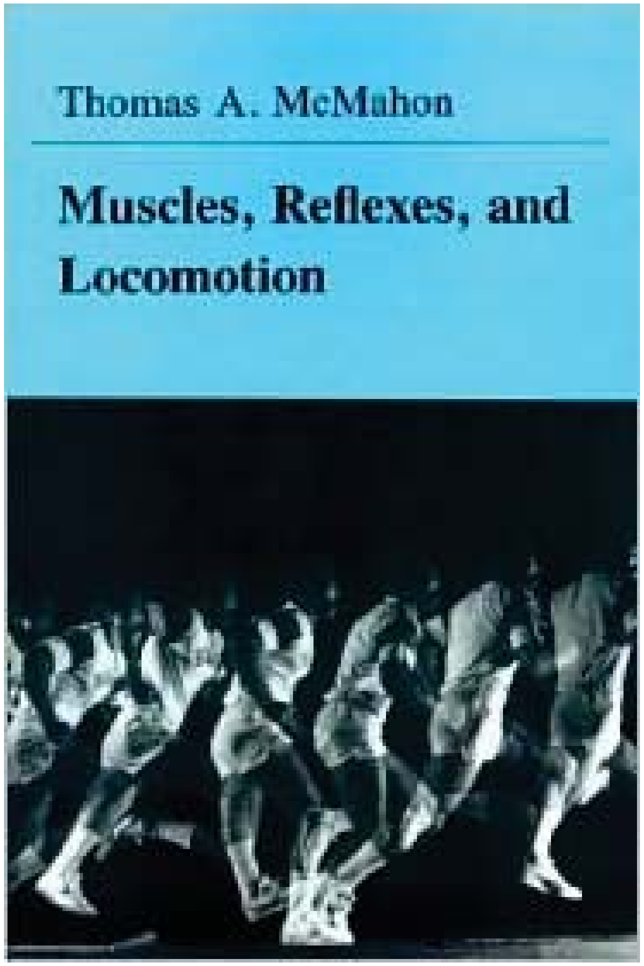
Who has run here?


Example Research Topic

MUSCLES, REFLEXES, AND LOCOMOTION

Published by Princeton University Press

- Design of a "tuned track"
  - stiffness, viscosity, and inertia (mechanical impedance)
  - equations of motion for a simple system
  - fantastic results with a simple model



Tuned Track

The prevailing wisdom in 1975 was that people ran faster on very hard surfaces

Goal: increase in running speed and a decrease in the potential for injuries.

How can a person run faster?

- Increase stride frequency
- Increase step length (define speed)
- Optimize forces

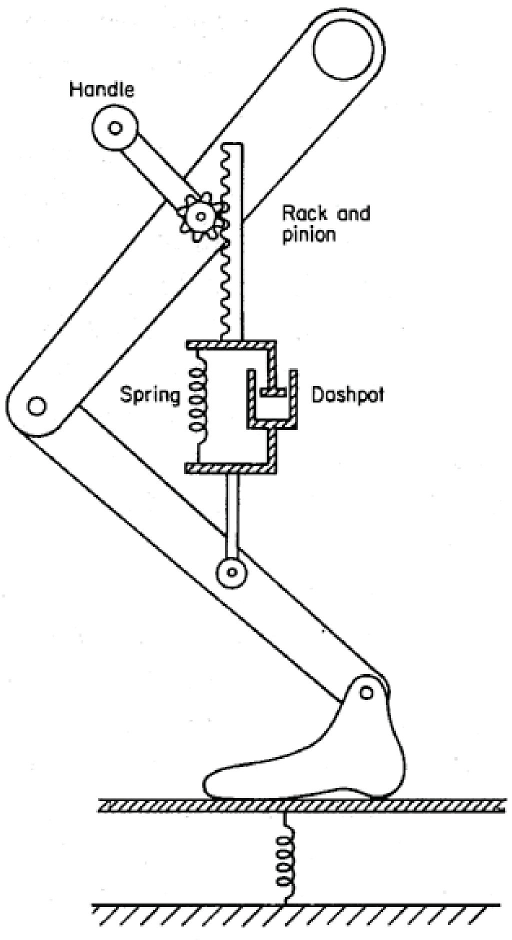
How can injury rate be decreased?

- Decrease peak forces

Running Model

- McMahon proposed a simple model for running
- This model is composed of a rack and pinion mechanism
- The rebound of the runner's leg is set by the dynamics of the spring and dashpot that comprise the spring system

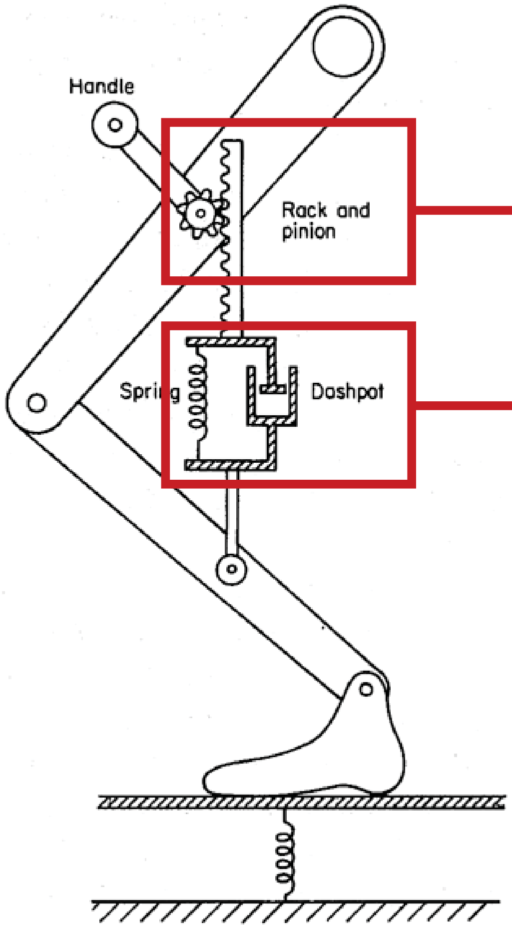
The Model



A spring system supports the runner's mass and is comprised of a spring and dashpot in parallel and this system is in series with the track spring.

Figure: T.A. McMahon, Muscles, Reflexes and Locomotion

The Model



Rack and pinion set by CNS for landing

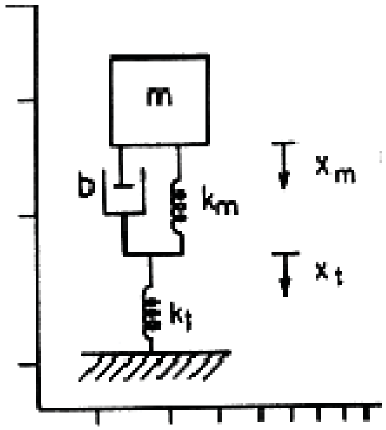
Mechanics of muscle followed by muscle under reflex control

Equations of Motion

Important equations for deriving the equation of motion for the system:

$F = k\Delta x$ Spring equation

$F = bv$ Dashpot equation



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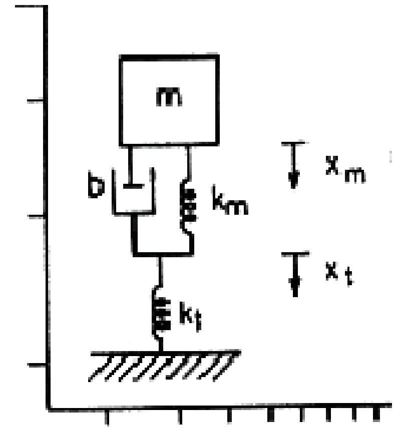


Derive the equation of motion at point A, where the leg contacts the track:

$b(v_m - v_t) + k_m(x_m - x_t) - k_t x_t = 0$ Eqn. 1

Now describe the motion of the mass:

$ma_m + b(v_m - v_t) + k_m(x_m - x_t) = 0$ Eqn. 2

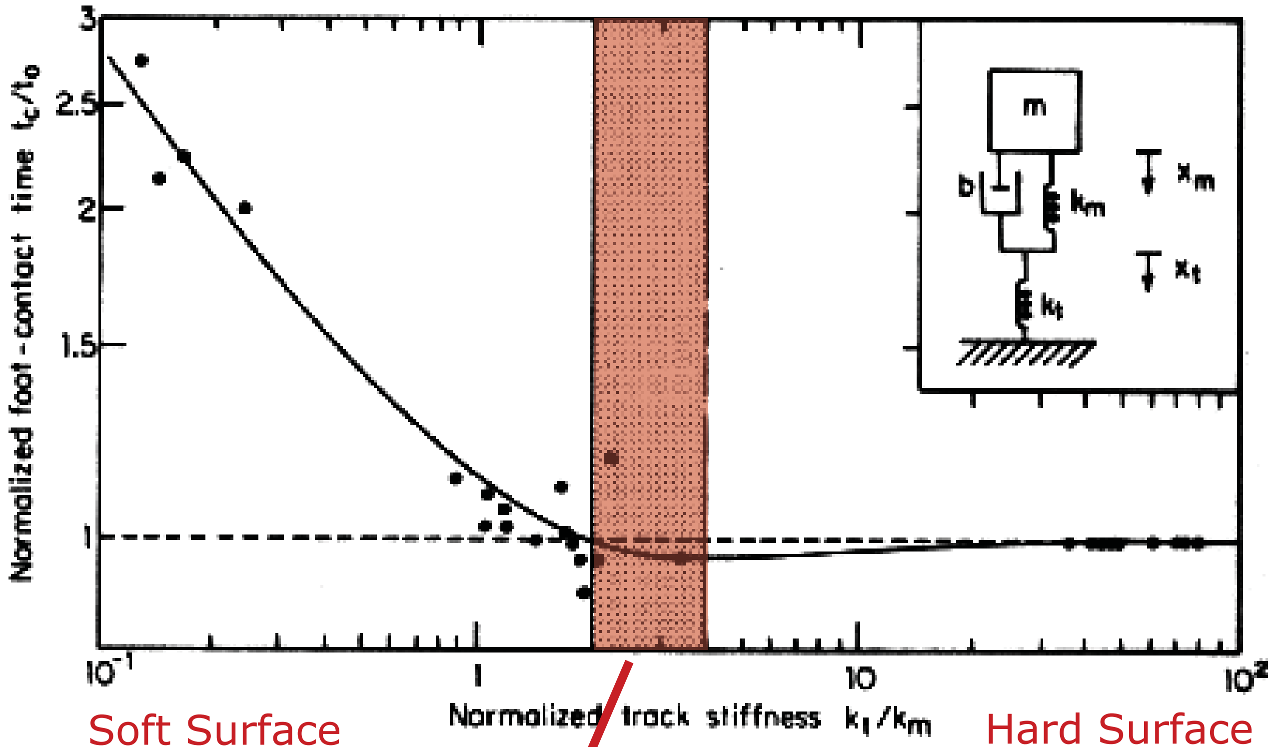
Solution

Now that we have described the system dynamics, the damped natural frequency (ω_d) of the system can be calculated by assigning values for k_m, k_t, and b.

With the assumption that the foot contact time, t_c, is equal to the period of oscillation and that $t_c = \pi/\omega_{d.}$ you can see that by altering the stiffness of the track it is possible to alter the contact time of the foot.

Foot Contact Time *vs.* Track Stiffness

Solution for the equations of motion



"Tuned Region" in which track stiffnesses result in lower foot contact times.

Figure: T.A. McMahon

Stride Length

Contact time varies with track compliance

Next, find a range for k_t in which the stride length increases over the stride length on a hard track

Figure: T.A. McMahon

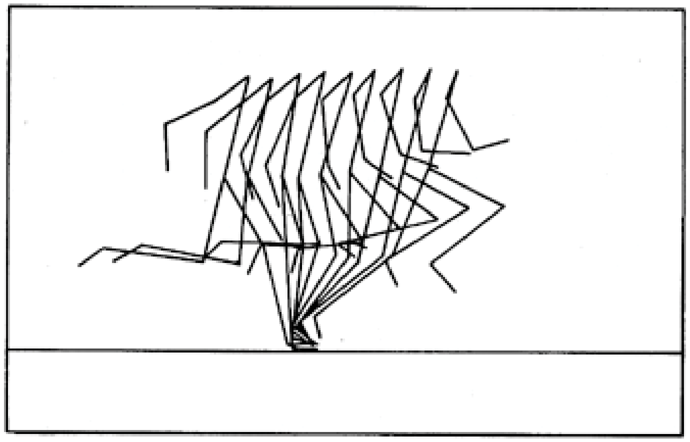
Change of Stride Length w/ Track Compliance

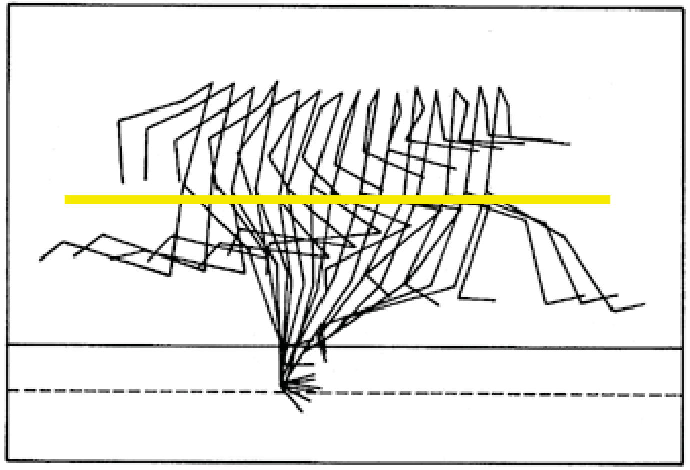
Stride length is longer on the compliant track.

Contact time is also longer on compliant track (more stick figures).

The hip stays pretty level (justifies rack and pinion).

Hard Track





Compliant Track

Figure: T.A. McMahon

Determining Step Length

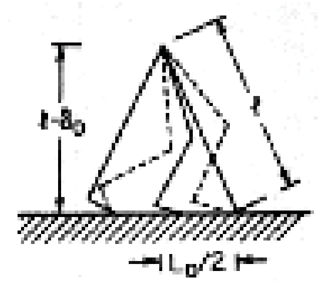
Assumption: $\delta = mg/k_t$
deflection of the track = static deflection)

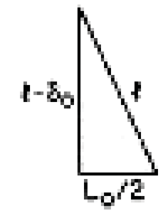
$$L = 2(\ell^2 - (\ell - \delta_o - \delta)^2)^{1/2}$$ Compliant

$$\delta_o = \ell - (\ell^2 - L_o^2/4)^{1/2}$$ Hard

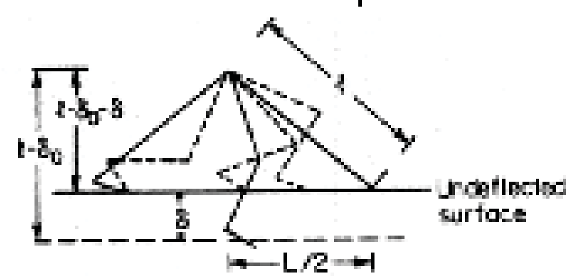
where L = stride length
ℓ = leg length
k_t = track stiffness
L_o = hard track step length

Hard Track





Compliant Track



Determining Step Length

From the preceding equations, an equation describing the stride length can be determined:

$$L = 2\left(\ell^2 - (\ell^2 - L_o^2/4)^{1/2} - mg/k_t \right)^{1/2}$$

where L = stride length

ℓ = leg length

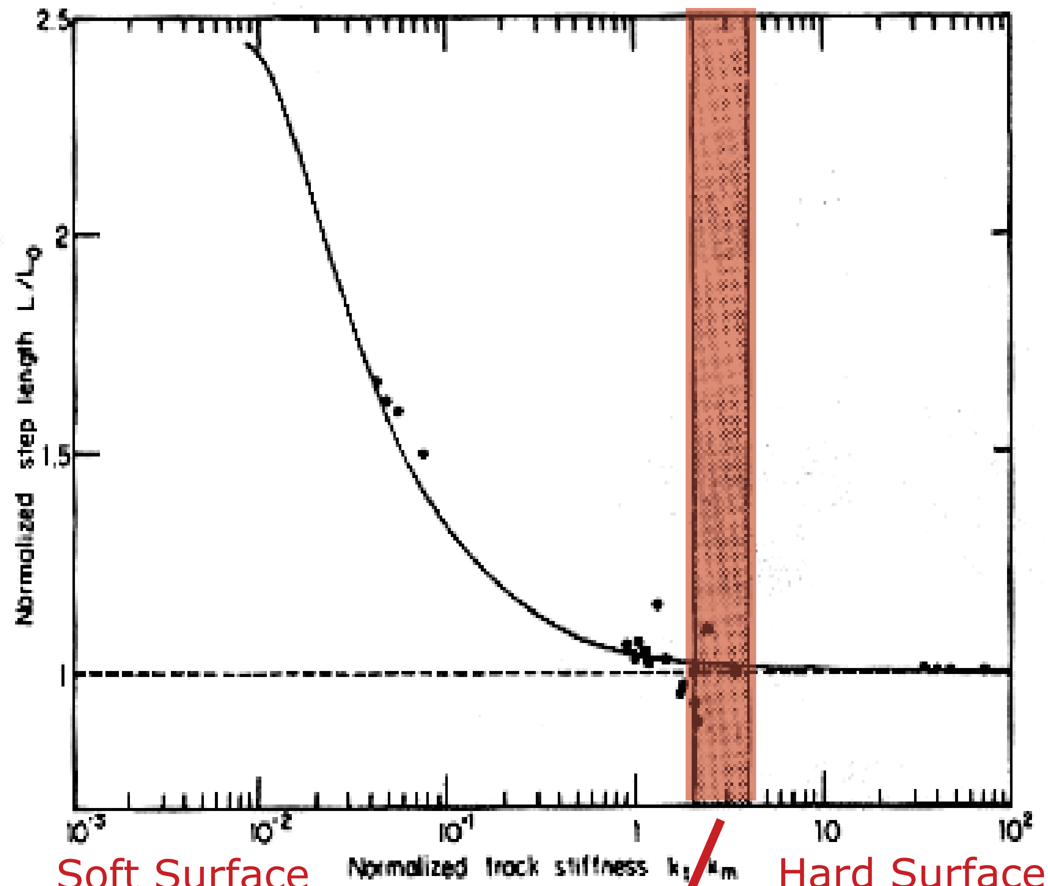
k_t = track stiffness

L_o = hard track step length

Track Stiffness and Step Length

Subjects ran on tracks of varying stiffnesses.

Find stride length given $\ell,\ k_t,\ and\ L_o$



Range of track stiffnesses where the stride length increases and contact time decreases

The First Tuned Track

- Harvard’s indoor track was built with the compliance in the tuned range.
- The surface was wood coated with polyurathane.
- Runners were able to decrease their times by about 2-3% or about 5 seconds/mile.
- Equally important, there was a 50% decrease in the rate of injuries because the peak forces measured in the tuned, compliant track were much lower than in the stiff track.

Tuned Track Extensions

The tuned track is a great design problem: optimized the way in which humans interact with their environment

- Decrease contact time, increase stride length

Have you ever seen this done anywhere else?

Tuned Track Extensions: Shoes

Reebok DMX: ”progressive heel damping”

Merrell Flash: chips to tune the firmness of the shoe

Nike Shox springs for cushioning and energy return

Popular Mechanics, Nike

How about these springs

Be Careful When Tuning Floors

The old floor in Maples installed in 1969

9 inches of cross-hatched wood & air designed for "springy" effect to reduce injuries

Men's b-ball had 13 stress related injuries in last 10 yrs of floor (3x rest of Pac-10)

Tipoff Press

The tuned track is a fantastic example of what you can do with knowledge of biomechanics and a great deal of creativity.

You can do something fantastic in biomechanics. What will it be?

Was George Curious About Biomechanics?

Movies: McNeill Alexander, How Animals Move

Athletes of the Week

Machines that hop and walk. Can you build one that does this?

Athletes of the Week

… or does this?

Researchers are working on it.

AI Lab MIT

Main Points of the Example Research Project

Basic equations for dynamic systems

$$F = ma \qquad F = k\Delta x \qquad F = bv$$

Use of a simple model for biomechanics

Example of success of biomechanics in action

What can you do for your assignment?

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Administrative Details

- Review the handout

Grading

- Assignment due **October 10th at 4pm**
- **Late** assignments get **lower grade**

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For Next Time…

- Start to think about topics for your research project and form teams
- Find out what others have done already
- Continue thinking about your research project
- Complete and turn in your team's assignment

Contributors

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Rob Siston

Image Credits

McNeill Alexander, How Animals Move

Thomas McMahon, Muscles Reflexes and Locomotion