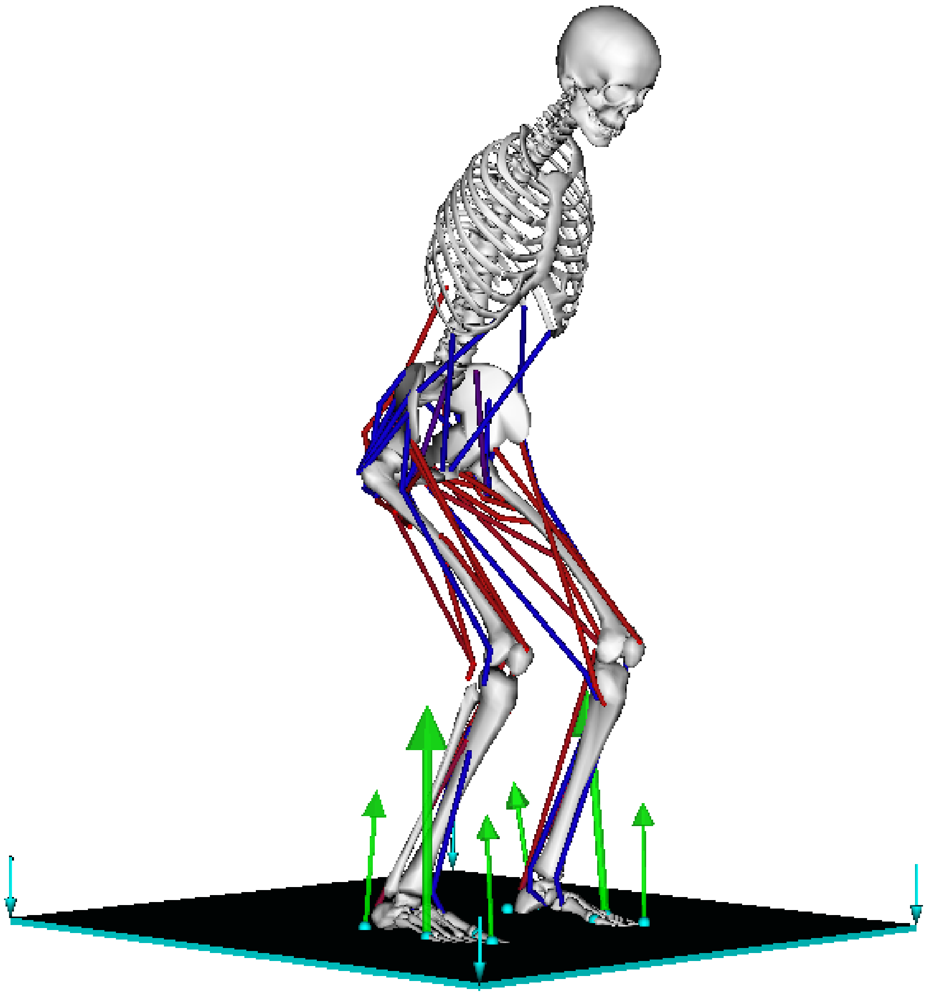


Simulation Lab #1

Lecture 2

BME 599: Modeling & Simulation of Movement

Question of the Day

How high can you jump without an approach or swinging your arms?

How should you ***coordinate muscle forces*** to produce a maximum height jump?

Outline for Today

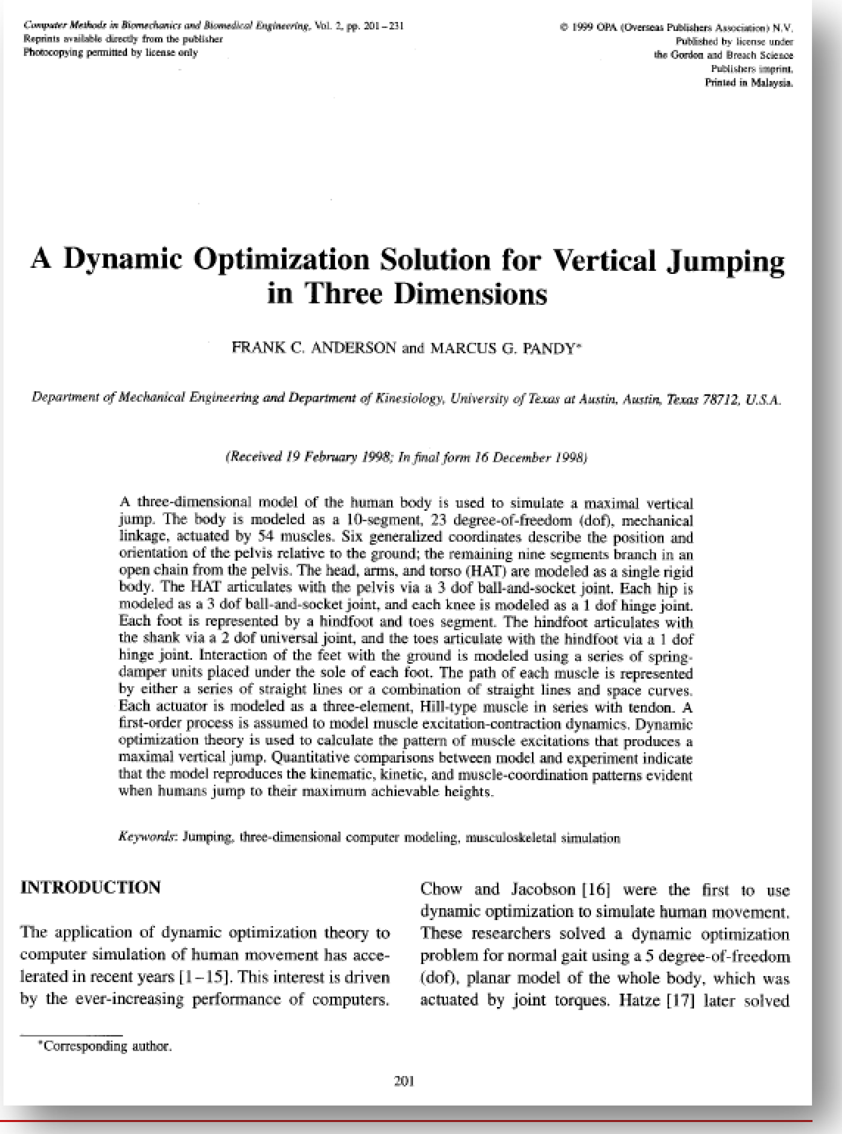
- Question of the day
- Anderson and Pandy, 1999
- Objectives of Simulation Lab #1
- Getting started with simulation of jumping
- Answer your questions!

Anderson and Pandy, 1999

Vertical Jumping

Why did they choose jumping as a dynamic optimization problem?

- Goal is ***unambiguous: maximize jump height***
- Involves ***coordinated motion*** that can be ***compared with experiment***



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A Dynamic Optimization Solution for Vertical Jumping in Three Dimensions

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(Received 19 February 1998; In final form 16 December 1998)

A three-dimensional model of the human body is used to simulate a maximal vertical jump. The body is modeled as a 10-segment, 23 degree-of-freedom (dof), mechanical linkage, actuated by 54 muscles. Six generalized coordinates describe the position and orientation of the pelvis relative to the ground; the remaining nine segments branch in an open chain from the pelvis. The head, arms, and torso (HAT) are modeled as a single rigid body. The HAT articulates with the pelvis via a 3 dof ball-and-socket joint. Each hip is modeled as a 3 dof ball-and-socket joint, and each knee is modeled as a 1 dof hinge joint. Each foot is represented by a hindfoot and toes segment. The hindfoot articulates with the shank via a 2 dof universal joint, and the toes articulate with the hindfoot via a 1 dof hinge joint. Interaction of the feet with the ground is modeled using a series of spring-damper units placed under the sole of each foot. The path of each muscle is represented by either a series of straight lines or a combination of straight lines and space curves. Each actuator is modeled as a three-element, Hill-type muscle in series with tendon. A first-order process is assumed to model muscle excitation-contraction dynamics. Dynamic optimization theory is used to calculate the pattern of muscle excitations that produces a maximal vertical jump. Quantitative comparisons between model and experiment indicate that the model reproduces the kinematic, kinetic, and muscle-coordination patterns evident when humans jump to their maximum achievable heights.

Keywords: Jumping, three-dimensional computer modeling, musculoskeletal simulation

INTRODUCTION

The application of dynamic optimization theory to computer simulation of human movement has accelerated in recent years [1 – 15]. This interest is driven by the ever-increasing performance of computers.

Chow and Jacobson [16] were the first to use dynamic optimization to simulate human movement. These researchers solved a dynamic optimization problem for normal gait using a 5 degree-of-freedom (dof), planar model of the whole body, which was actuated by joint torques. Hatze [17] later solved

---

*Corresponding author.

Final paragraph of Introduction

Anderson and Pandy, 1999

Musculoskeletal Model

- What do you think about this model? Good? Bad?
  - Joints?
  - Foot-ground interface?
  - Anthropometry?
  - Ligaments?
  - Musculotendon dynamics?
  - Excitation-contraction dynamics?
  - Musculoskeletal geometry?
  - Strength scaling?
  - Body-segmental dynamics?

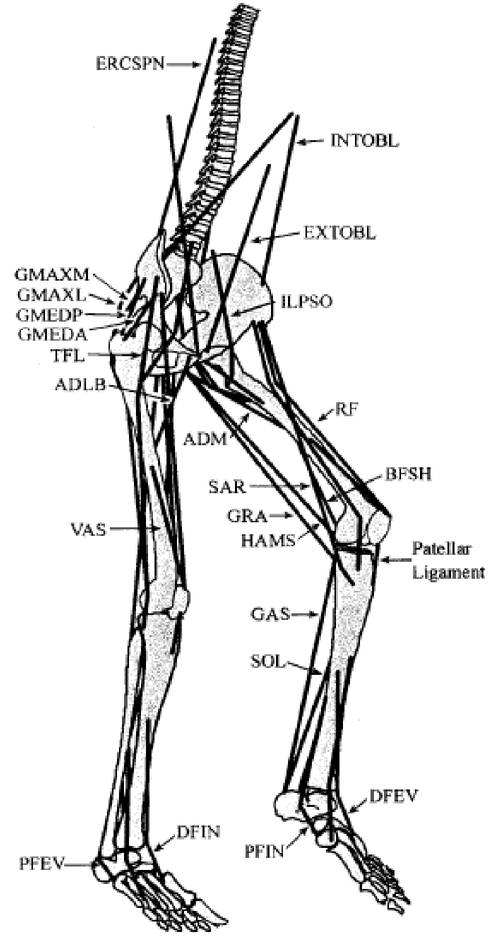


FIGURE 1 Diagram showing the geometry of the 54 muscles in the model. See Table III for abbreviations and parameters. Muscles included in the model but not shown in the diagram are: Piriformis; Pectinius; Flexor Digitorum Longus/Brevis and Flexor Hallucis Longus/Brevis lumped together; and Extensor Digitorum Longus/Brevis and Extensor Hallucis Longus/Brevis lumped together.

First section of methodology

Anderson and Pandy, 1999

Dynamic Optimization Problem

- Maximize jump height: $J = Y_{cm}(t_f) + \dot{Y}^2_{cm}(t_f)/2g, \qquad (10)$
  - Center of mass vertical position + velocity^2 / 2*gravity
  - Subject to equations of motion
- Minimize joint hyperextension:

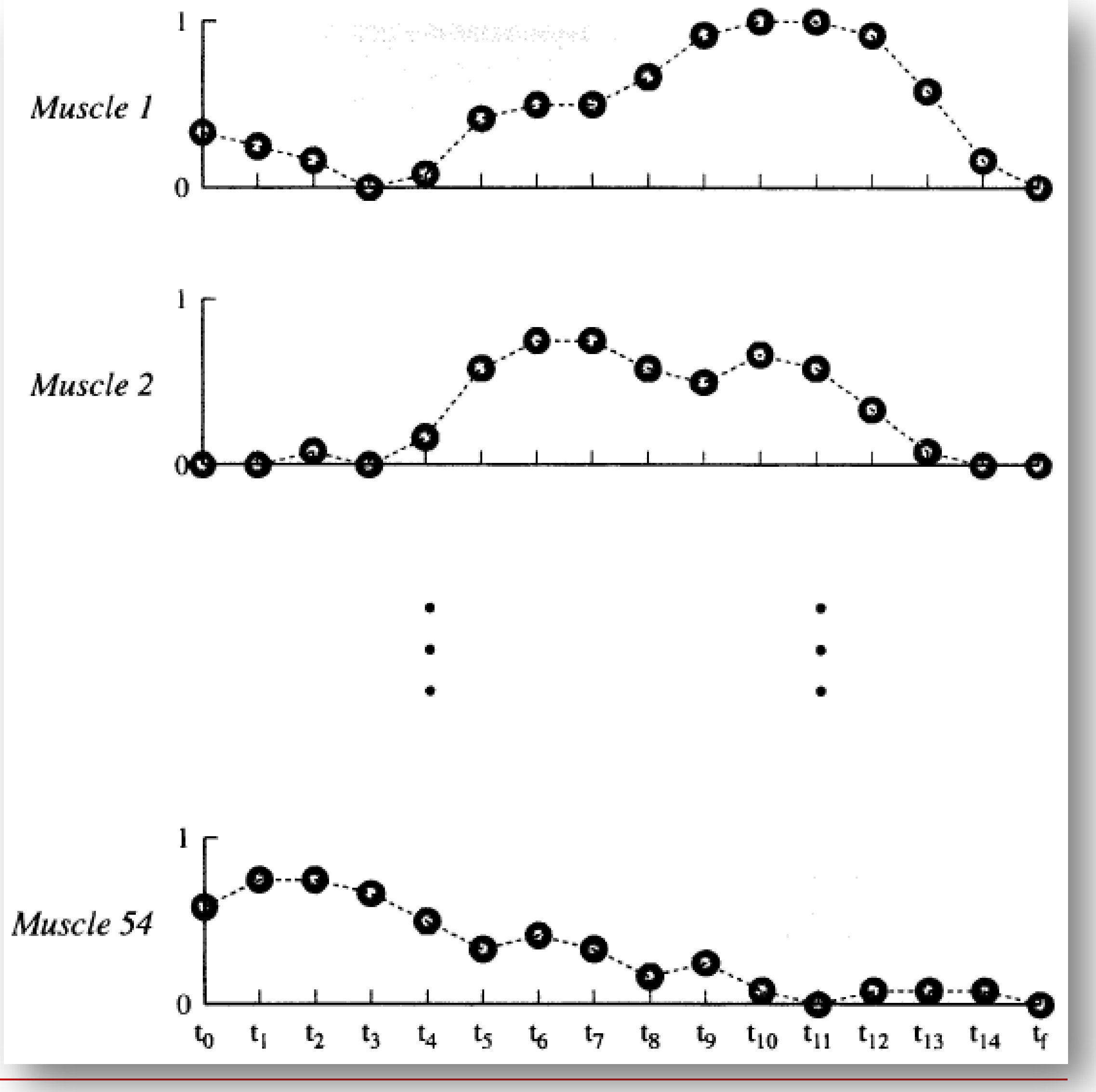
$$\phi = w \int_0^{t_f} \left[\sum_{j=1}^{17} T^2_{lig_j} \right] \mathrm{d}t \qquad (11)$$

  - Weighting (0.001) * time integral of ligament torque^2

Anderson and Pandy, 1999

Parameter Optimization Problem

- Each muscle excitation is discretized into a set of control nodes
- Find nodes that produce highest jump

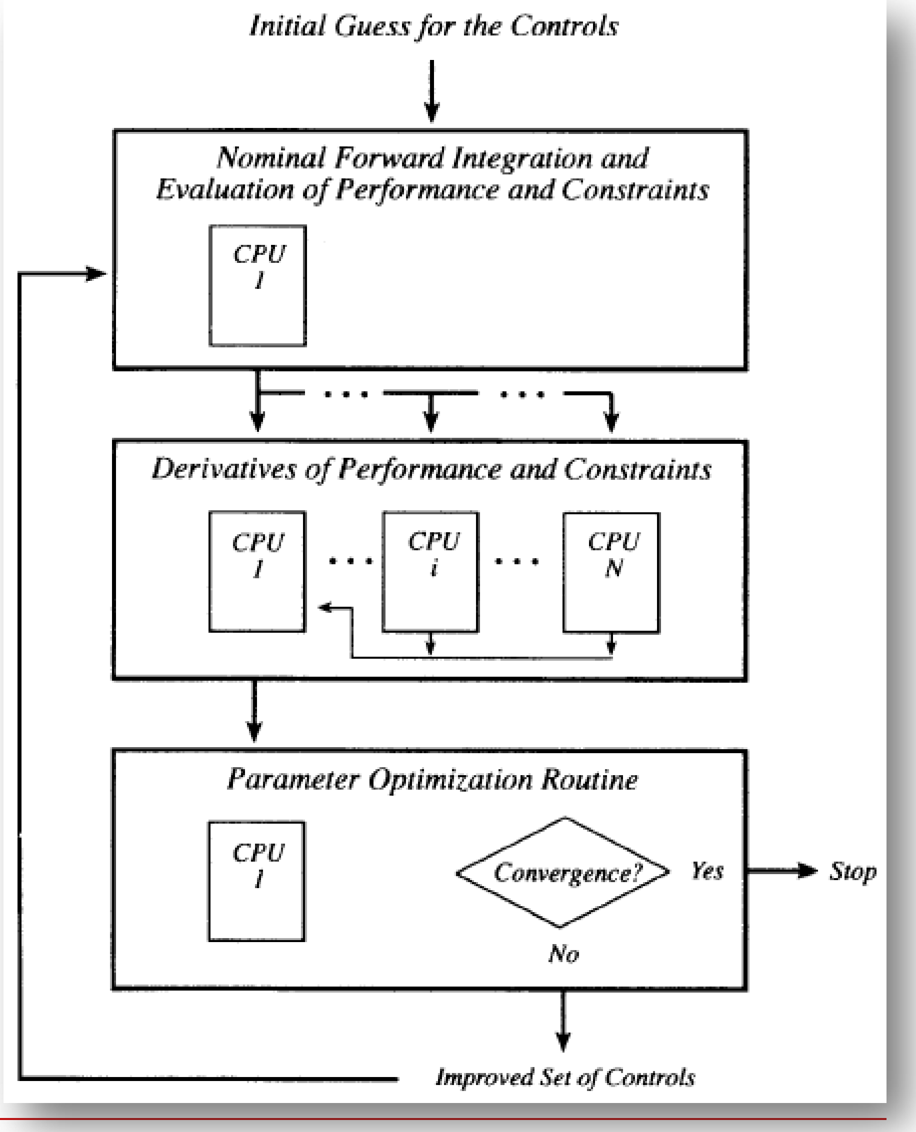


Fifth section of methodology

Anderson and Pandy, 1999

Computational Algorithm

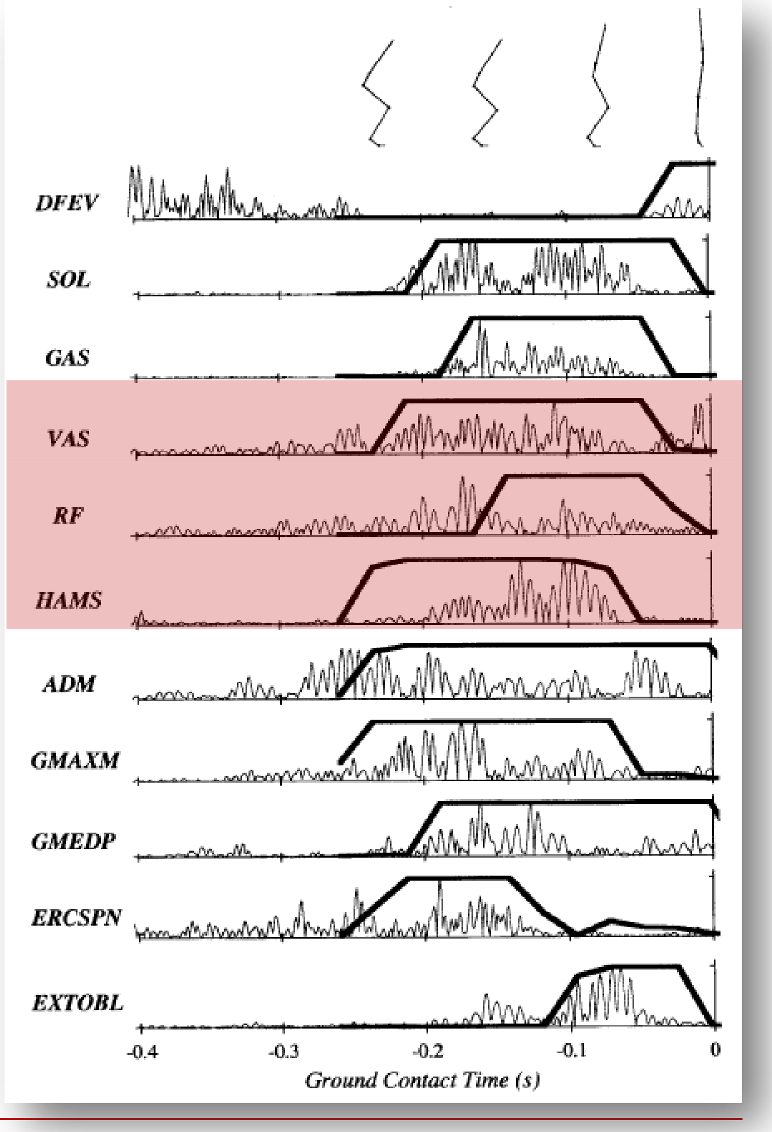
- Three steps
  - Forward integration
  - Perturbed forward integrations to get derivative of jump height wrt. each control node
  - Optimization to find new controls nodes to improve jump height



Anderson and Pandy, 1999

Optimal Solution c/w Experiment

- Agreement between the model muscle excitations and subject EMG
- Minor differences
  - HAMS (activated earlier)
  - RF (activated later)
  - VAS (deactivated before liftoff)

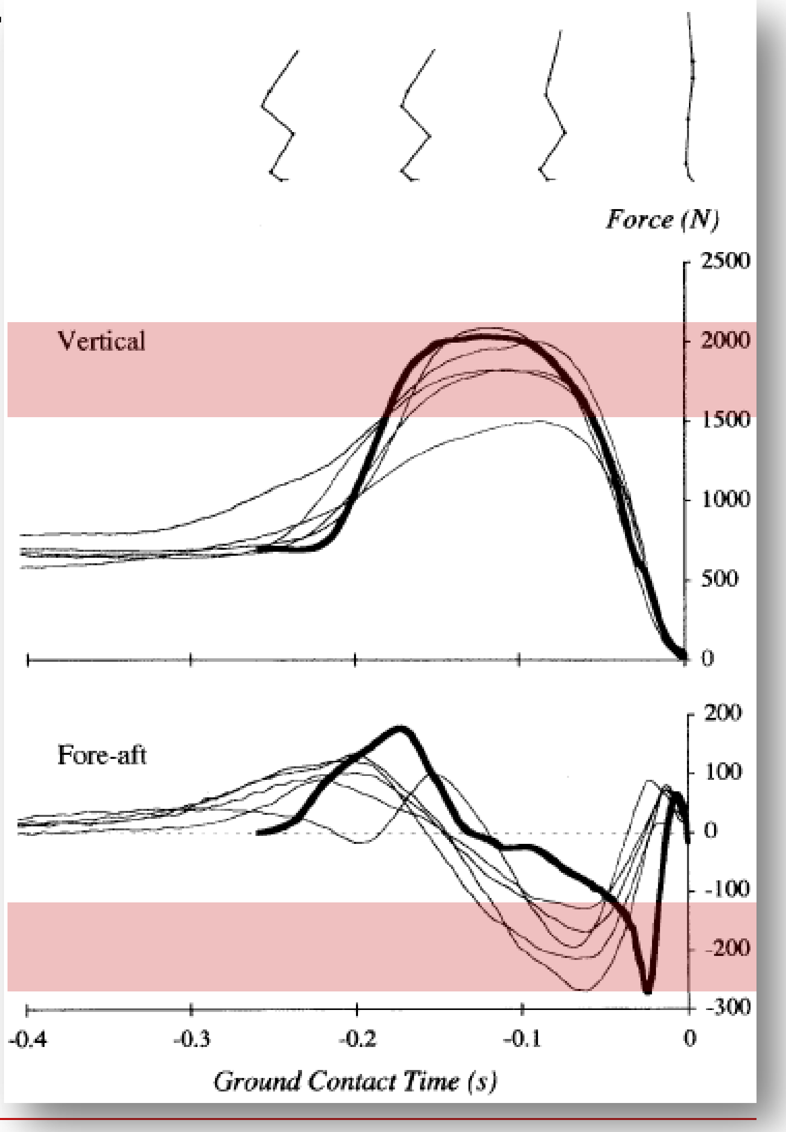


Results section

Anderson and Pandy, 1999

Optimal Solution c/w Experiment

- Agreement between the model and subject ground reaction forces
- Peak vertical forces
  - 2000N (model)
  - 1500 to 2100N (subjects)
- Peak fore-aft forces
  - 270N (model)
  - 120 to 270N (subjects)

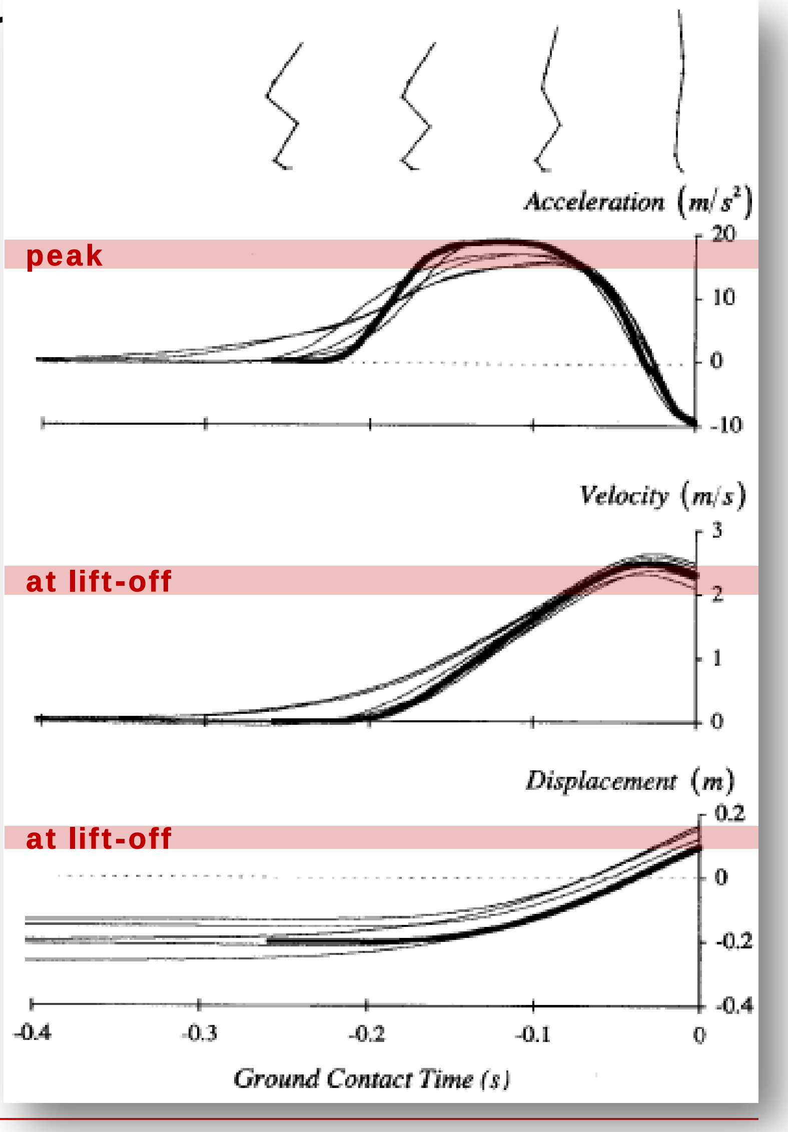


Results section

Anderson and Pandy, 1999

Optimal Solution c/w Experiment

- Agreement between the model and subject motion
- Peak vertical acceleration
  - 19 m/s^2 (model)
  - 15 to 19 m/s^2 (subjects)
- Lift-off vertical velocity
  - 2.3 m/s (model)
  - 2.0 to 2.5 m/s (subjects)
- Peak vertical position
  - 36.9 cm (model)
  - 33 to 41 cm (subjects)



Results section

Anderson and Pandy, 1999

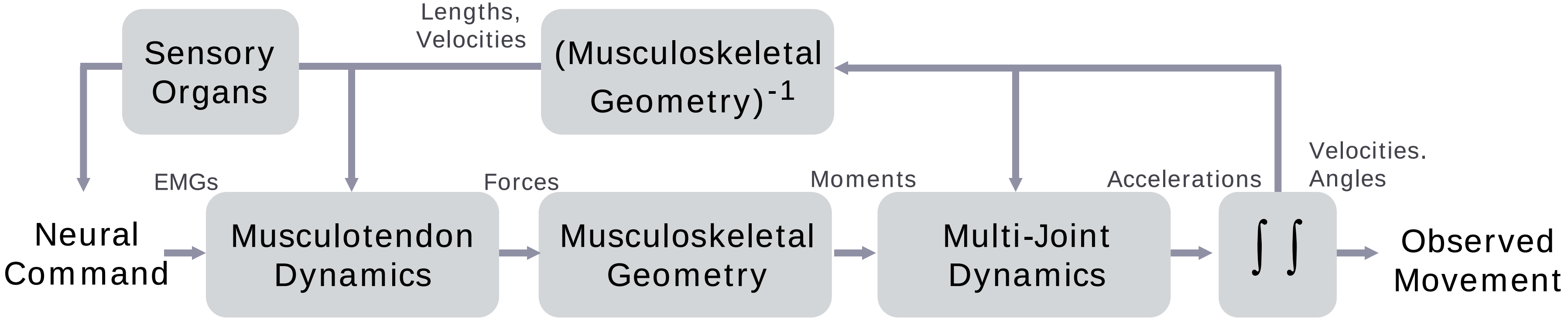
Discussion

- Better than previous studies of jumping
  - Whole-body, 3-dimensional, foot-ground contact
  - 2 times more segments (10)
  - 2 to 6 times more degrees of freedom (23)
  - 2 to 5 times more muscles (54)
- Limitations of model
  - Fewer muscles than in actual body (24 vs. 51 in leg)
  - Simple set of abdomen muscles (6 vs. 60 back)
  - Single degree of freedom back joint
  - Fixed axes of rotation at the joints

Outline for Today

- Question of the day
- Anderson and Pandy, 1999
- Objectives of Simulation Lab #1
- Getting started with simulation of jumping
- Answer your questions!

Simulation Lab 1:
Dynamic Simulation of Jumping

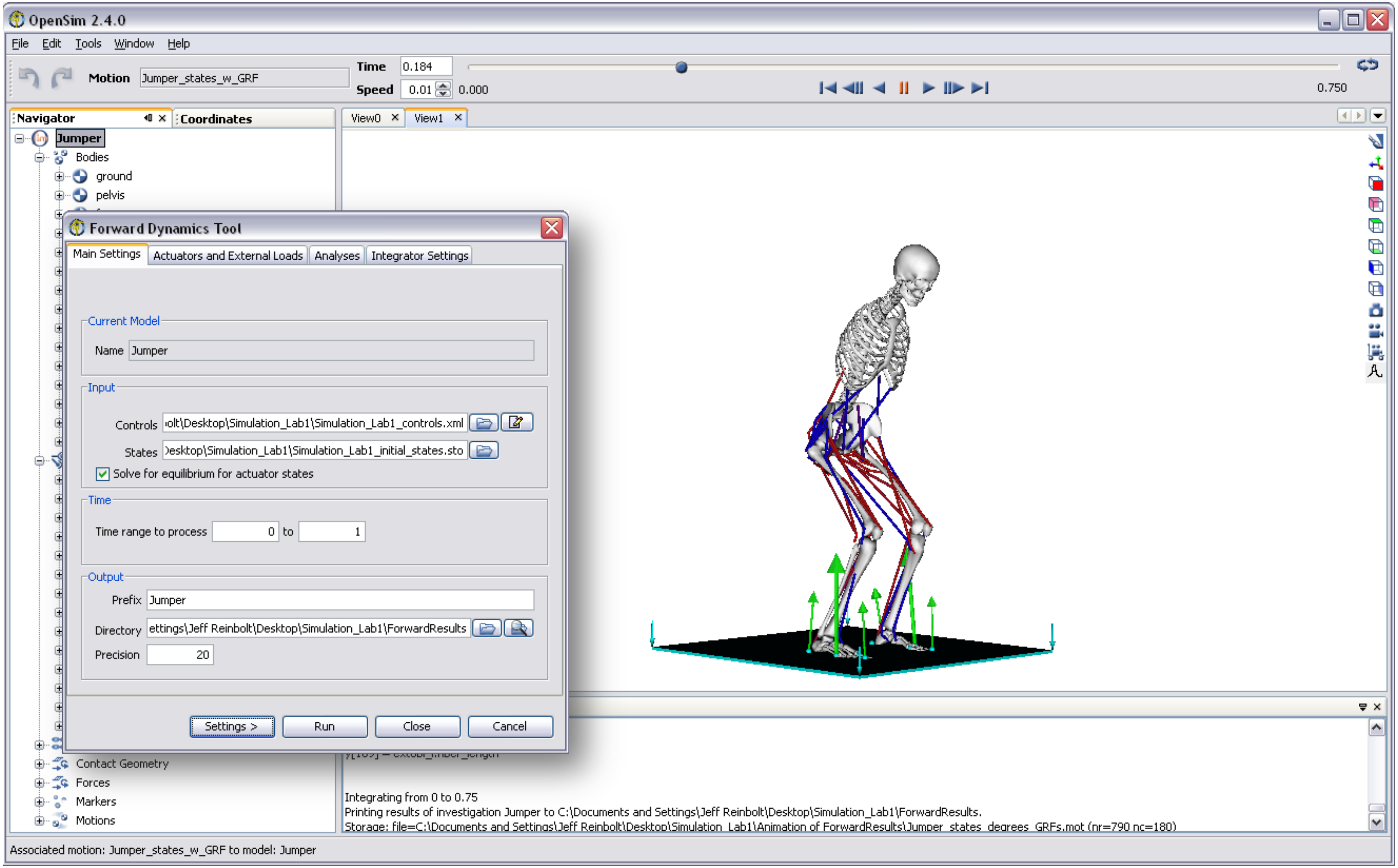


Objectives

Hands-on experience with complex, dynamic model and simulation of human movement

- Determine excitations to produce a well-coordinated jump
- Investigate actions of muscles in isolation and with others
- Compare simulation with optimal and experimental data
- Quantify the magnitude of the hip forces
- Examine force generated by the vasti muscle group

Getting started…



Motion: Jumper_states_w_GRF

Time: 0.184

Speed: 0.01

Current Model

Name: Jumper

Input

Controls: olt\Desktop\Simulation_Lab1\Simulation_Lab1_controls.xml

States: Desktop\Simulation_Lab1\Simulation_Lab1_initial_states.sto

☑ Solve for equilibrium for actuator states

Time

Time range to process: 0 to 1

Output

Prefix: Jumper

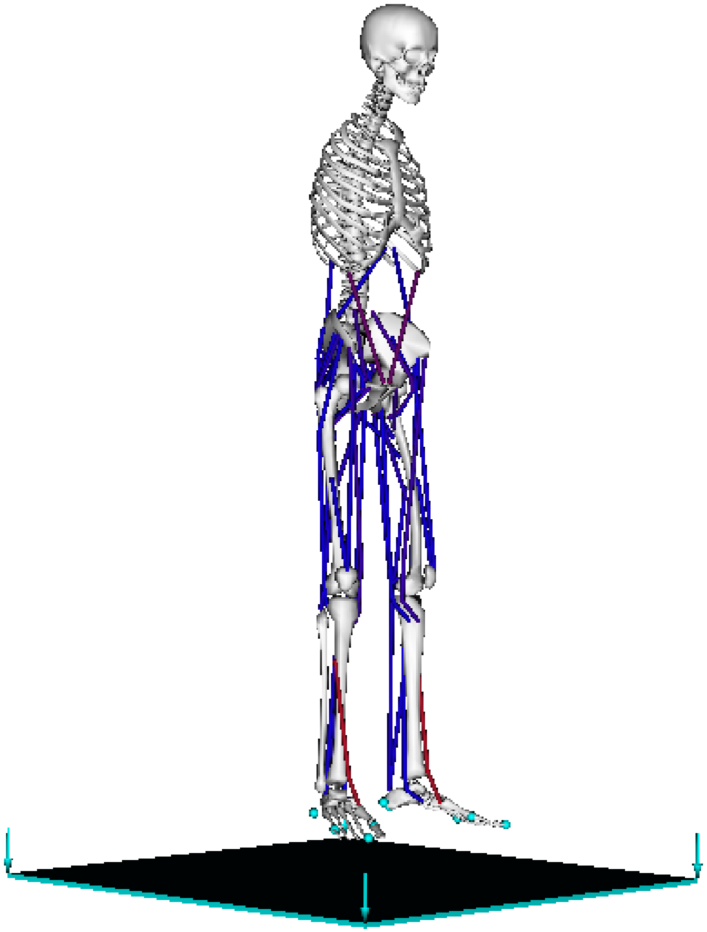
Directory: ettings\Jeff Reinbolt\Desktop\Simulation_Lab1\ForwardResults

Precision: 20

```
Integrating from 0 to 0.75
Printing results of investigation Jumper to C:\Documents and Settings\Jeff Reinbolt\Desktop\Simulation_Lab1\ForwardResults.
Storage: file=C:\Documents and Settings\Jeff Reinbolt\Desktop\Simulation_Lab1\Animation of ForwardResults\Jumper_states_degrees_GRFs.mot (nr=790 nc=180)
```

Associated motion: Jumper_states_w_GRF to model: Jumper

...in the end



For Next Time…

- Read ***articles*** #3-5 of the Course Reader
  - ***Zajac, 1993***
  - ***Buchanan et al., 2004***
  - ***Erdermir et al., 2007***
- Continue to think about topics for your ***individual research project***
- Work on ***Simulation Lab #1*** early! ***Due Jan 31***