Mechanical Engineering Seminar (U-Grad)
Special Topics in Mechano-Informatics II (Grad)
"Biomechanics of Human Movement"

Academic Year 2014

Dr. Emel Demircan

Course Information

Instructor:

- Dr. Emel Demircan
  Contact: emel@ynl.t.u-tokyo.ac.jp
  Office Hours and Location: Friday 16:30-17:30, Engineering Building 2, Room 82D1

Assistants:

- Tianwei Zhang
  Contact: zhang@ynl.t.u-tokyo.ac.jp
  Office Hours and Location: Tuesday 14:00-15:00, Engineering Building 2, Room 82C1
- Kazunari Takeichi
  Contact: takeichi@ynl.t.u-tokyo.ac.jp
  Office Hours and Location: Friday 16:30-17:30, Engineering Building 2, Room 82C1

Course Information

Course Grading:

Attendance: 40%
Homeworks: 30%
Final Project Presentation: 30%

Homeworks:

Please submit each homework electronically to **emel@ynl.t.u-tokyo.ac.jp** by its deadline.

4/25: HW1 out
5/2: HW1 due, 5pm
5/9: HW2 out
5/23: HW2 due, 5pm
6/6: HW 3 out
6/27: HW 3 due, 5pm

Course Information

Final Project:
Students form teams and each team selects one topic from the list below:

- Exoskeleton Robots & Rehabilitation Robotics
- Human Performance Augmentation
- Animation and Simulation
- Human & Humanoid in Aging Society
- Human & Humanoid Skills/Cognition
- Human Motion Tracking
- Gait Analysis & Rehabilitation
- Human Musculoskeletal Modeling
- Socially Assistive Robots
- Natural Motion Generation in Humanoid Robotics
- Motion Analysis for Workspace Ergonomics
- Children Gait and Posture Rehabilitation
- Real-time Feedback Modalities for Motion Training

Schedule

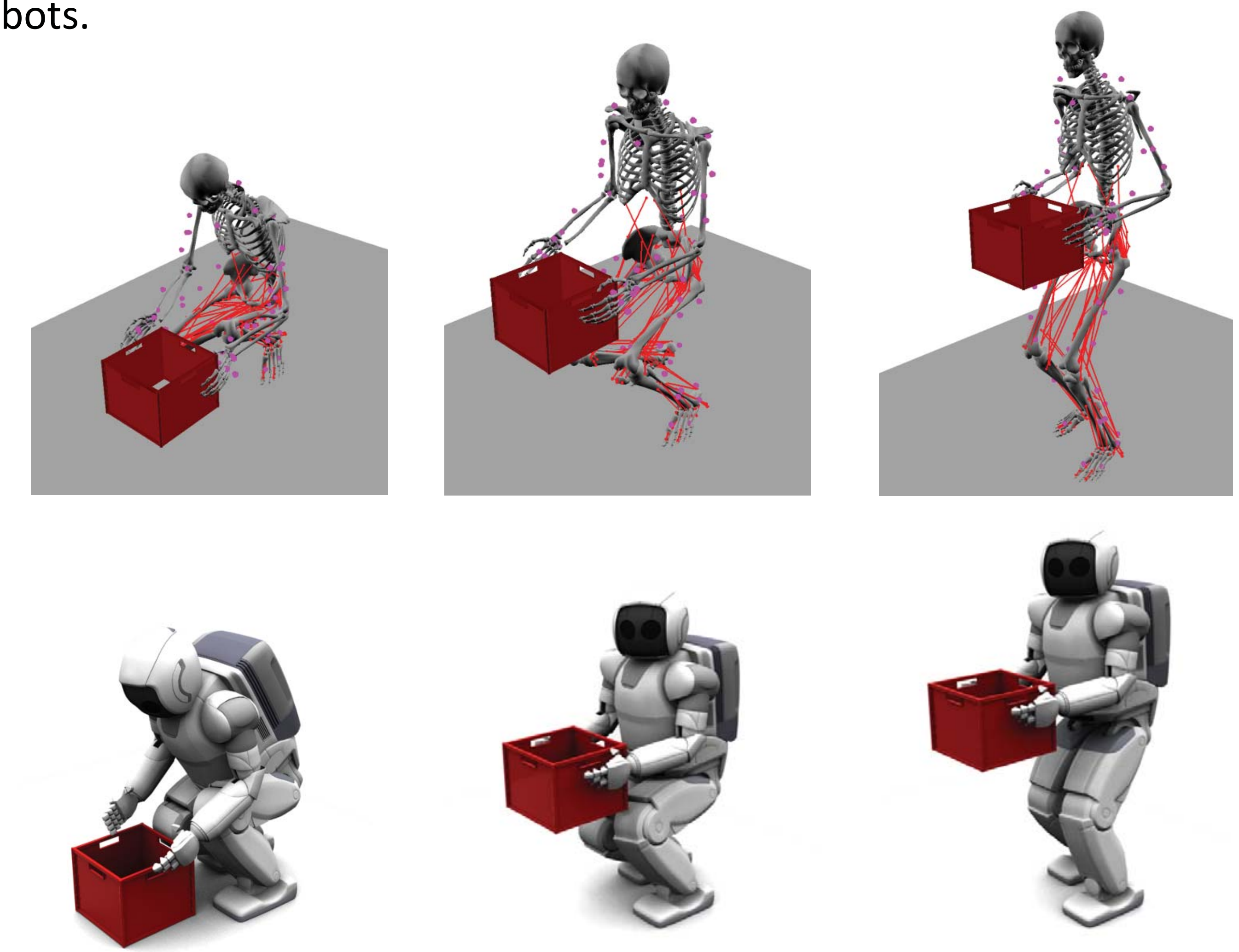
4/18: Introduction
4/25: Spatial Descriptions, Kinematics, Introduction to Biomechanical Simulation
5/2: Skeletal Muscle Structure, Force Generation, Musculoskeletal Geometry
5/9: Production of Movement
5/23: Motion Tracking Techniques
6/6: Inverse Dynamics, Control, Operational Space Formulation
6/27: Human Articulated Body Model, Dynamics, and Motion Control
7/4: Advanced Topics in Human Motion Analysis, Student Presentations

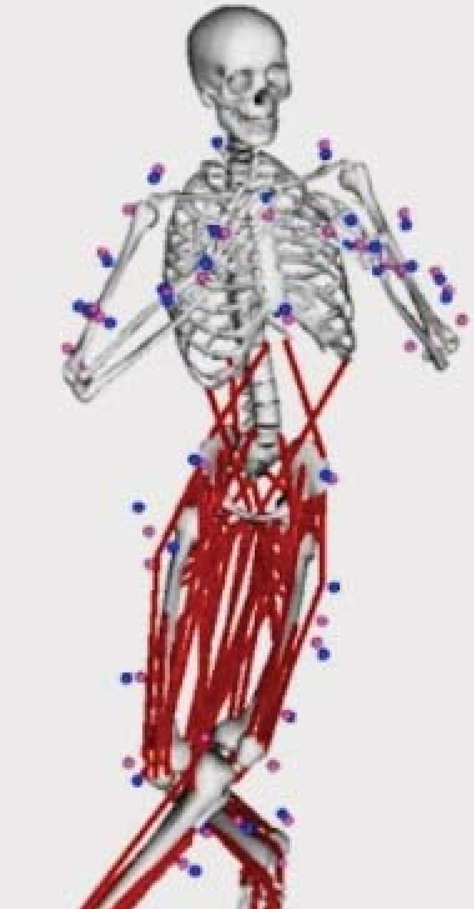
Today

- Why to Study Human Motion?
- How to Study Human Motion? - Multi-Disciplinary Research
- Components and Functions of the Musculoskeletal System
- Examples of Applications

Understanding and Applying Human Motion to Robots

- To observe and understand how humans move. To apply similar strategies to robots.





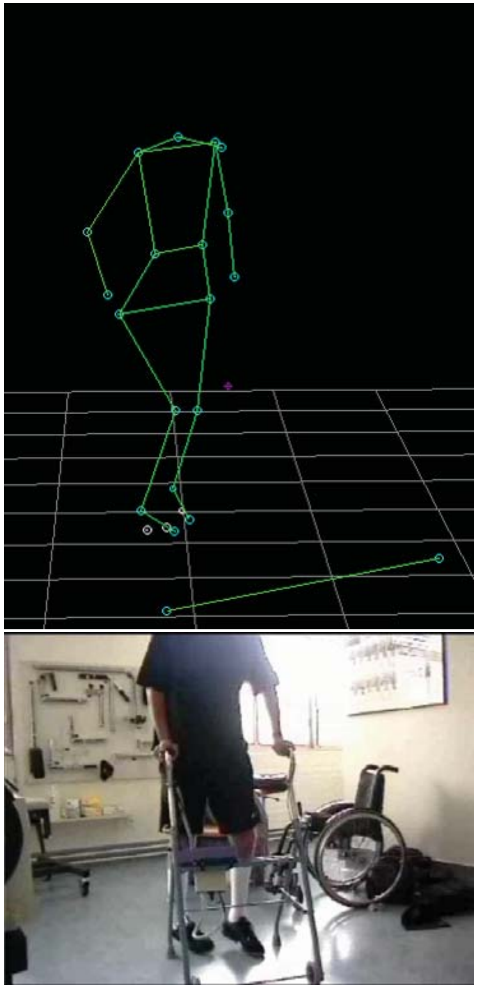
Today

- **Why to Study Human Motion?**
- How to Study Human Motion? **-** Multi-Disciplinary Research
- Components and Functions of the Musculoskeletal System
- Examples of Applications

Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques

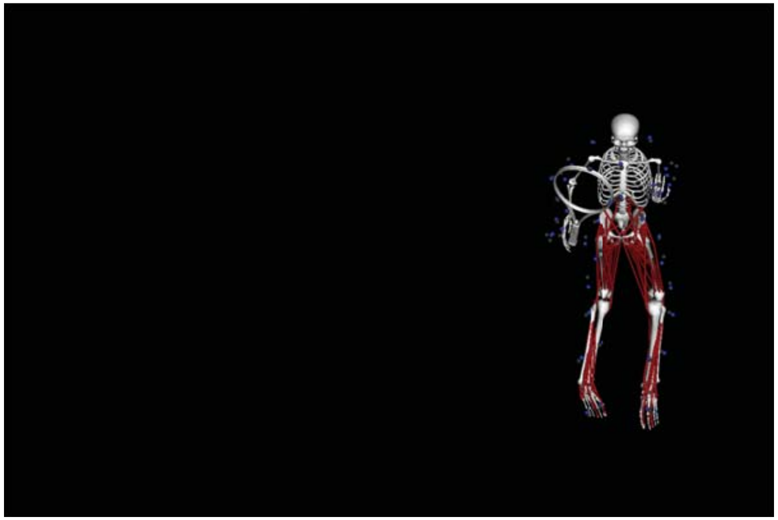


LIRMM, Universite de Montpellier II

Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
- to evaluate injuries



Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
- to evaluate injuries
- for ergonomic analysis and design

Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
- to evaluate injuries
- for ergonomic analysis and design
- to synthesize realistic interactions in computer-simulated environment

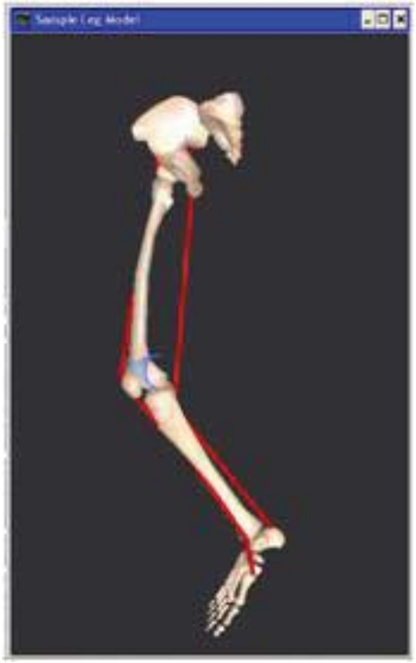
Today

- Why to Study Human Motion?
- **How to Study Human Motion? - Multi-Disciplinary Research**
- Components and Functions of the Musculoskeletal System
- Examples of Applications

Biomechanical Tools

Human Musculoskeletal Models

- Multi-body, rigid, tree-like branching structure
- Upper and lower body models



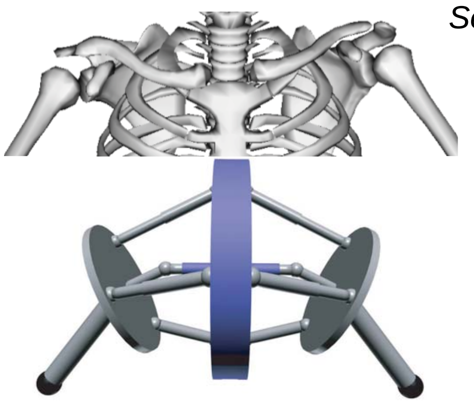
Human Musculoskeletal Models adapted from: Delp, S.L., Loan, J.P., Hoy, M.G., Zajac, F.E., Topp E.L., Rosen, J.M. An interactive graphics-based model of the lower extremity to study orthopaedic surgical procedures. IEEE Transactions on Biomedical Engineering, vol. 37, pp. 757-767, 1990.
and: Holzbaur, K.R.S., Murray, W.M., Delp, S.L. A Model of the Upper Extremity for Simulating Musculoskeletal Surgery and Analyzing Neuromuscular Control. Annals of Biomedical Engineering, vol 33, pp 829–840, 2005.

Biochemical Tools

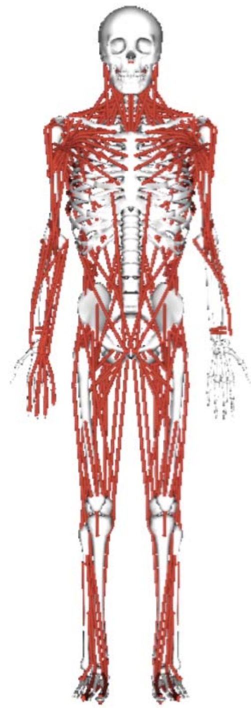
Human Musculoskeletal Models

- Multi-body, rigid, tree-like branching structure
- Upper and lower body models
- Different levels of complexity

Seth et al.'10



Lenarciˇc et al.'00
DeSapio et al.'06



Joint	Degree of freedom	Type	Function
Hip	3	Ball and socket	Adduction/ abduction Flexion/extension Rotation
Knee	1	Revolute	Flexion/extension
Ankle	1	Revolute	Dorsiflexion/plantar flexion
Subtalar	1	Revolute	Eversion/inversion
Tarsal	1	Revolute	Flexion/extension
Lumbar	3	Ball and socket	Ext./bend./rot.
Shoulder	3	Ball and socket	Adduction/ abduction Flexion/extension rotation
Elbow	1	Revolute	Flexion/extension
Wrist	3	Revolute	Flexion/extension Ulnar/radial deviations Pronation/ supination

Experimental Tools

Sensing Human Motion

- Accurate 3D position data – Motion Capture (mocap)
- Easy to use, continuous whole-body sensing
- Synchronize with contact force, muscle activity data

History of Human Movement Science

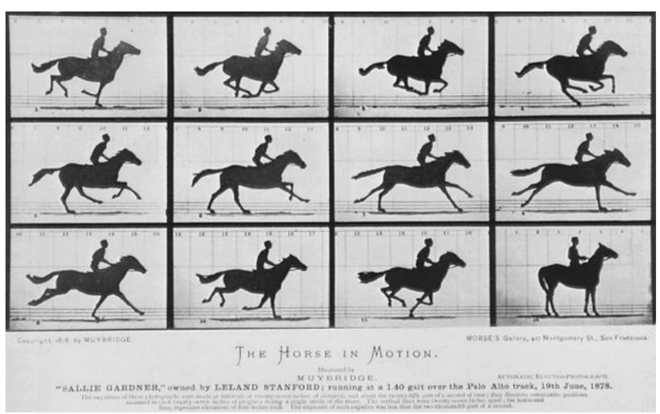
1543: Andreas Vesalius publishes the first illustrated systematic anatomical atlas of the human body.

1872: former Governor of California **Leland Stanford**, had taken a position on a popularly-debated question of the day: whether all four of a horse's hooves left the ground at the same time during a gallop.

1877: Muybridge settles the bet with a single photographic plate showing Occident, Stanford's own racehorse, with all feet in the air. By **1878**, **Muybridge** had successfully photographed a horse in fast motion using a series of twenty-four cameras

1887: Etienne Jules Marey invents the "chronophotograph"

1894: Etienne Jules Marey invents the first slow motion camera



" No natural phenomenon can be understood without carefully considering how it emerged"
N. A. Bernstein, " On Dexterity and Its Development", 1996.

Robotics
Dynamics and Control

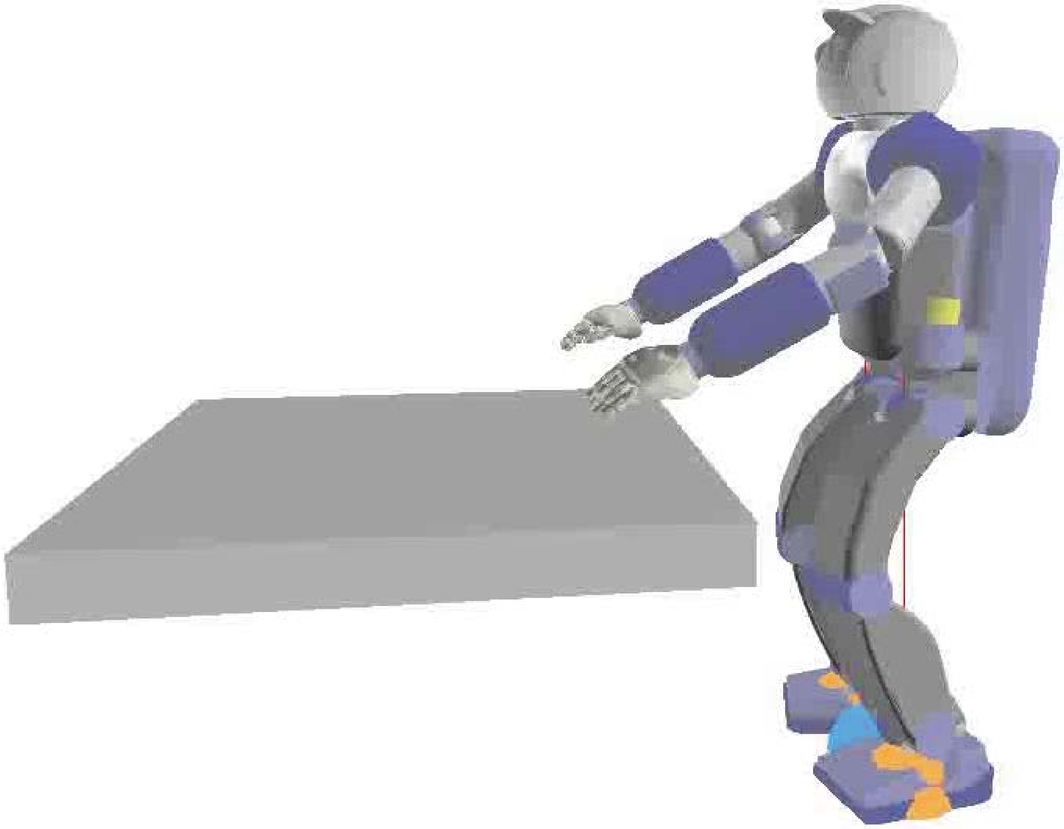
Balance

Internal Constraints
Self Collision
Local Obstacles

Contact

Task

Posture



Robotics
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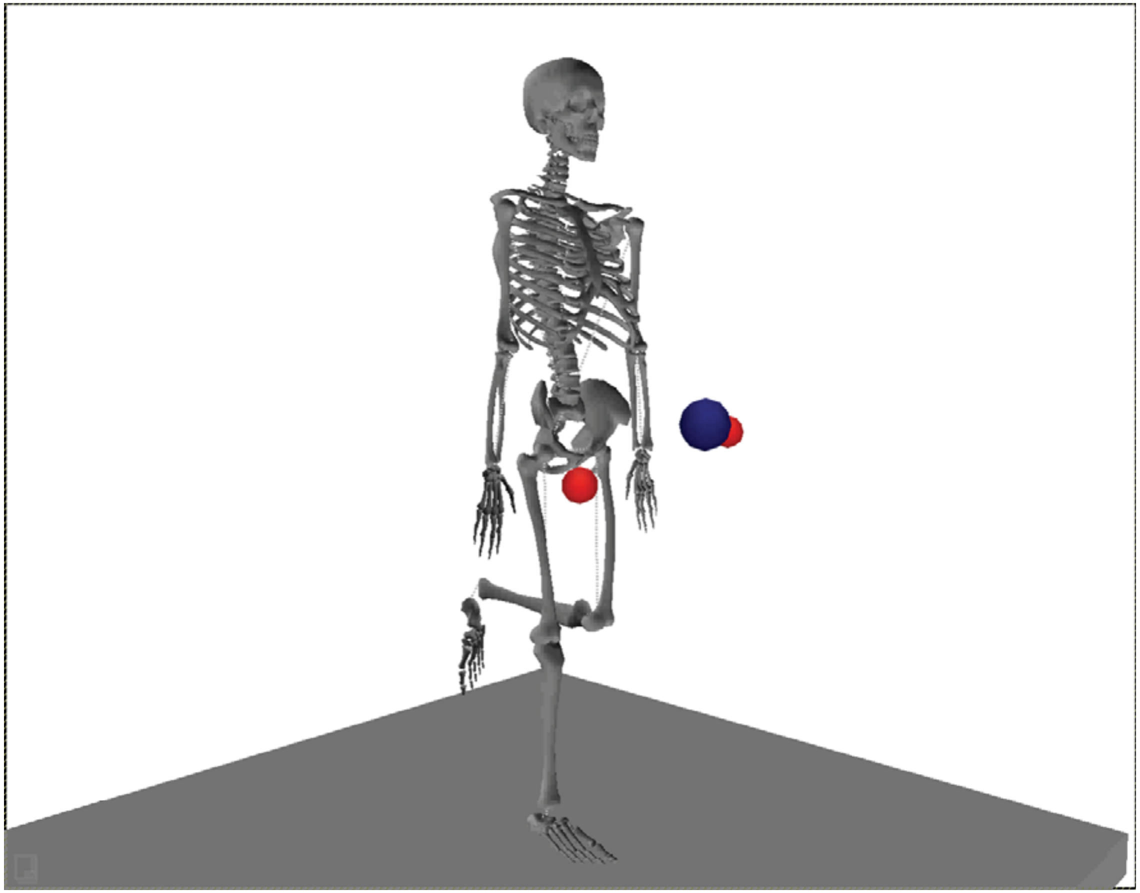
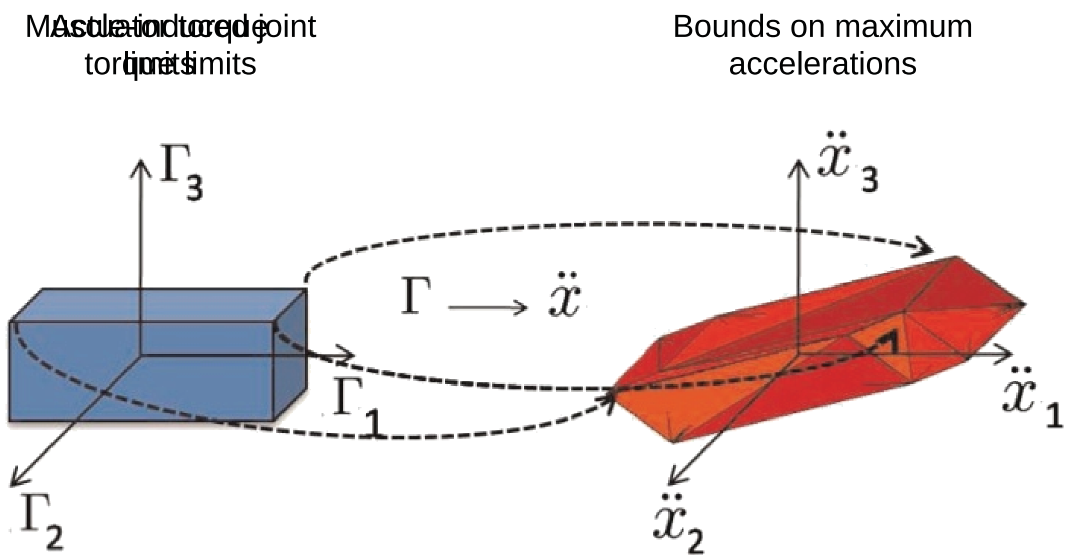
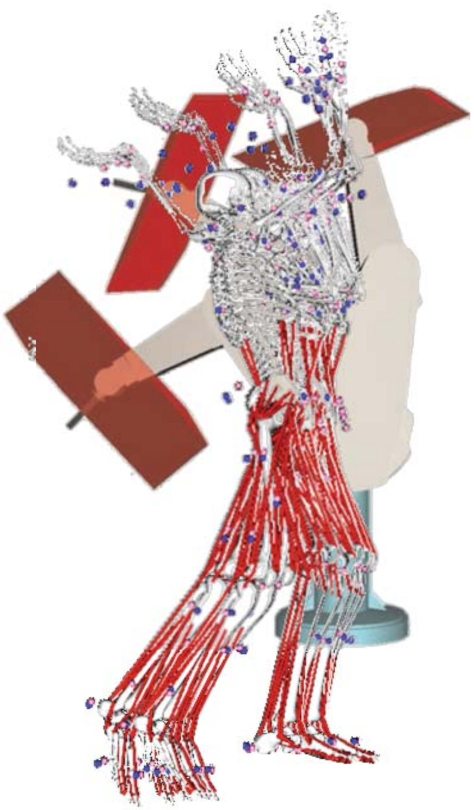


Robotics

Actuation and Dynamics Characterization Tools

- Robotics provide methods to assess the dynamic performance of multi-degrees of freedom manipulators (Khatib and Burdick, 1987)
- Dynamics can be reflected at the wrist of robotics systems using the feasible set of operational space accelerations

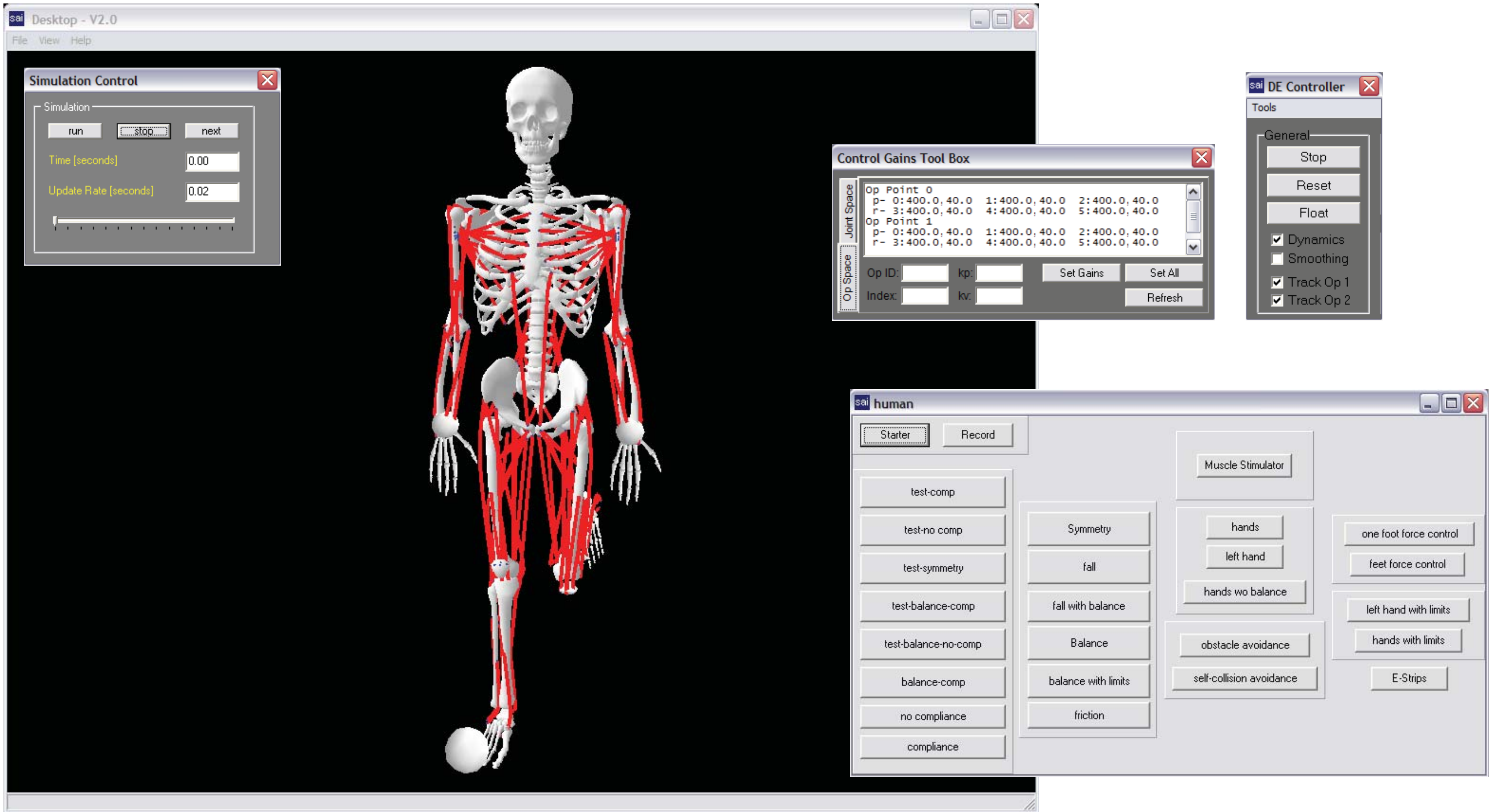




Neuromuscular Library

Multidisciplinary Research

Physiology | Model | Dynamics | Control | Analysis



Today

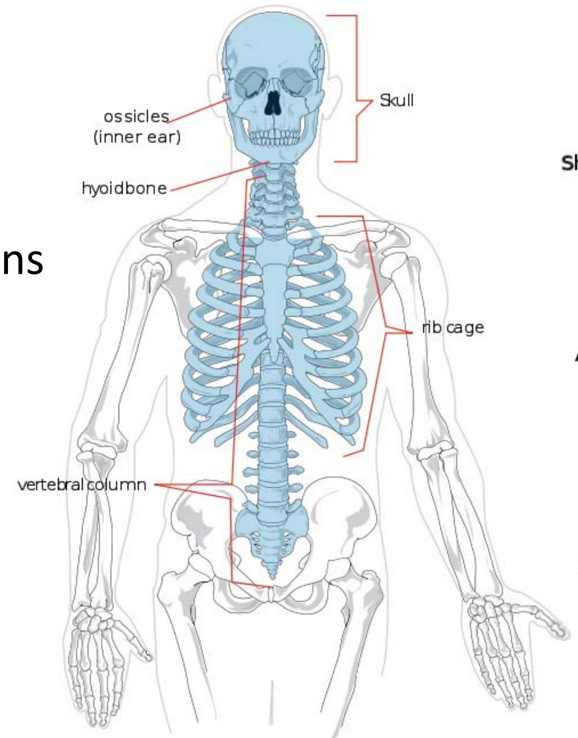
- Why to Study Human Motion?
- How to Study Human Motion? - Multi-Disciplinary Research
- **Components & Functions of the Musculoskeletal System**
- Examples of Applications

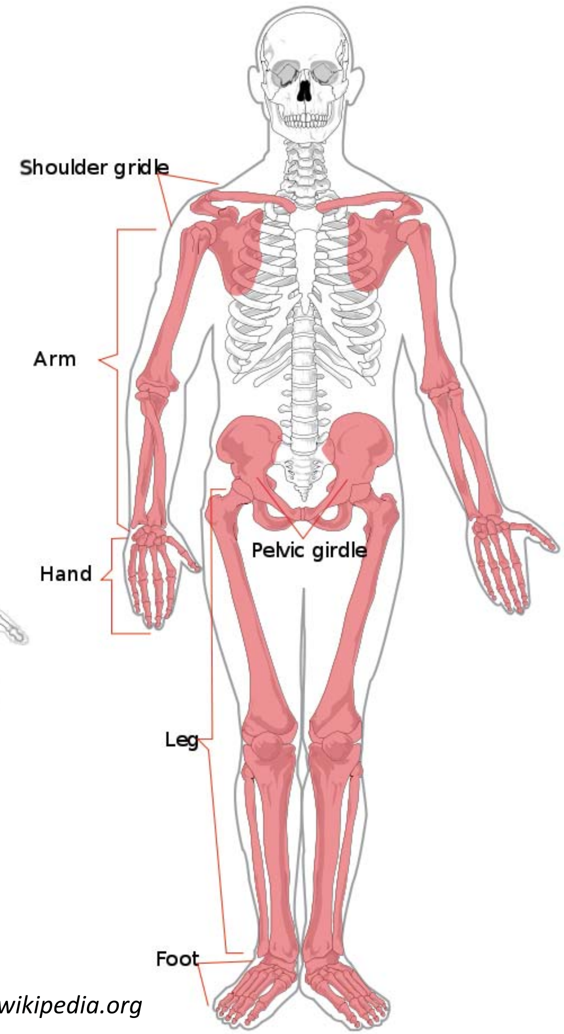
Components of the Musculoskeletal System

- Skeleton
  - Appendicular & Axial
  - Mineral Storage
  - Protection of Vital Organs
- Joints
  - Linkage
- Muscles
  - Force Production
  - Support

Components of the Musculoskeletal System

- Skeleton
  - Appendicular & Axial
  - Mineral Storage
  - Protection of Vital Organs

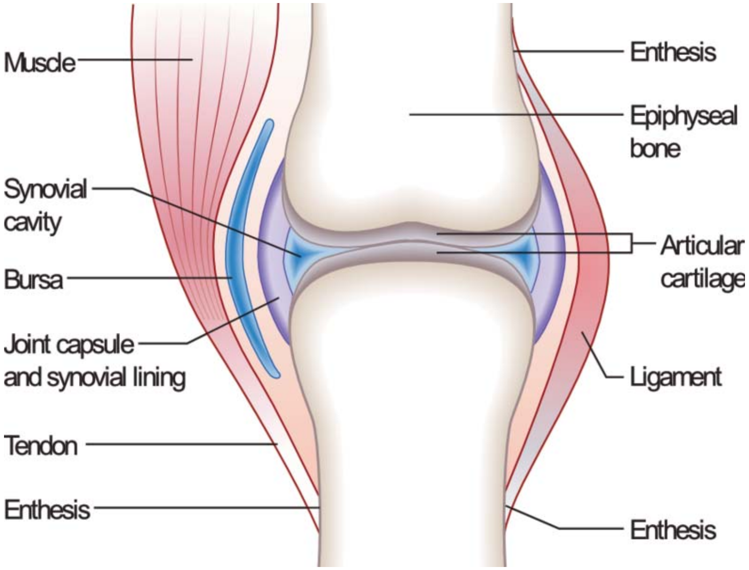




wikipedia.org

Components of the Musculoskeletal System

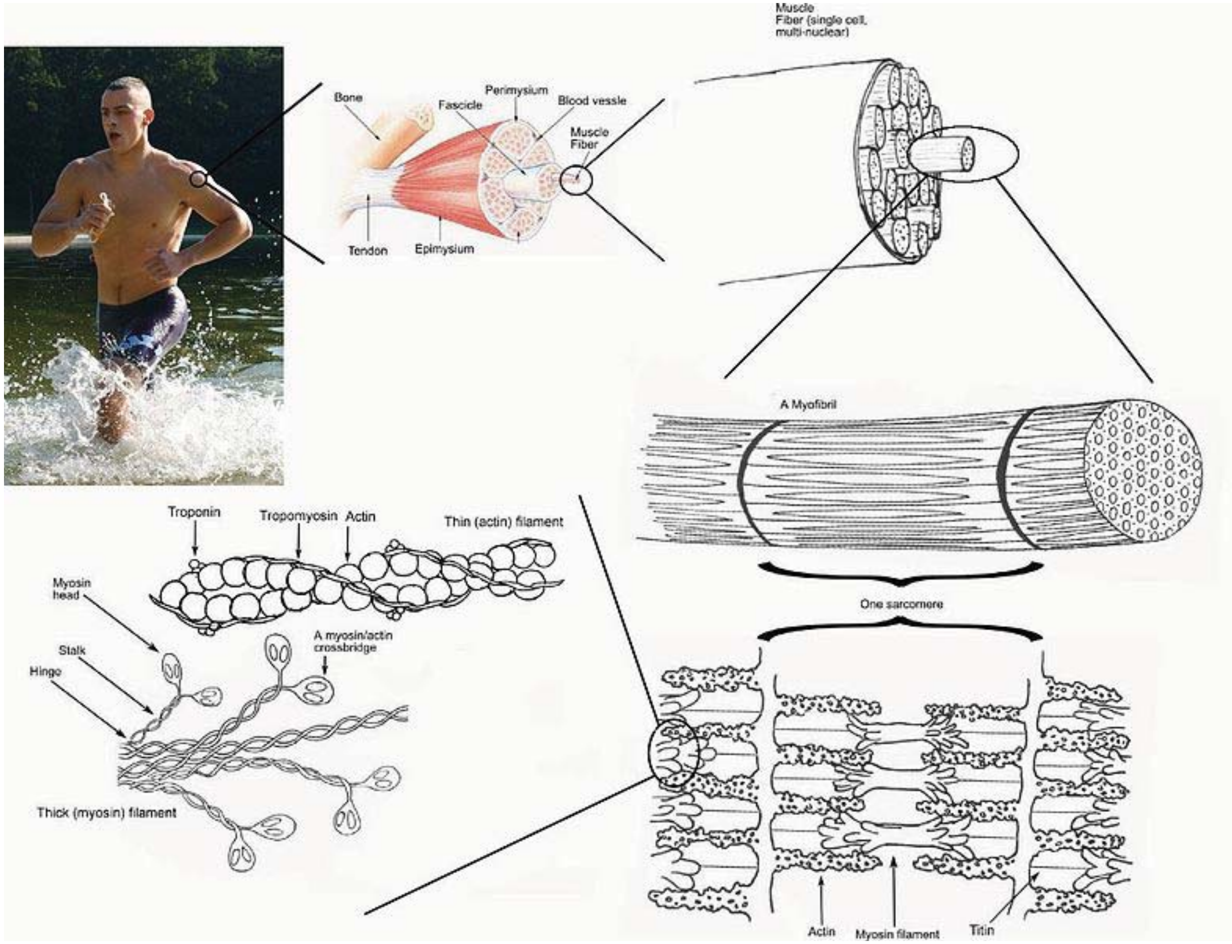
- Joints
  - Provide linkage
  - Human Motion involves rotation of body segments about their joint axes
  - The force produced by a muscle is coupled with its moment arm to generate torque about the joint that it crosses
  - Torques are always determined with respect to a specific axis of rotation



wikipedia.org

Components of the Musculoskeletal System

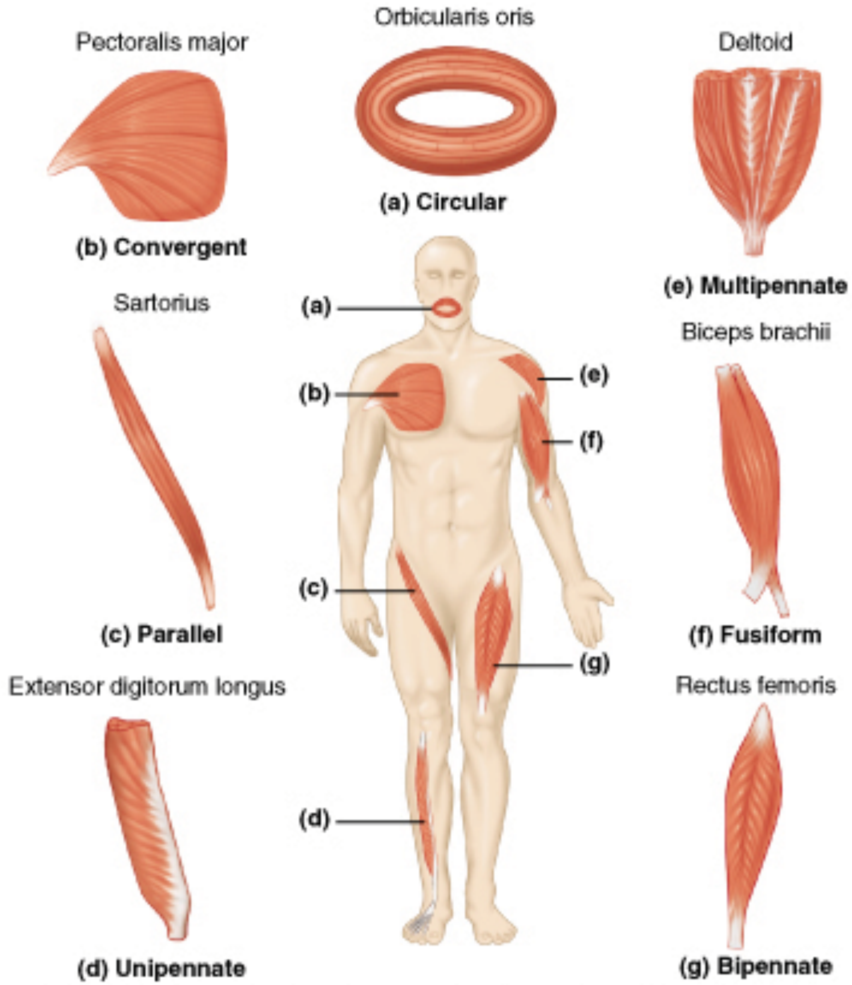
- Muscles
  - Force Production
  - Support



wikipedia.org

Components of the Musculoskeletal System

- Muscle Types



Today

- Why to Study Human Motion?
- How to Study Human Motion? - Multi-Disciplinary Research
- Components & Functions of the Musculoskeletal System
- **Examples of Applications**

Biomechanics of Human Movement
Applications

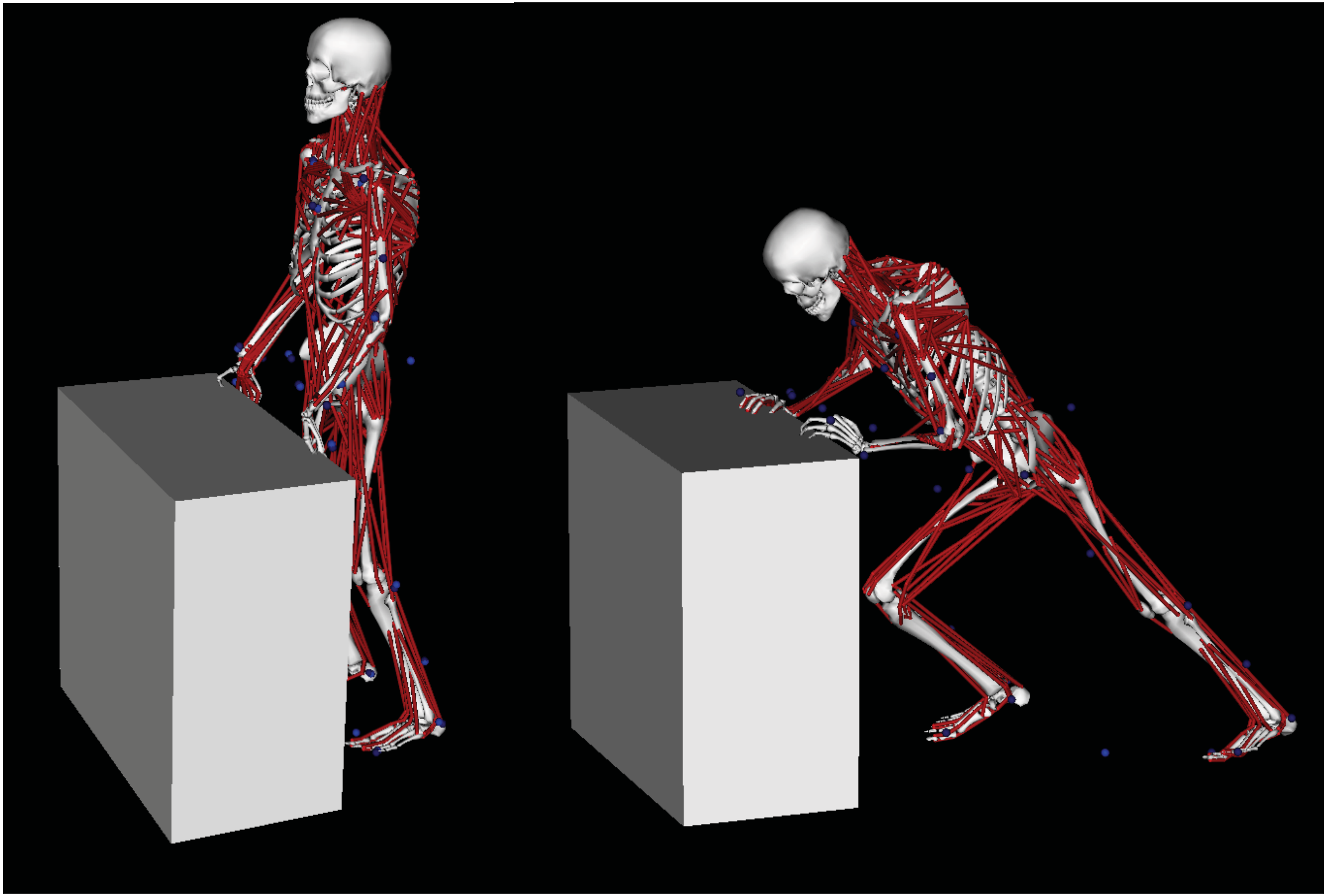
Ergonomics and
Occupational Health

Computer Animation

Reeducation of
Neuro-Musculoskeletal
Disorders

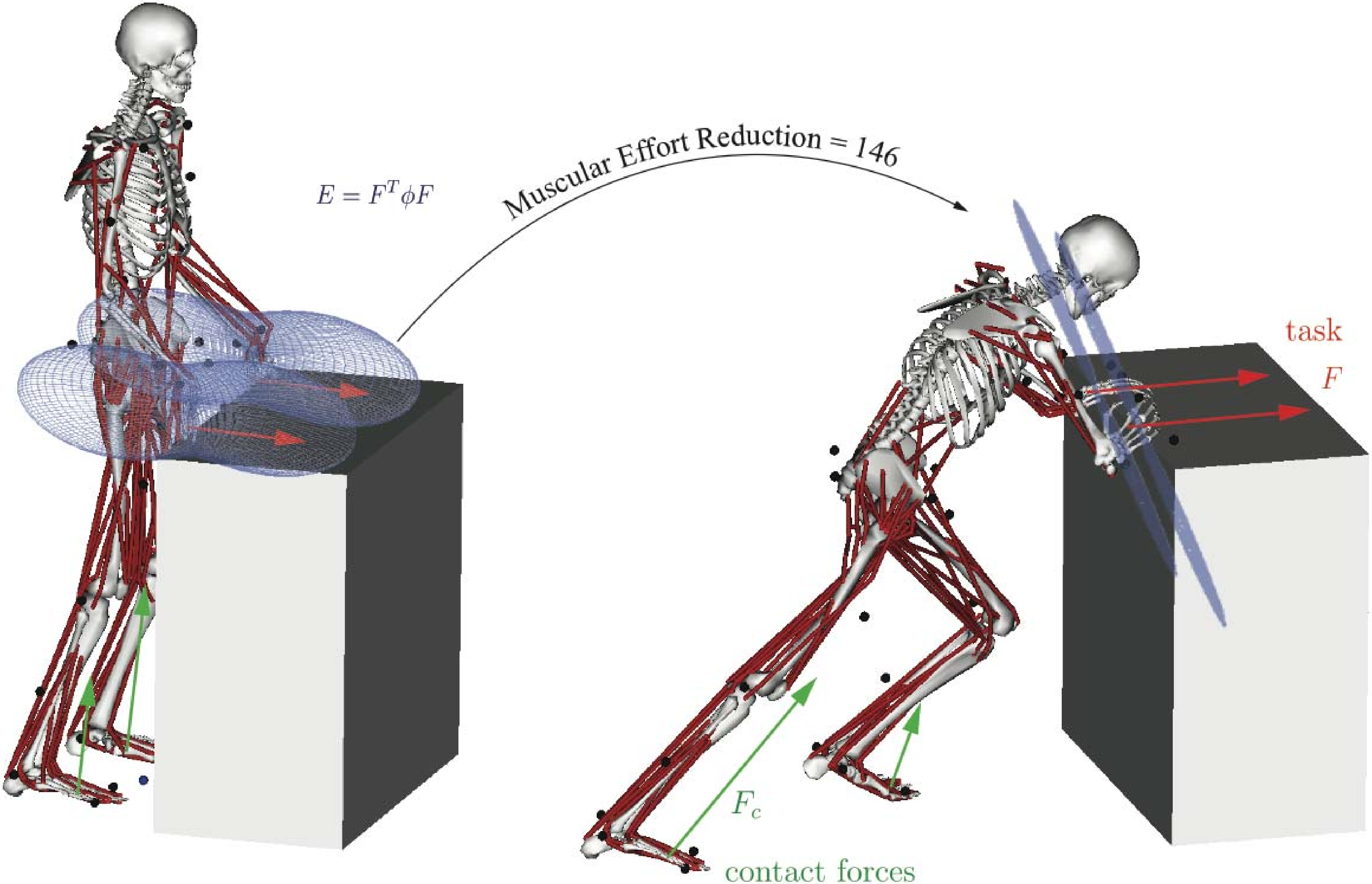
Athletics and
Sports Medicine

Human Motion Characterization



Whole-Body Muscular Effort

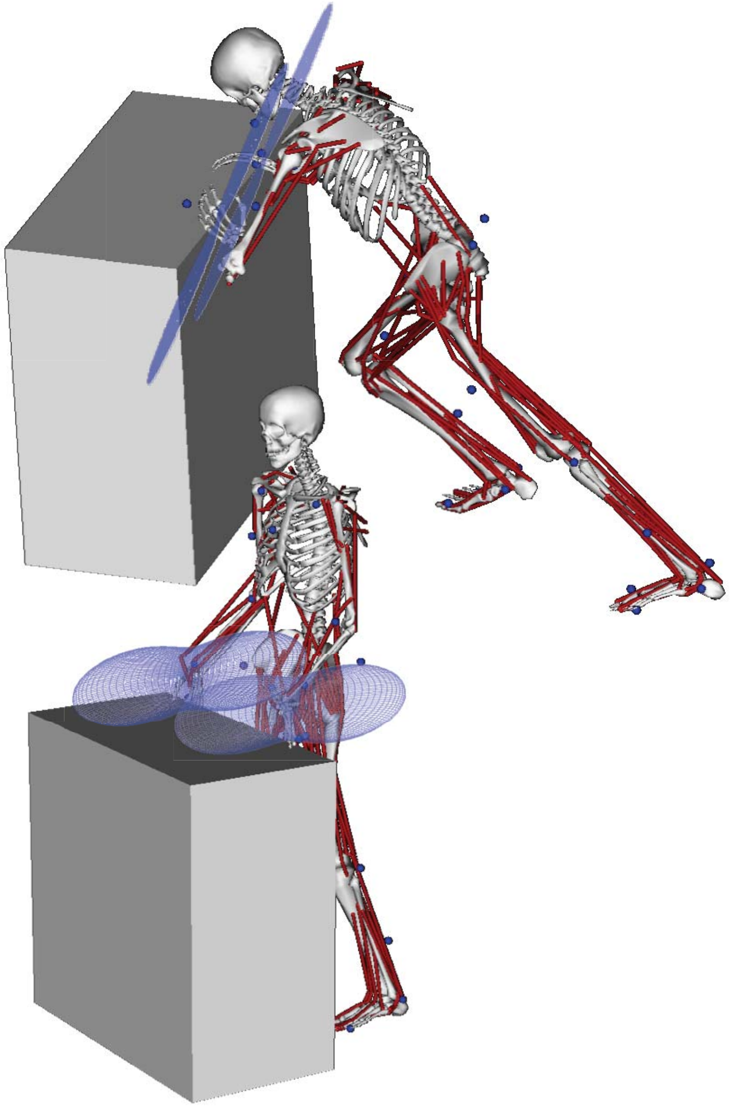
Physio-Mechanical Advantage



Ergonomics and Occupational Health

AnyBody

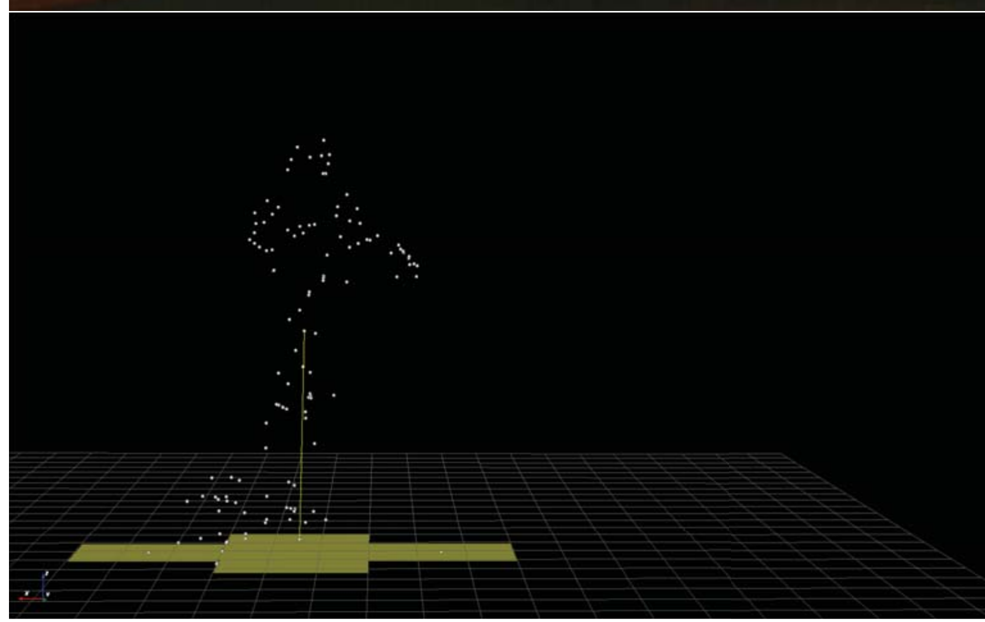
Which handle bar height results in the minimal load on the body?



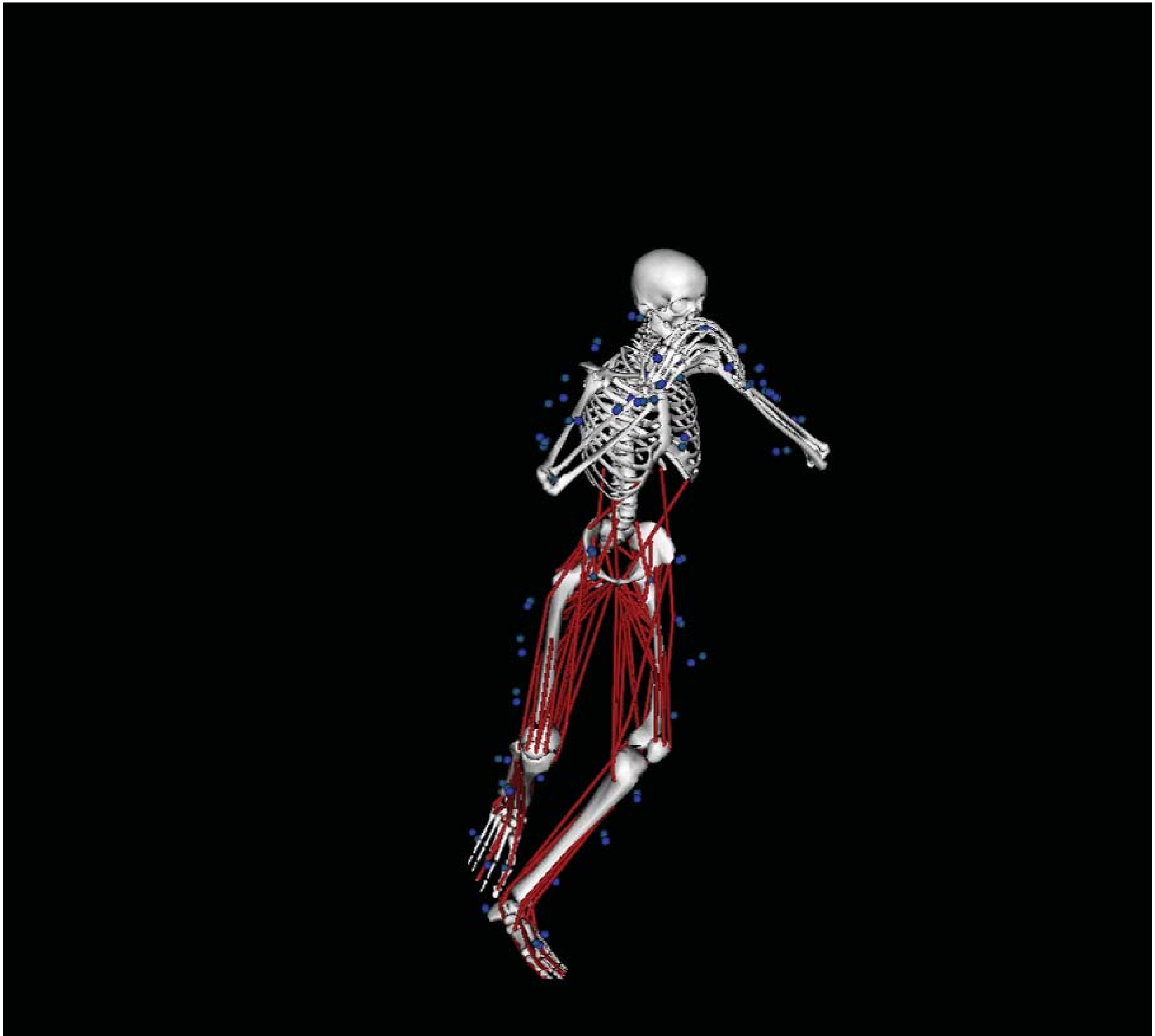
Experiment – Throwing

Professional Football Player

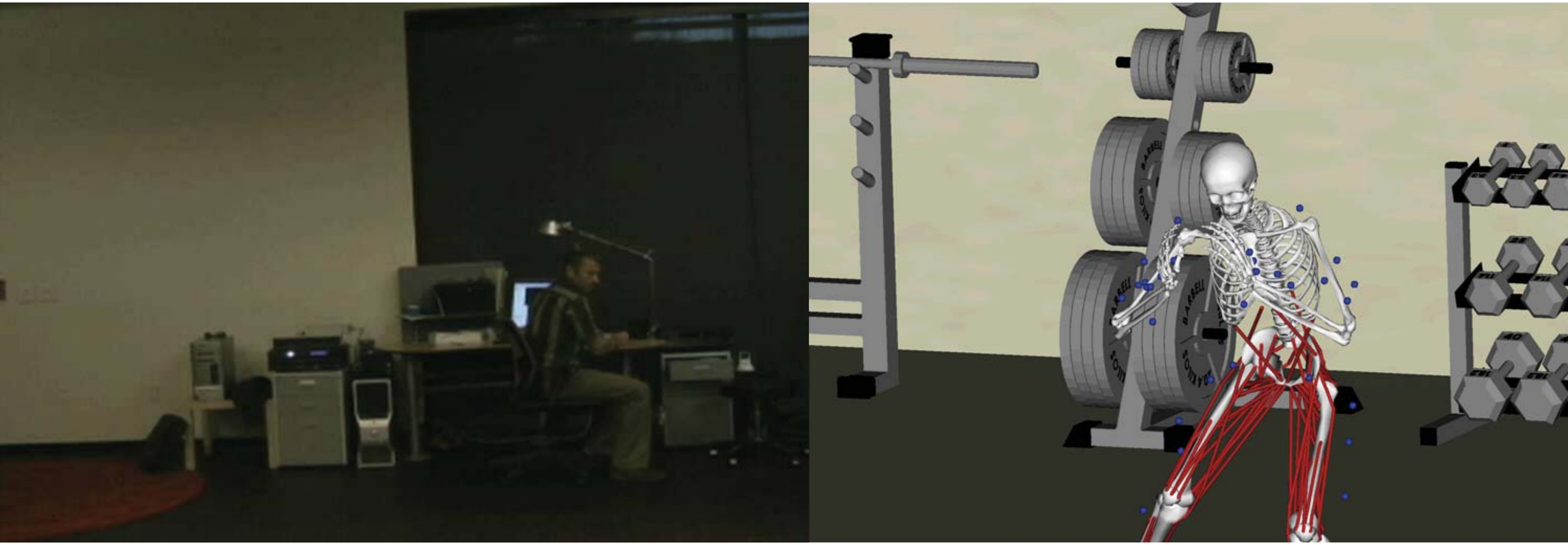
- Motion Capture
- Force Plate



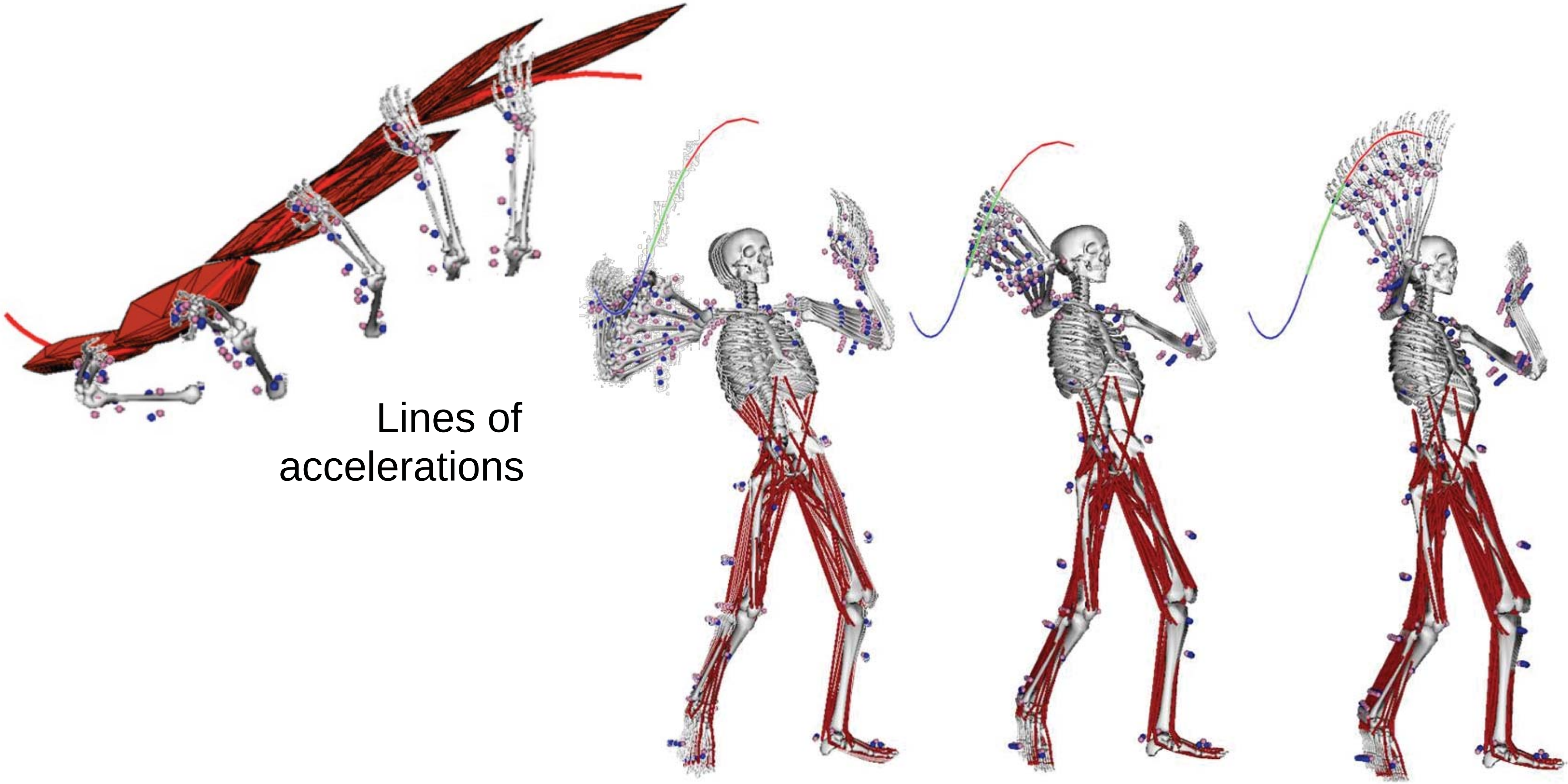
3-D Dynamic Simulation



3-D Dynamic Simulation
Professional Throwing

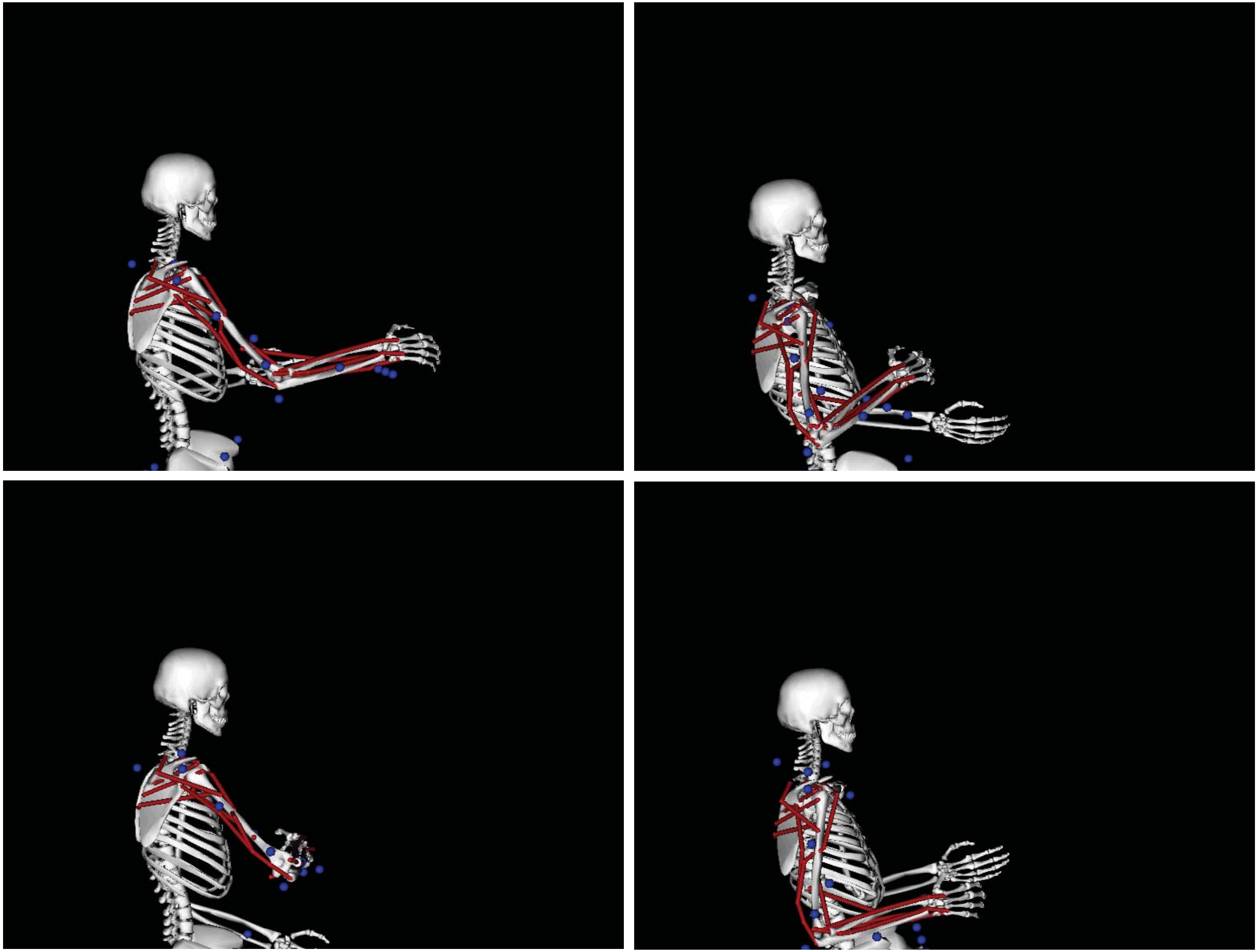


Dynamic Motion Analysis



Khatib, O., Demircan, E., De Sapio, V., Sentis, L., Besier, T., Delp, S., “Robotics-based Synthesis of Human Motion”, Journal of Physiology, 2009
Demircan, E., Khatib, O., Wheeler, J., and Delp, S., “Reconstruction and EMG-informed Control, Simulation and Analysis of Human Movement for Athletics: Performance Improvement and Injury Prevention”, IEEE EMBC, Minneapolis, 2009

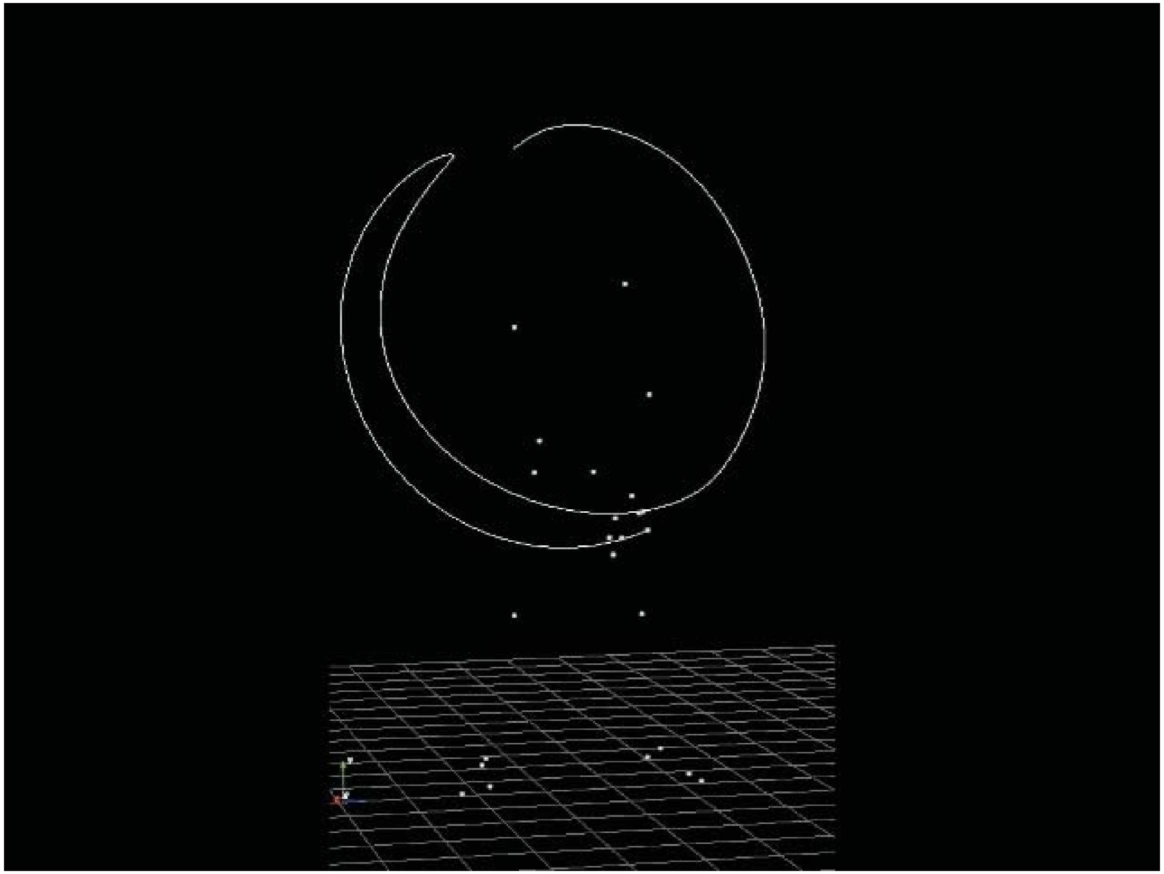
Optimal Throwing?



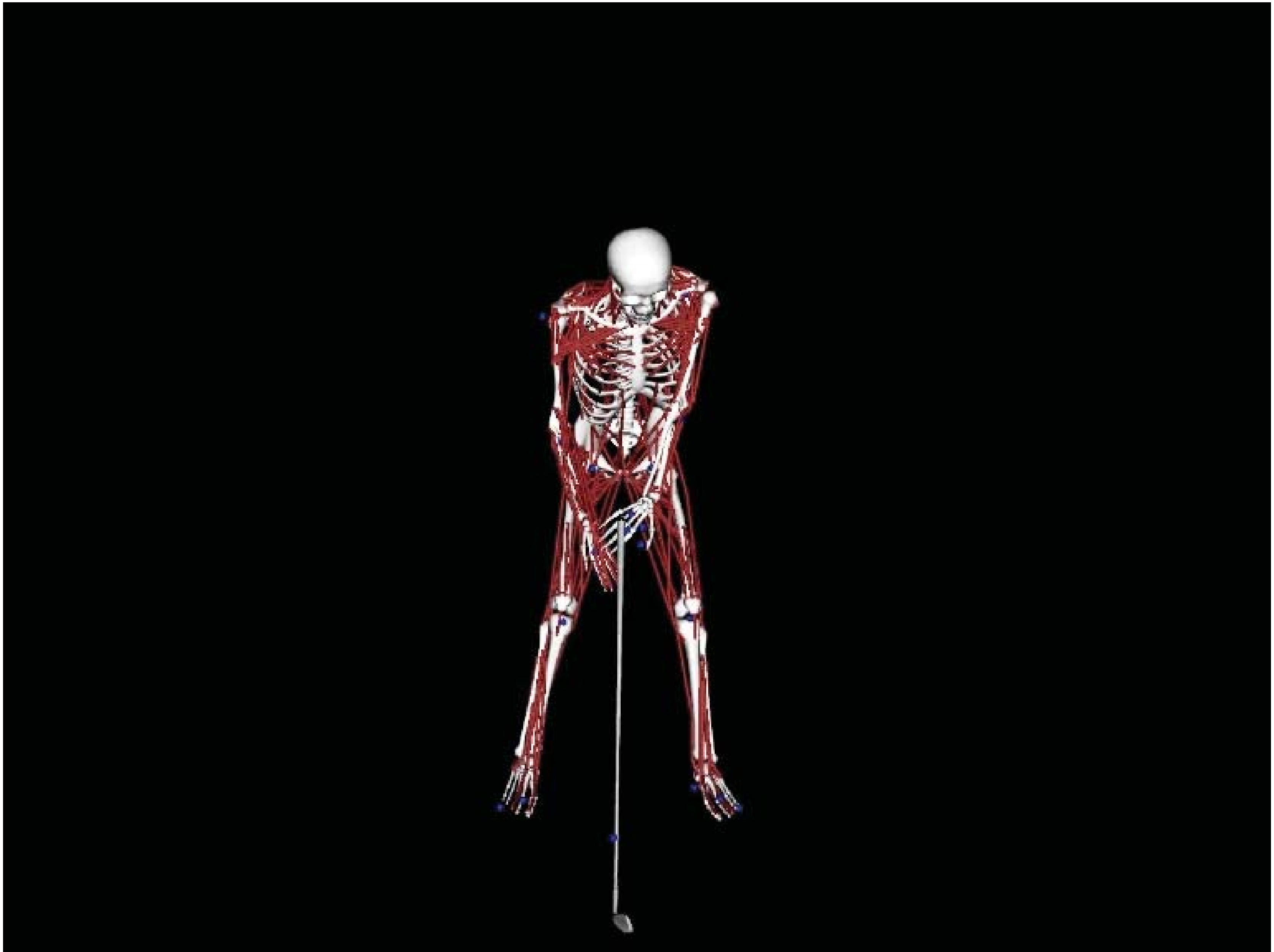
Experiment – Golf Swing

College-level Elite Golf Player

- Motion Capture
- Force Plate



3-D Dynamic Simulation of Golf Swing



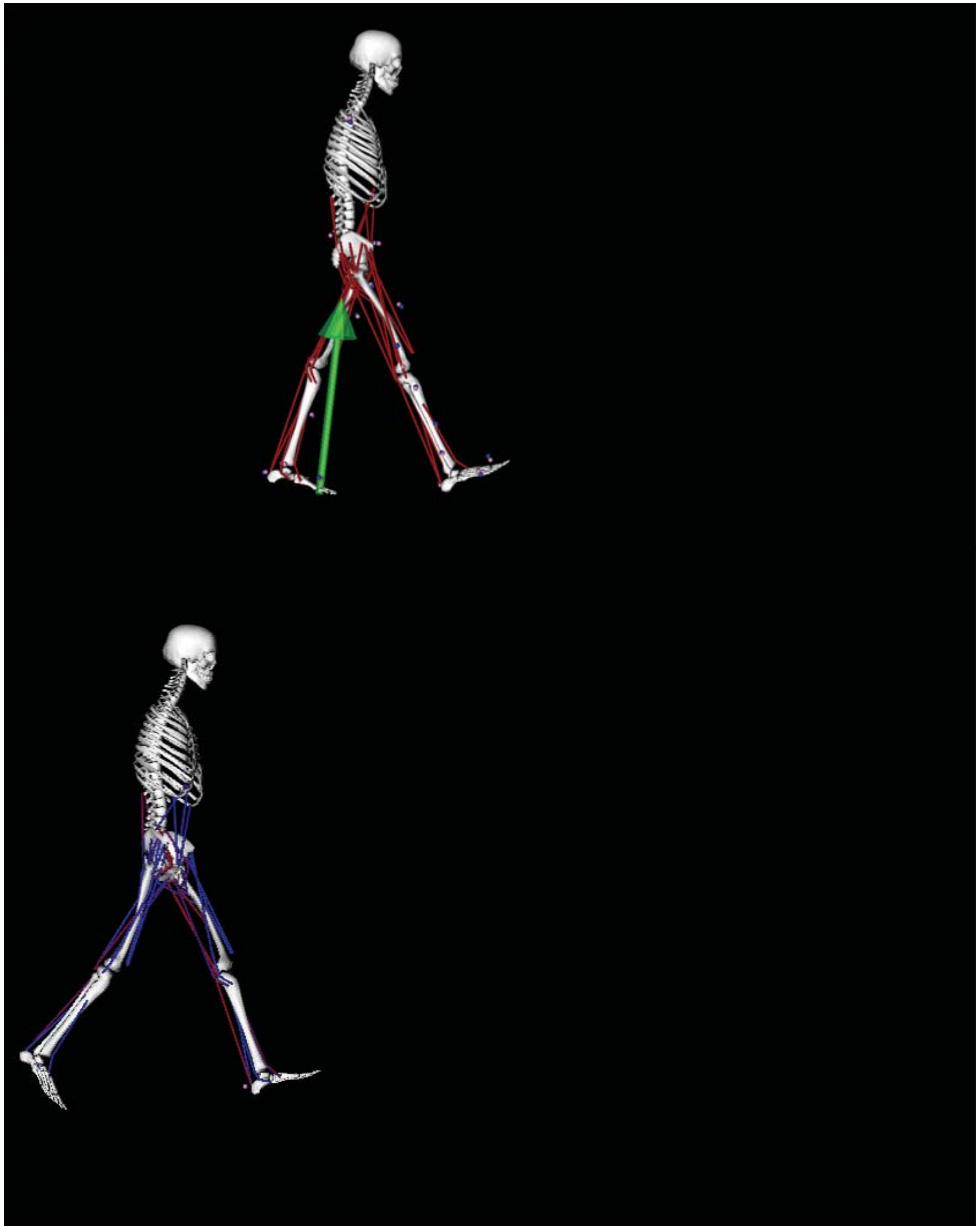
Subject-Specific Motion Analysis

Gait: Experiment and Simulation

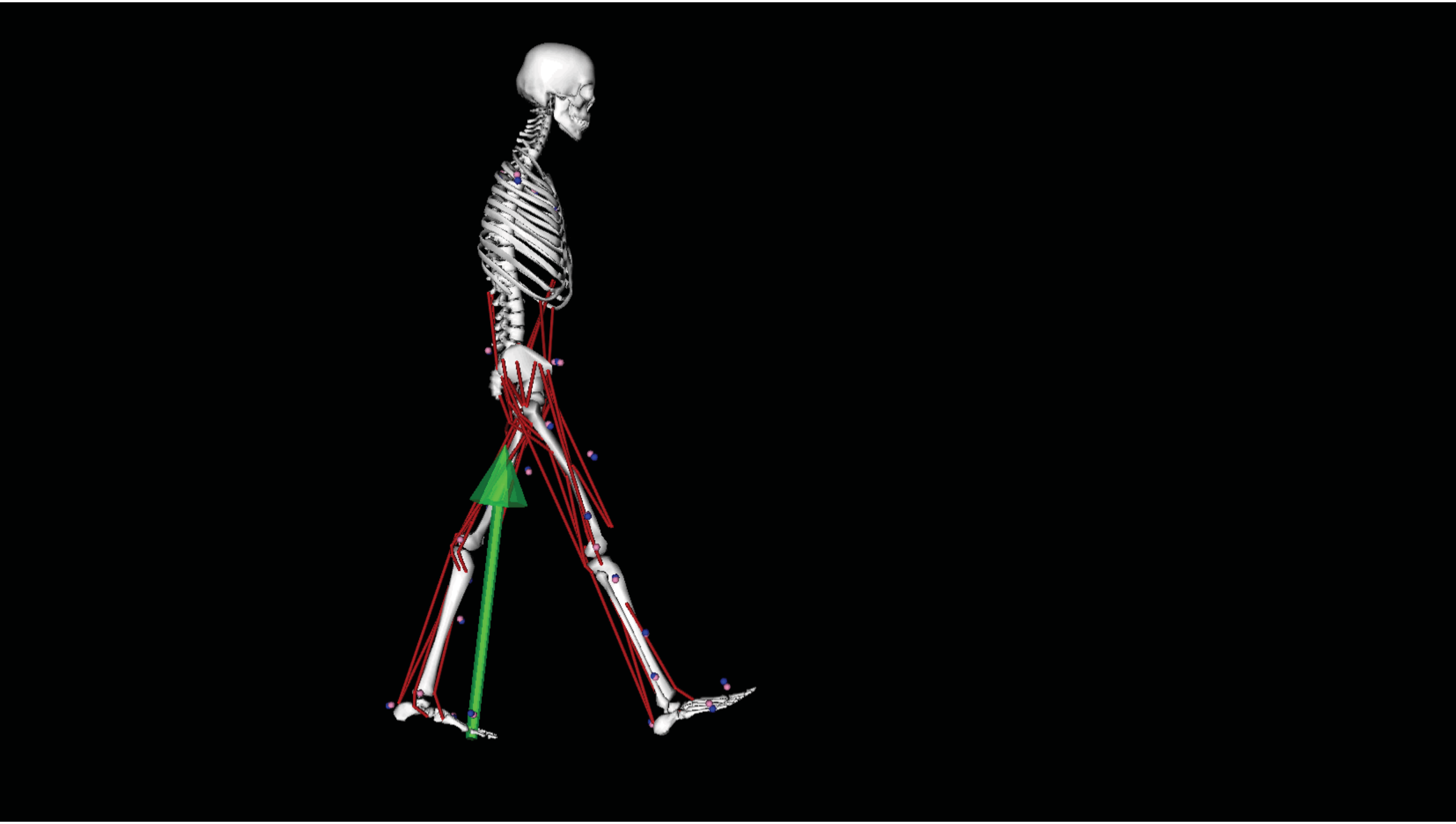
Healthy Male
Free Speed (1.75m/s)

- Motion Capture
- Force Plate
- Electromyography

23DOF actuated by
92 muscle-tendon units



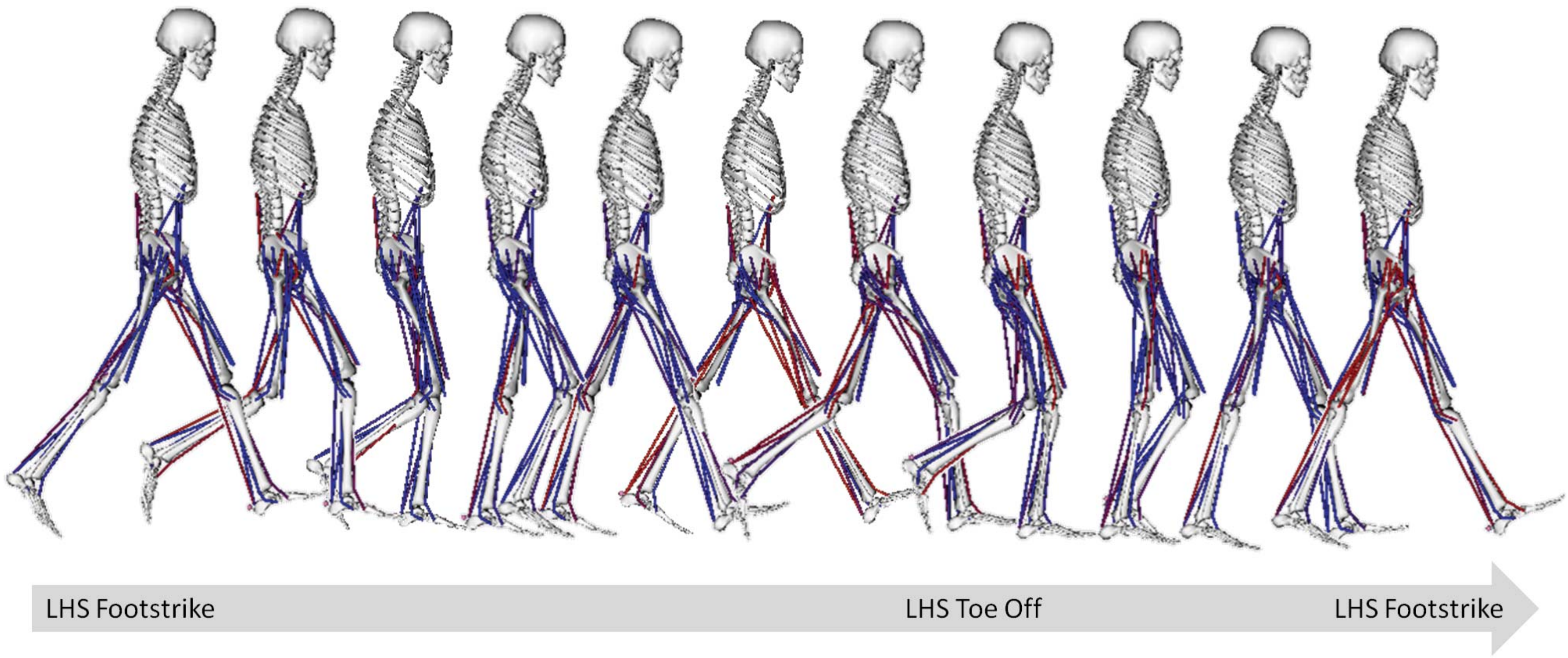
Gait: Experiment and Simulation



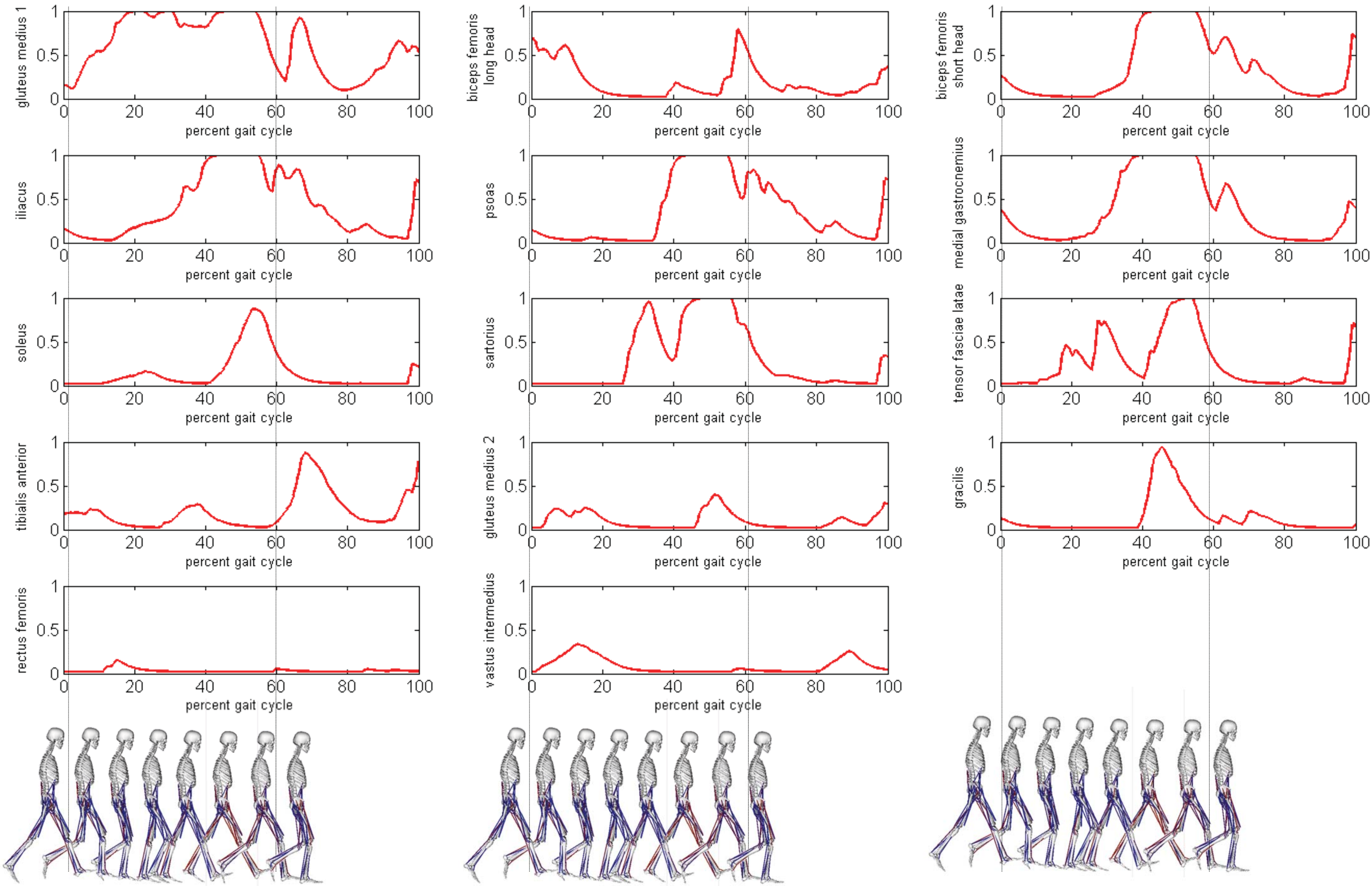
Gait: Experiment and Simulation

Experiment - Gait

- Contact forces were added in the dynamics
- Activation pattern scaled the muscle capacities
- Subject's dynamics was reflected at the center of mass

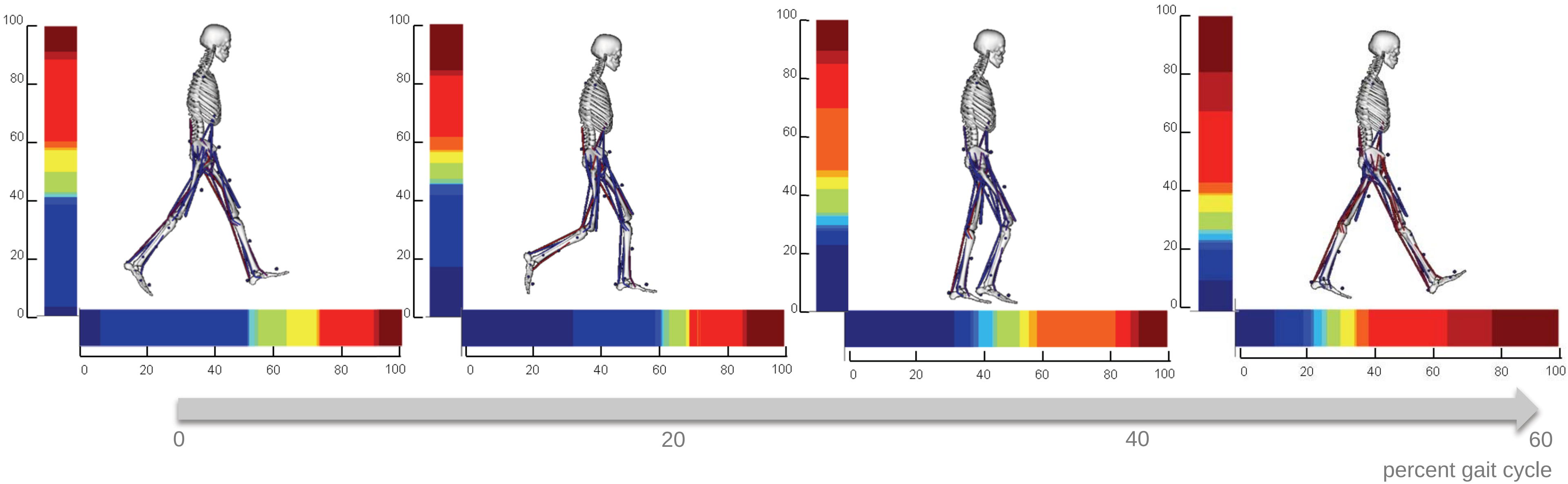


Muscle Activations during Normal Gait (1.75m/s)



Subject-Specific Gait Analysis

$$\ddot{x} = J(q)A(q)^{-1}(L^T m_{max} a - g(q) - J_{c_1}^T F_{ext_1} - J_{c_2}^T F_{ext_2})$$



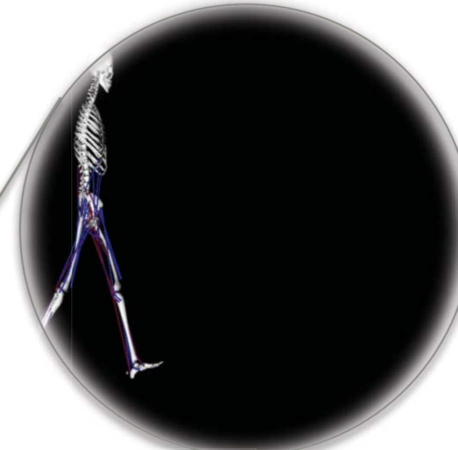
Results	Our findings	Liu et al. 2006	Neptune et al. 2004	Liu et al. 2008
Gluteus medius, vasti, hamstrings, gastrocnemius, soleus and dorsiflexors are important modulators of accelerations	✔	✔	✔	✔

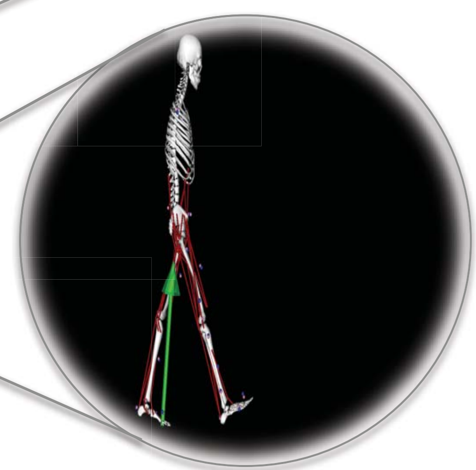
Demircan, E. and Khatib, O., “Constraint-Consistent Analysis of Muscle Force Contributions to Human Gait”, Advances in Robot Kinematics, Springer, 13th International Symposium, Innsbruck, Austria, June 2012

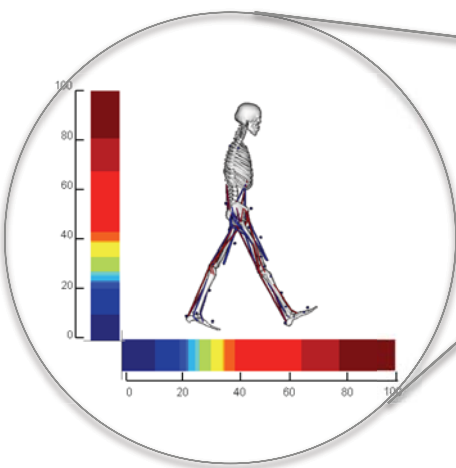
Subject-Specific Motion Analysis

Real-time Motion Dynamics, Task-based

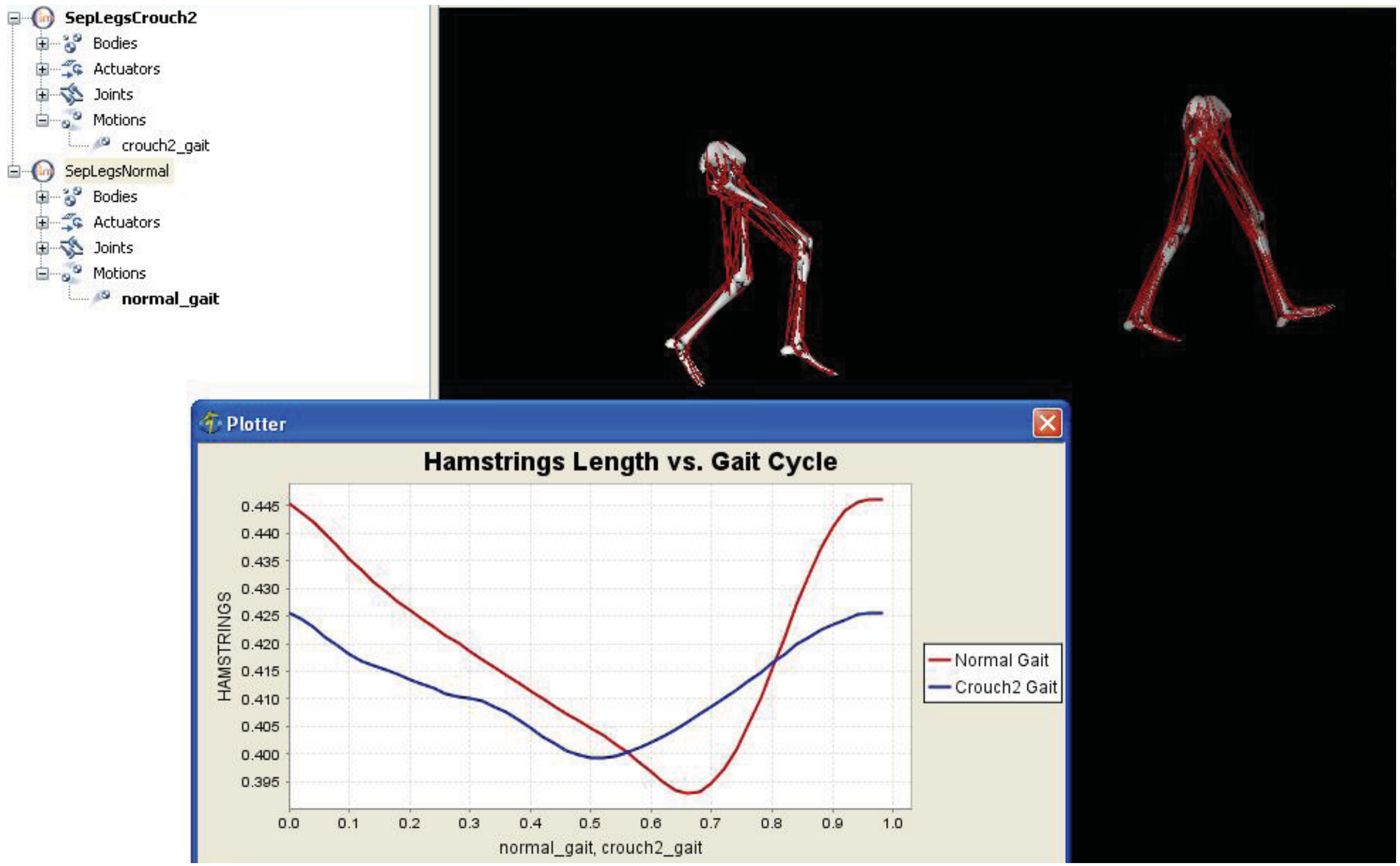
- **Decoupled control** of human motion, postural behaviors, contact and additional constraints
- **Real-time** motion dynamics
- Subject's dynamics at any **operational point**
- Real-time **feedback** (visual, haptic)





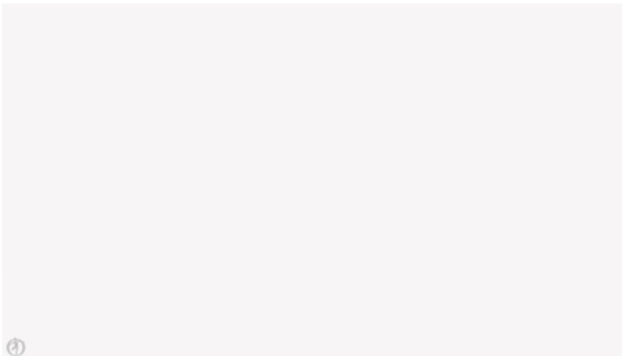


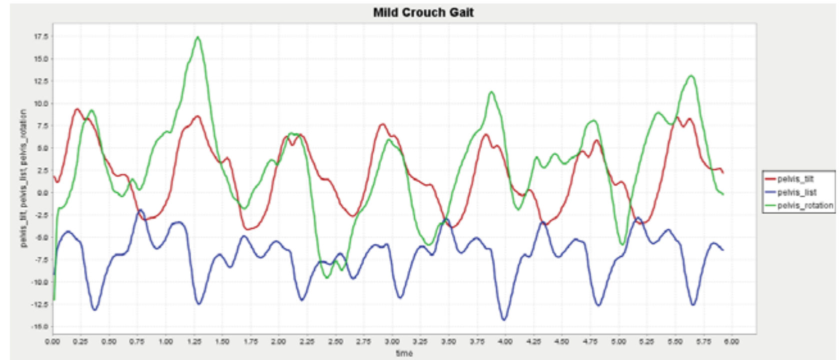
Musculoskeletal Disorders
Crouch vs. Normal Gait

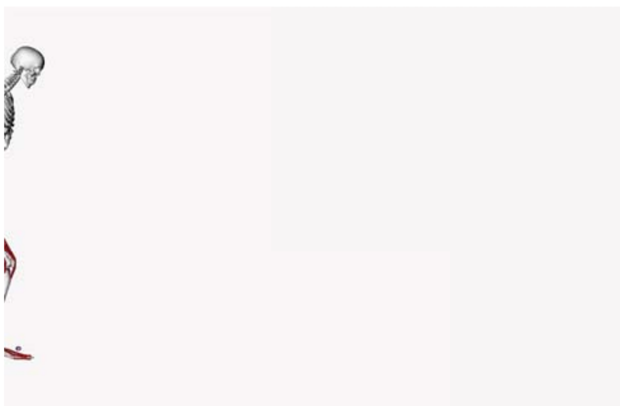


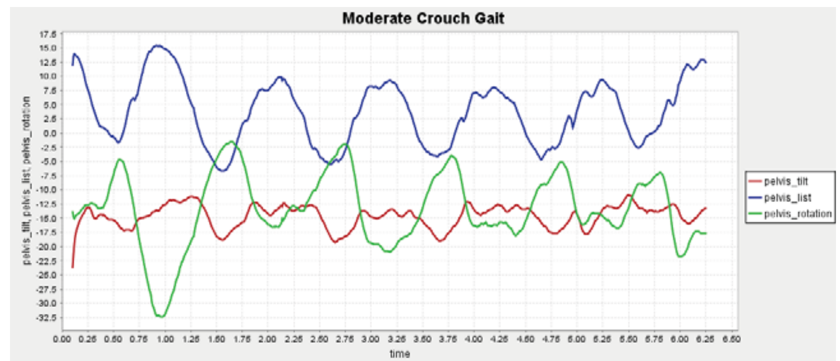
Professor Scott Delp – Department of Bioengineering
Professor Jessica Rose - Stanford Children Gait Hospital
Department of Orthopeadic Surgery, School of Medicine

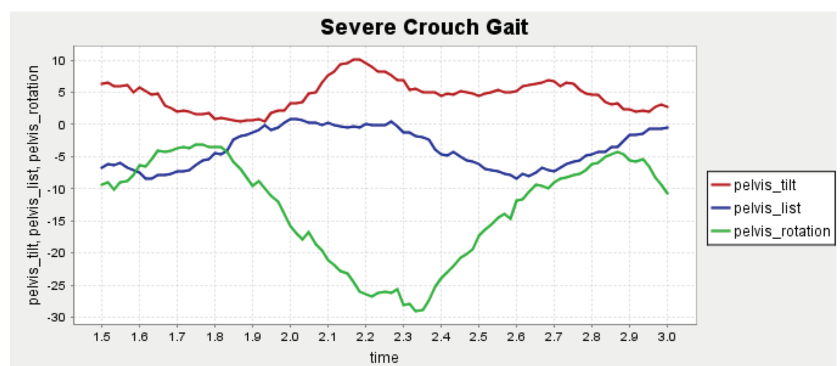
Reeducation of Musculoskeletal Disorders









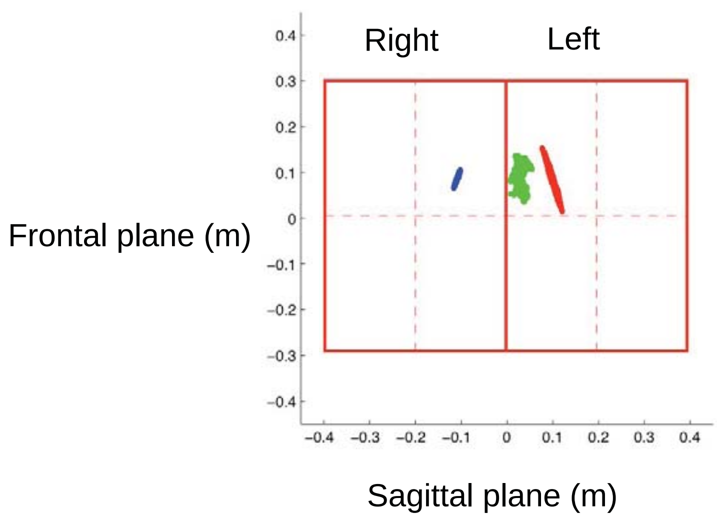


Reeducation of Stroke Patients

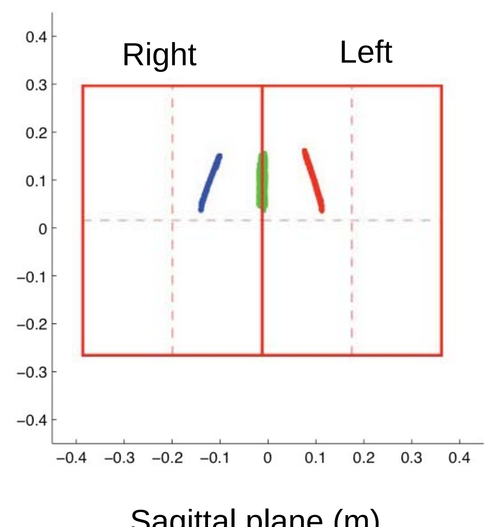
Universite de Montpellier II
LIRMM, France

COP

Post-Stroke subject

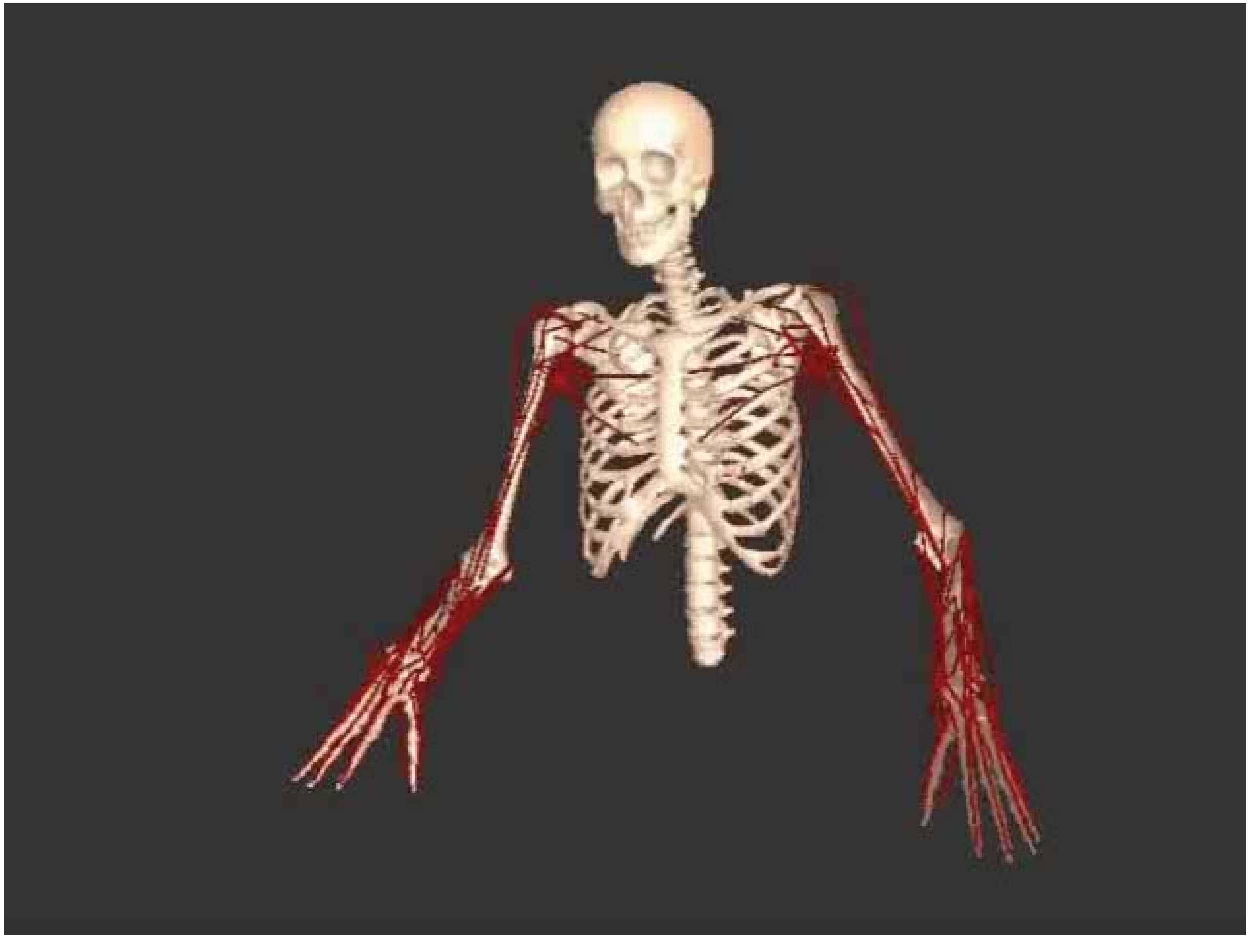


Healthy subject



Rehabilitation

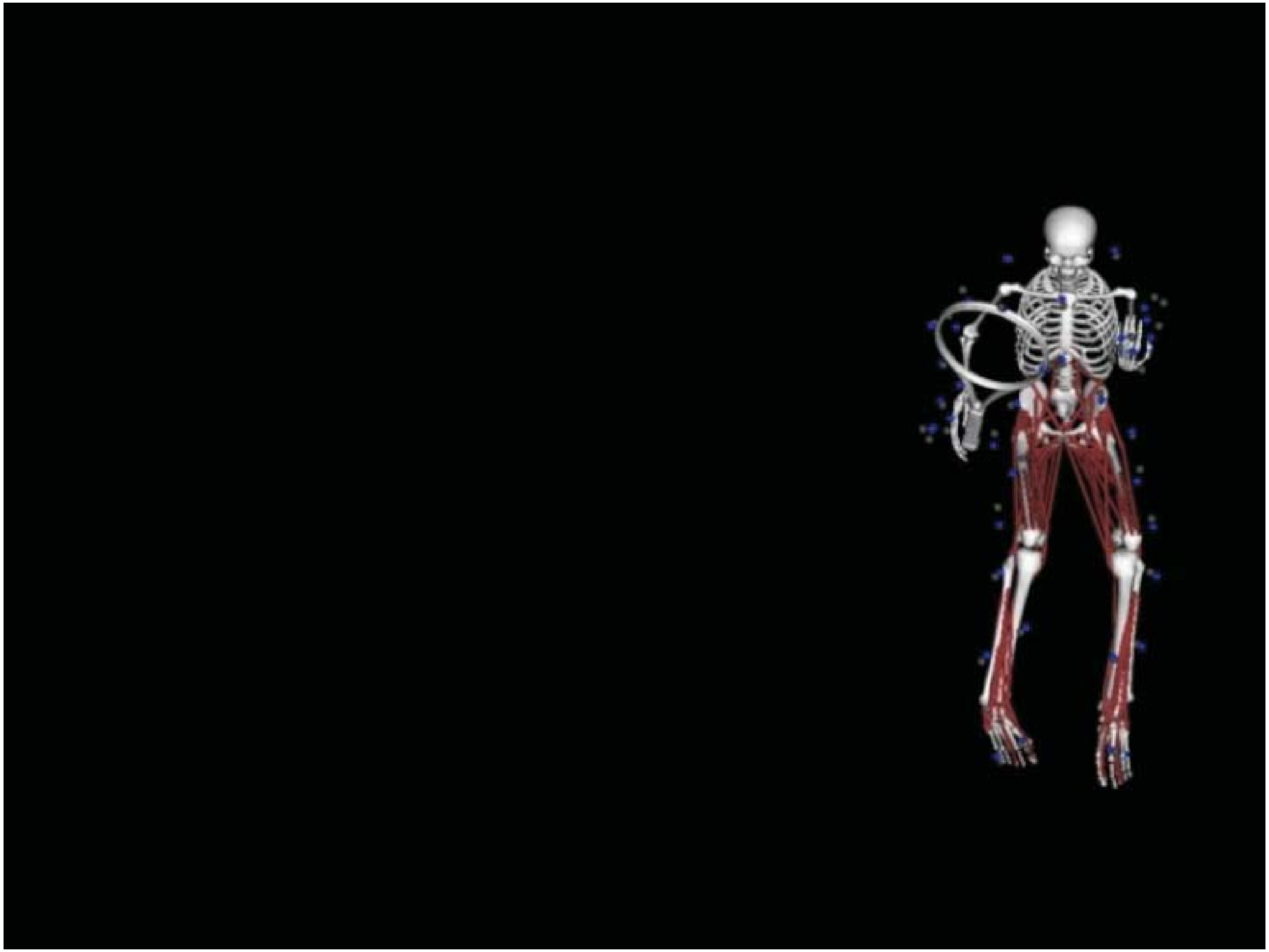
Reaching & Grasping



Stanford Children Gait Hospital
Department of Orthopeadic Surgery, School of Medicine

Athletics and Sports Medicine

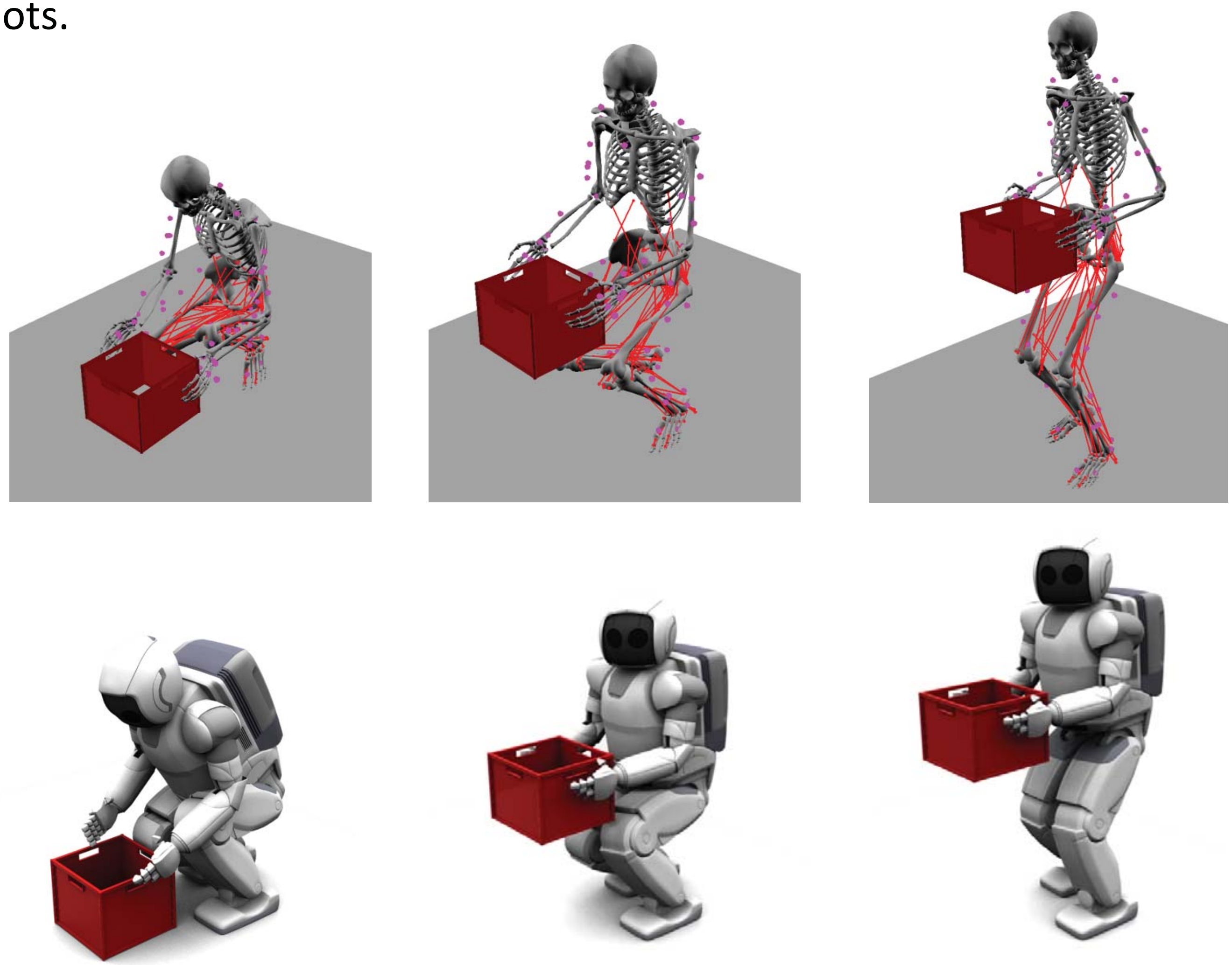
Injury Prevention in Sport



In a Collaboration with: Footwear Technological Institute, INESCOP, Mallorca

Understanding and Applying Human Motion to Robots

- To observe and understand how humans move. To apply similar strategies to robots.



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- How to Study Human Motion? - Multi-Disciplinary Research
- Components and Functions of the Musculoskeletal System
- Examples of Applications

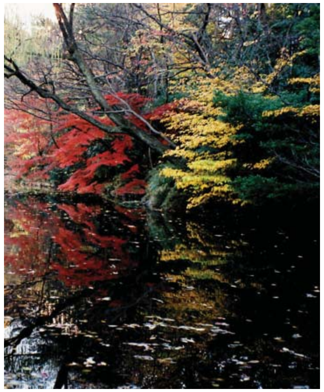
Next Week (4/25)

- Spatial Descriptions, Kinematics, Introduction to Biomechanical Simulation
  - **Please bring your laptop (windows)**
  - **Please download "OpenSim 3.2" with GUI from *simtk.org***

- Project teams & topics selection due (instructor office hour)

- Feel free to contact the instructor and the assistants for your questions

- Have a Nice Weekend!



Symposium on Biomechanics of Human Movement

Graduate Program for Social ICT Global Creative Leaders
JSPS Invitation Fellowship Program for Research in Japan (Short S)

April 19th, Saturday 9.15am-17.30pm
Yayoi Auditorium

http://www.ynl.t.u-tokyo.ac.jp/~emel/symposium/home.html