The webcast will start in a few minutes….

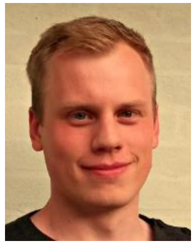
Simulating Man-Machine Symbiosis

IMPROVED DESIGN SOLUTIONS, FROM ERGONOMICS TO ASSISTIVE TECHNOLOGY

Outline

- Introduction by the Host
- Man-Machine simulations
  - Challenges and solutions
  - Live demo
- Final words from the host
- Questions and answers

Ananth Gopalakrishnan, PhD
AnyBody Technology
(Presenter)



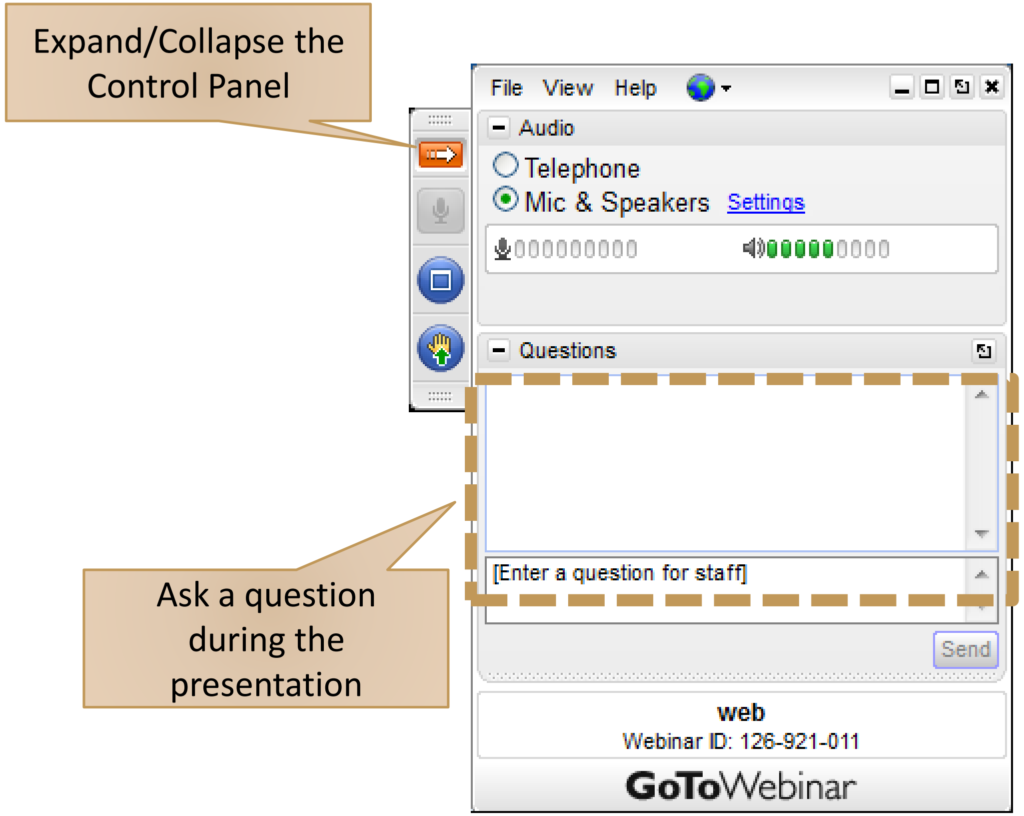
Kasper Pihl Rasmussen
(Host)

Control Panel

The Control Panel appears on the right side of your screen.

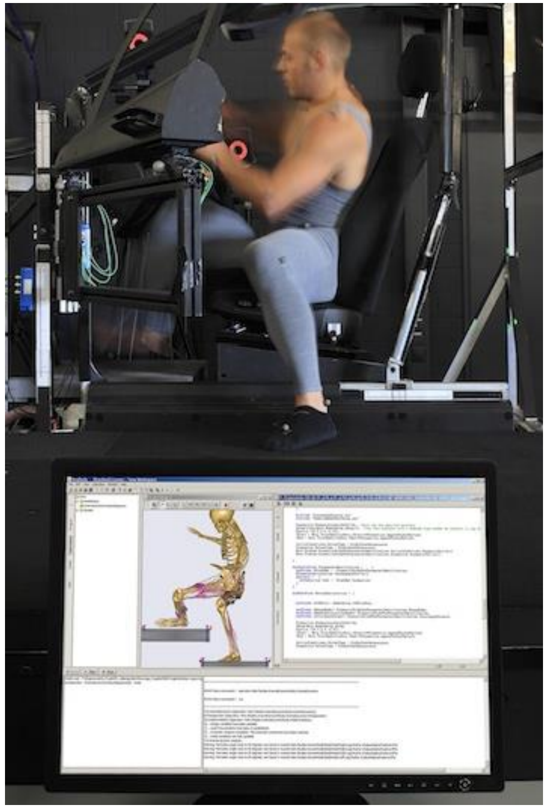
Submit questions and comments via the Questions panel.

Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.



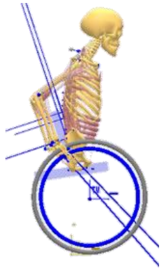
AnyBody Modeling System

- Musculoskeletal analysis
- AnyBody Managed Model Repository
- Wide range of simulation options
  - Motion capture
  - Ground reaction force prediction
  - Imaging → Patient-specific anatomy
  - Man-machine simulations



Rasmussen et. al. (2011), ORS Annual Meeting

ANYBODY TECHNOLOGY

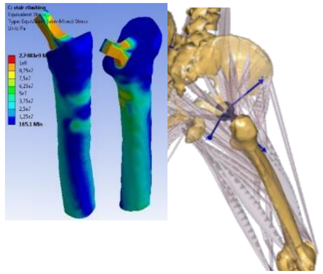


Product Design Optimization

Movement Analysis

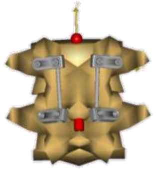
ANYBODY Modeling System

Ergonomic Analysis



Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation

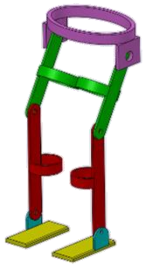


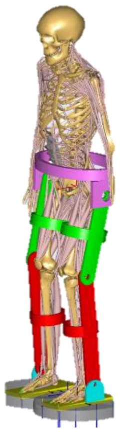
AnyBody Modelling System

Motion and Forces

Body model

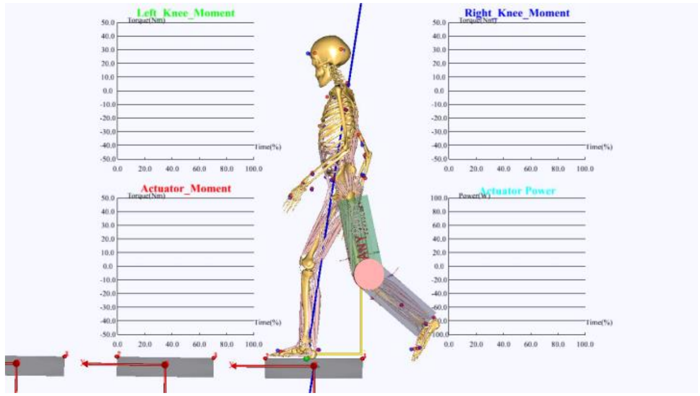
Environment model





Inverse dynamics
Muscle recruitment

Simulation



Internal body loads

- Muscle forces
- Joint forces

Design Optimization

Post Processing (e.g. FE tools)

Simulating Man-Machine Symbiosis

Ananth Gopalakrishnan

Application Engineer

AnyBody Technology

Outline

- Introducing Man-Machine systems
  - Why would we want to simulate them?
- Simulation theory
  - What are the conceptual challenges?
- Overcoming challenges
  - Tools/algorithms in AnyBody
- Solving a Man-Machine problem
  - Live Demo!

Man-Machine systems

- Newton’s second law:
  - Free movement requires human-environment interaction
- Environment
  - Including foreign objects mounted on human
  - E.g., Pavement, exoskeletons, car
  - Anything apart from biological human
- Let’s use the term ‘Machine’

www.wikipedia.org

Designing Machines

ReWalk Eksokeleton,
Argo Medical Technologies

How much external support?

www.commons.wikimedia.org

Design load for daily activities?

pixabay.com

Best design for performance?

What's Common? Effect of machine's design on human biomechanics

Man-Machine systems

- Machine's design also benefits from human biomechanics
  - Assistive power depends on baseline ability
  - Legs stronger in some phases of pedaling cycle
- 'Machine on human' & 'Human on machine'
  - A 'Symbiosis'
  - Best to study Man-Machine as a single system
- Mutual effects can be extremely unintuitive
  - Dynamic simulations of Man-Machine

ReWalk Eksokeleton, Argo Medical Technologies

pixabay.com

Why Man-Machine simulations?

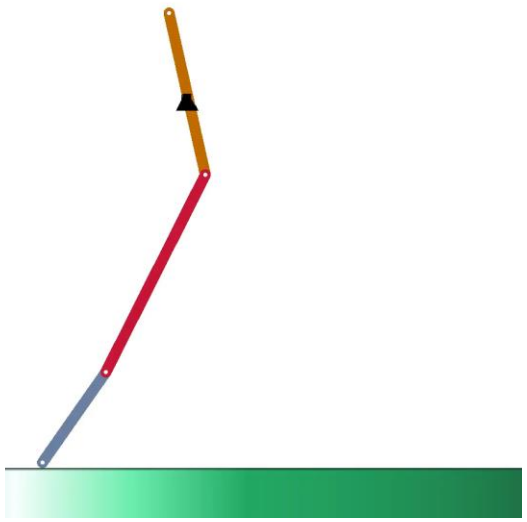
- Study machine's effect on human biomechanics
  - Kinematics, muscle and joint reaction forces
- Evaluate machine performance
  - Optimize design of machine
- Estimate Man-Machine interaction forces
  - E.g., rubbing friction due to orthosis straps
- Save Time and Costs
  - Fewer resources on experiments, prototypes
  - Quicker route to market

Man-Machine Simulations

Forward Dynamics

Inverse Dynamics

Standard Inverse Dynamics



Three link mechanism:

Open-chain

Revolute joints

Torque/Moment driven

Known

Measure Joint motion & External Forces

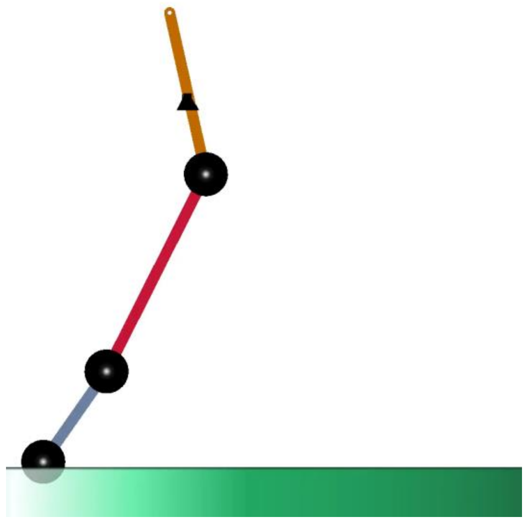
↓

Equations of motion

↓

Joint moments

Standard Inverse Dynamics



Three link mechanism:
Open-chain
Revolute joints
Torque/Moment driven

Measure Joint motion & External Forces

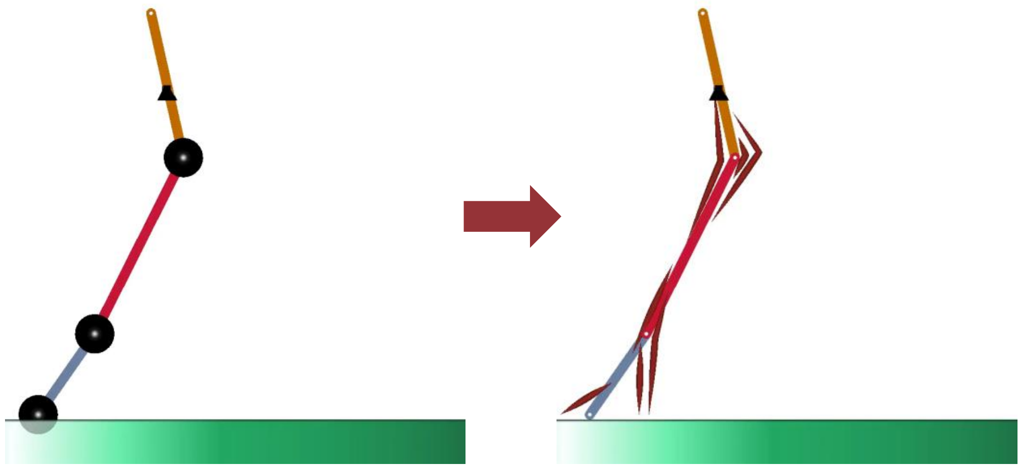
Equations of motion

Joint moments

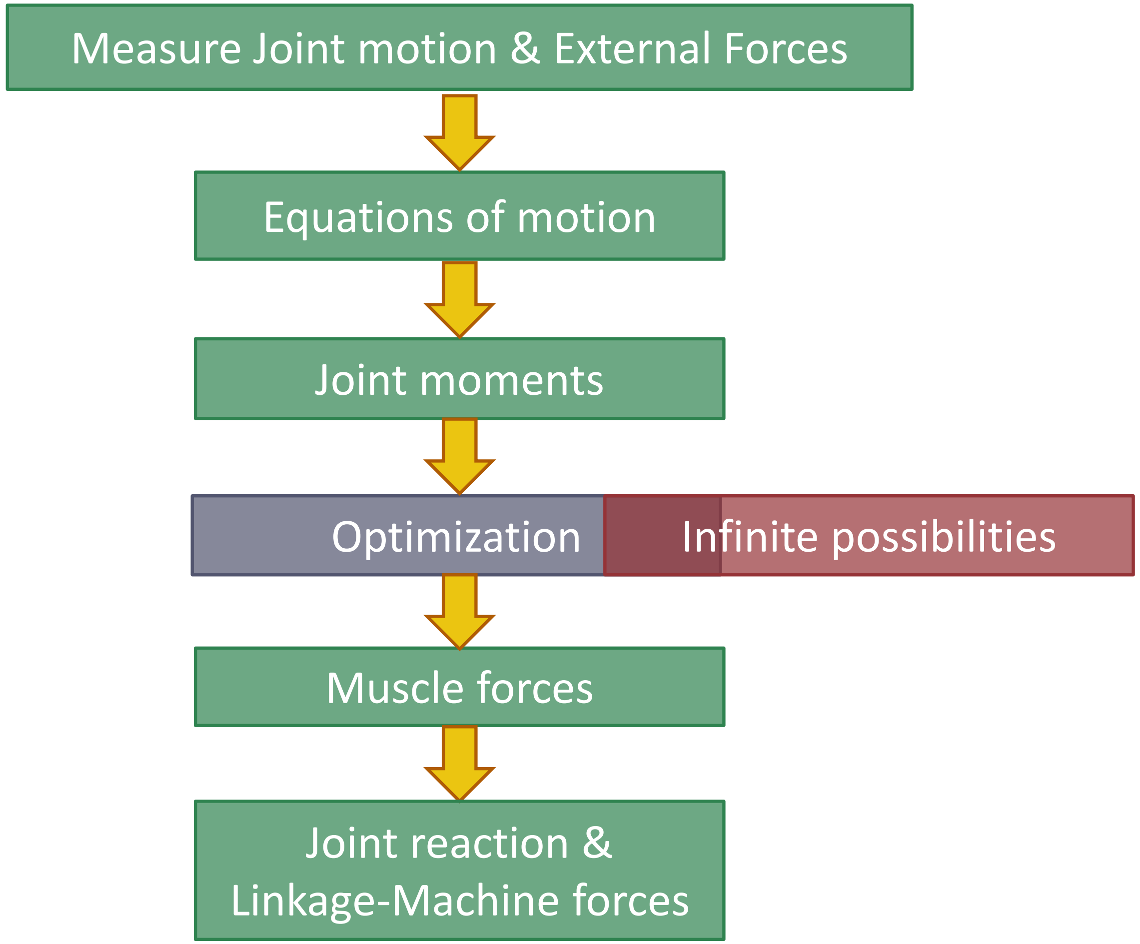
Joint reaction
&
Linkage-Machine forces

What if joint moment motors were replaced by muscles?

Standard Inverse Dynamics - Muscles



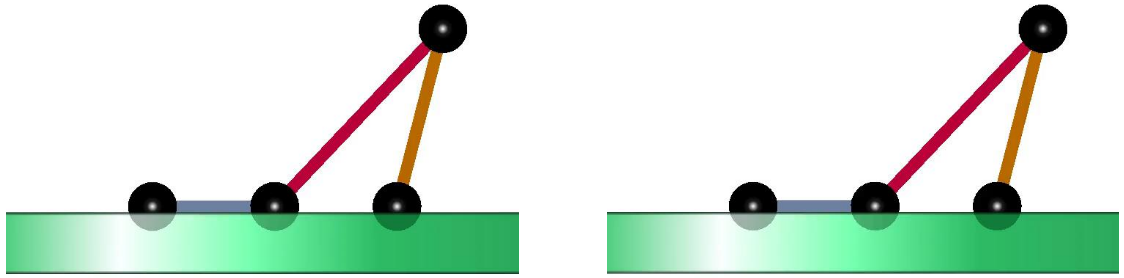
- **Decompose joint moments into muscle force values**
- **No. of muscles > No. of mechanical DOFs**
  - **Infinite combinations of feasible muscle forces**
- **Choose optimal muscle recruitment**
  - **Cost function E.g., $F = min(\sum_i a_i^3)$**



Standard Inverse Dynamics

- Open-chain Musculoskeletal models:
  - Limbs → Rigid links
  - Mechanical joints
  - Piecewise Linear muscle paths

Standard Inv. Dynamics - Closed Loops



Create a closed chain
Three link → Four link mechanism
3 DOFs → 1 DOF

Measure Joint motion & External Forces

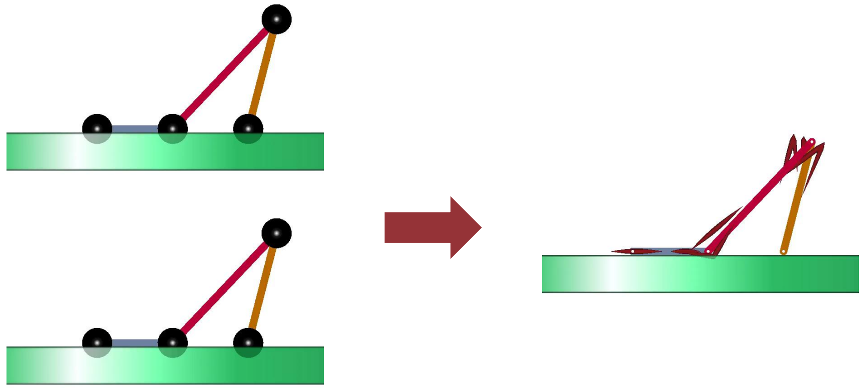
↓

Equations of motion

Infinite possibilities

Joint moments

Standard Inv. Dynamics - Closed Loops



Measure Joint motion & External Forces

Equations of motion

Infinite possibilities

Joint moments

Infinite possibilities

Muscle forces ???

Joint reaction forces???

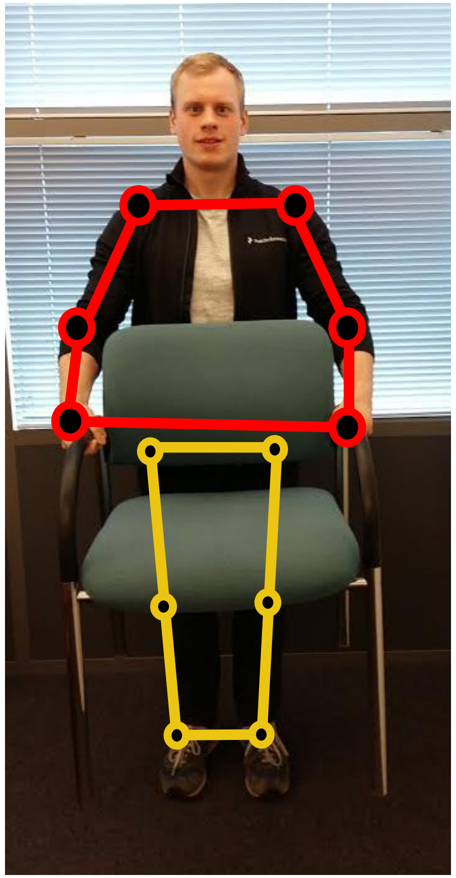
Linkage-Machine forces???

Two levels of optimization:
Extremely slow simulations

Standard Inv. Dynamics - Closed Loops

WHY ARE CLOSED LOOPS RELEVANT?

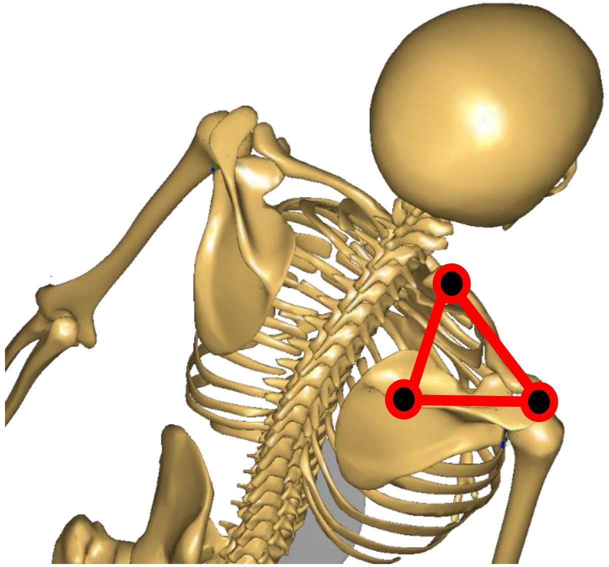
Man-Machine Closed Loops

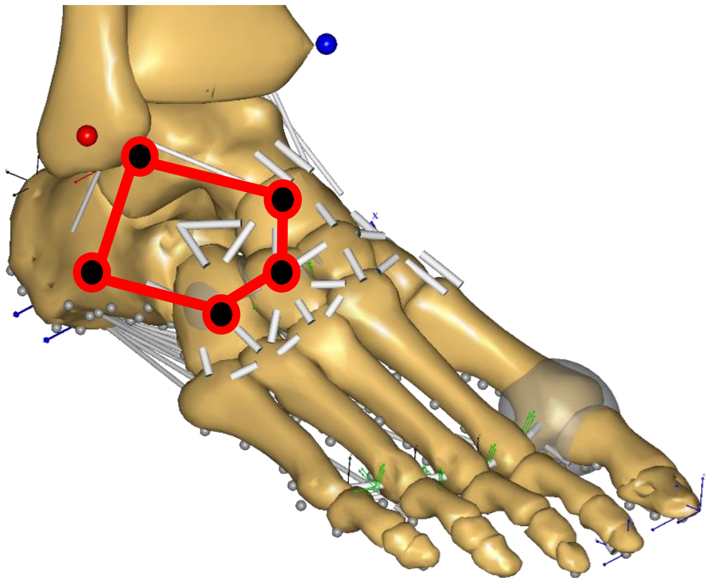


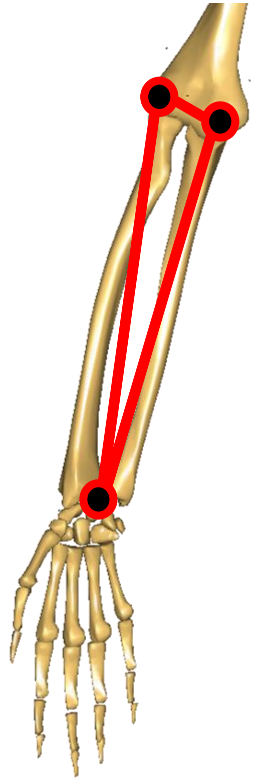
Man-Machine Closed Loops

- Measure kinematics of pose
- There are Infinite possibilities
  - Joint moments
  - Muscle forces
  - Man-Machine forces

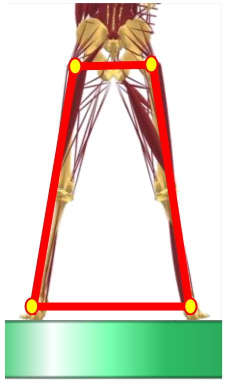
Closed Loops Within Man

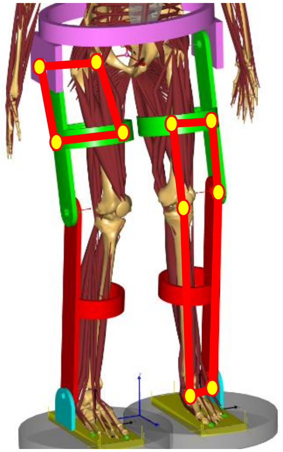


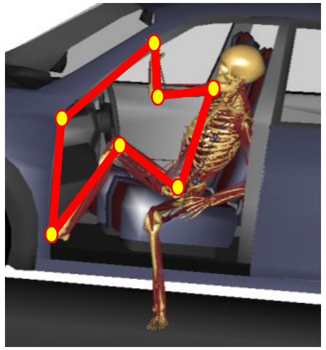


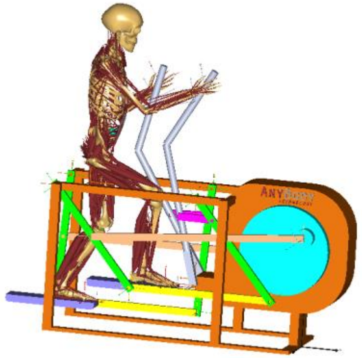


Man-Machine Inv Dynamics: Challenges





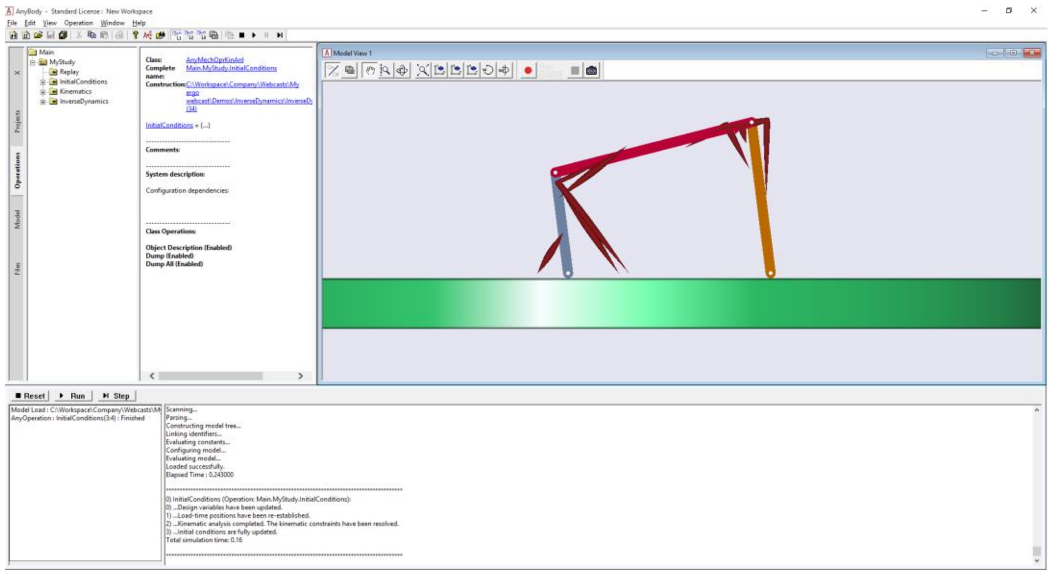




- Standard Inverse Dynamics
  - Fails with closed-loop kinematic chains
  - Cannot compute forces
- Creating Man-Machine models
  - Creating closed loops, challenge in itself
- Control of Man-Machine interaction forces
  - E.g.., Pinch holding an egg vs metal ball
  - Standard Inv Dyn cannot modulate pinch force on egg

The Man-Machine in AnyBody

How does AnyBody overcome the challenges?

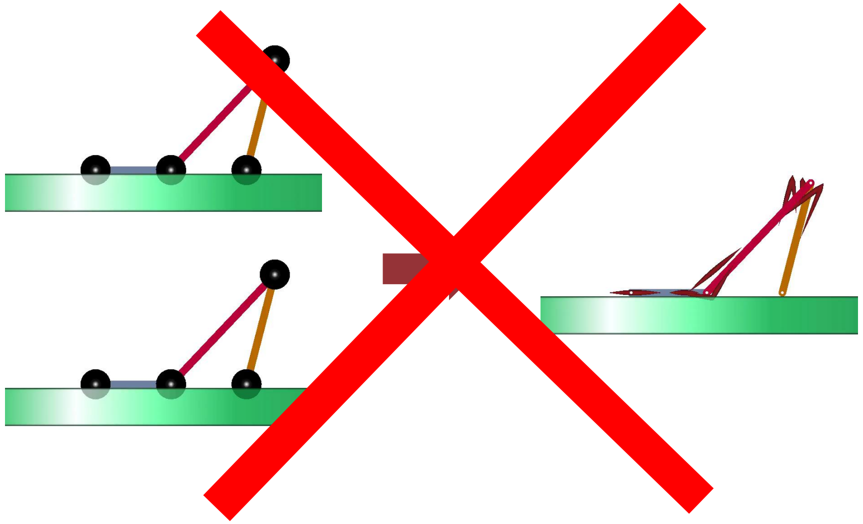


The Man-Machine in AnyBody

How Can Closed Loop Inverse Dynamics Succeed?

DIRECT MUSCLE RECRUITMENT

Standard Inverse Dynamics



Measure Joint motion & External Forces

Equations of motion

Infinite possibilities

Joint moments

Infinite possibilities

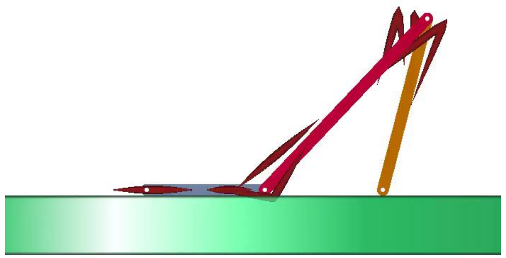
Muscle forces ???

Joint reaction forces???

Linkage-Machine forces ???

Direct Muscle Recruitment

- Directly compute forces producing measured motion
- No intermediate joint moments !!
- Direct Muscle Recruitment



Measure Joint motion & External Forces

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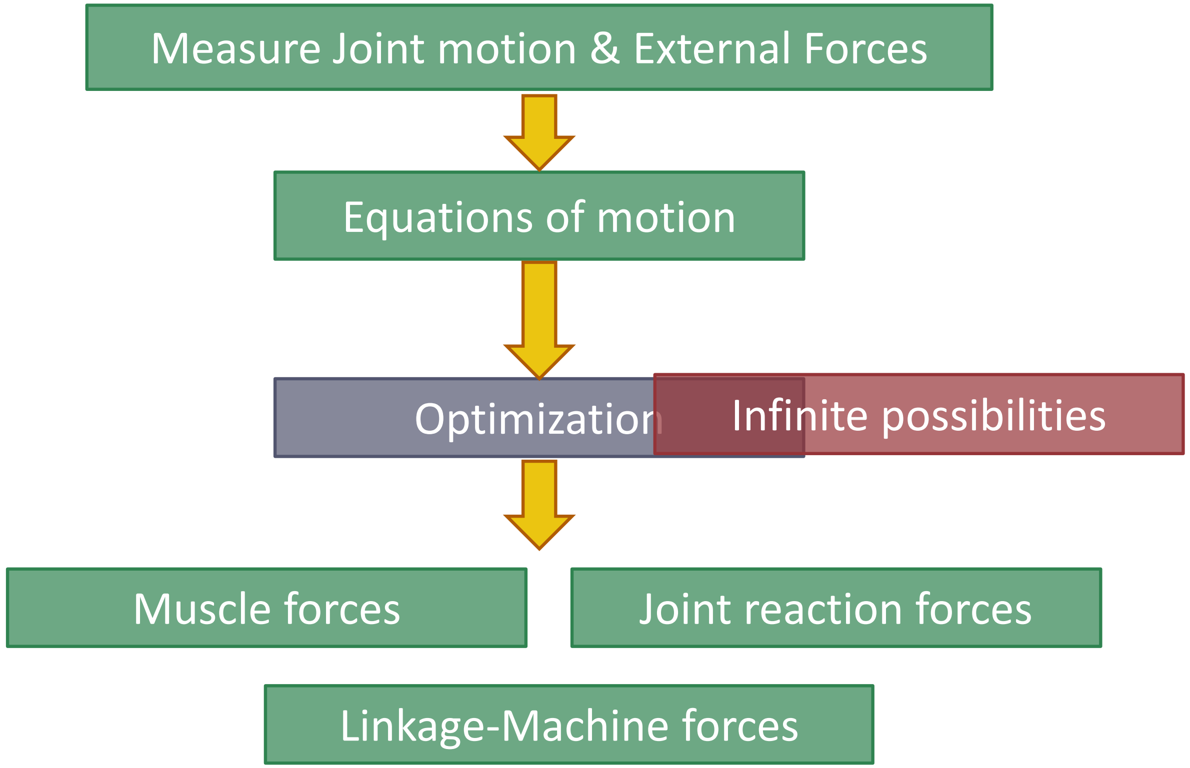
Joint reaction forces???

Linkage-Machine forces ???

Direct Muscle Recruitment

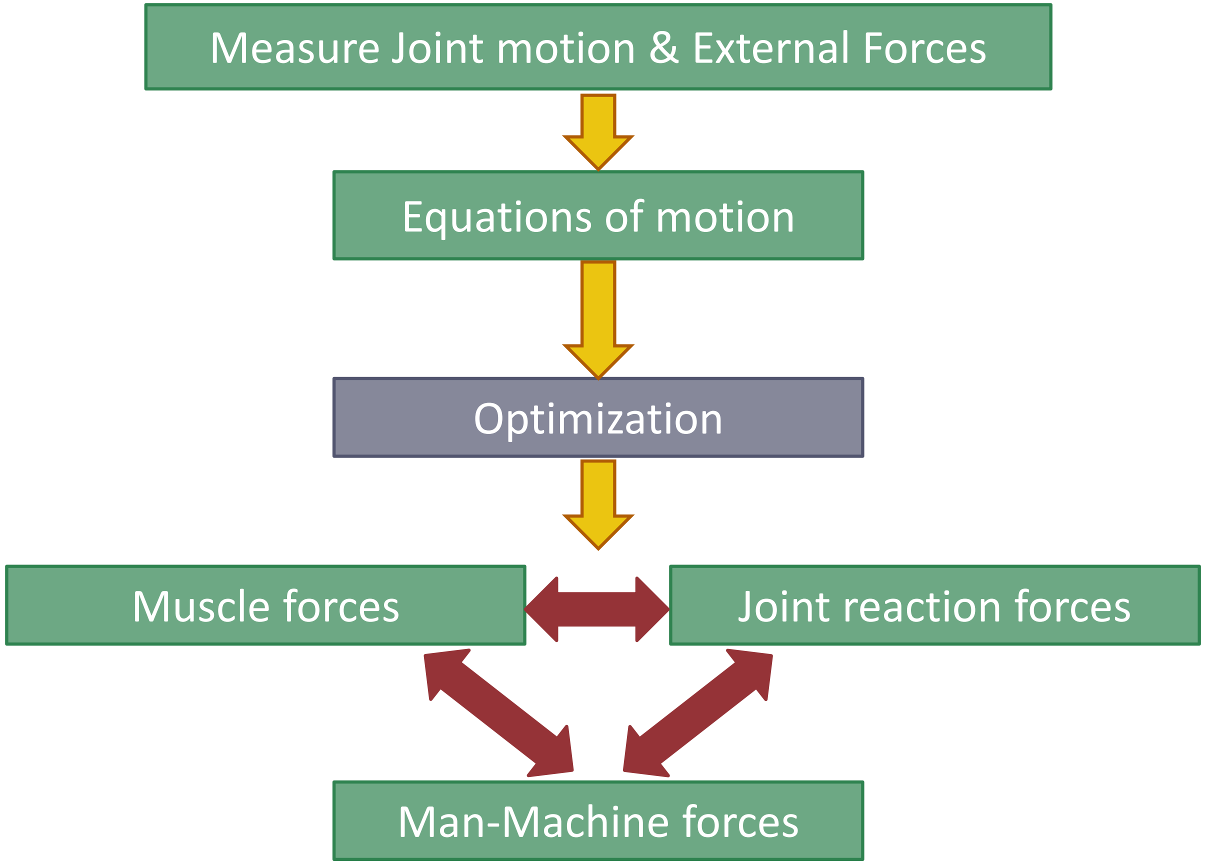
- Need to resolve infinite possibilites

- Optimization
  - Motion produced by most optimal muscle recruitment



Direct Muscle Recruitment

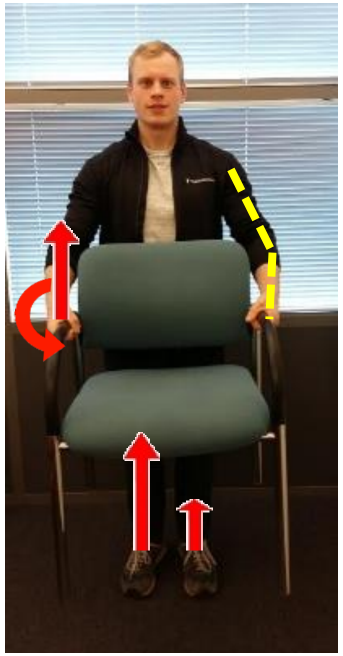
- Need to resolve infinite possibilites
- Optimization
  - Motion produced by most optimal muscle recruitment
  - All forces computed simultaneously
  - Exploit Man-Machine Boundary Conditions



Direct Muscle Recruitment

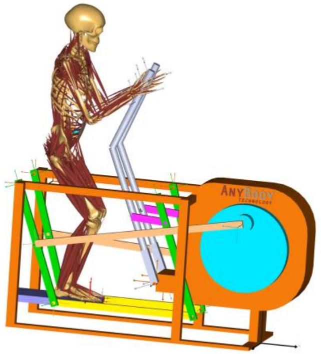
- Example
- Optimization

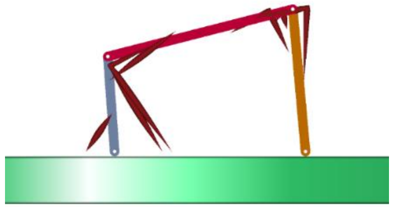
$$Cost\ Fun = min(\sum_i a_i{}^3)$$

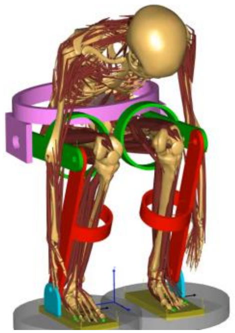


Direct Muscle Recruitment

- AnyBody’s default Inverse Dynamics algorithm
  - Solves open and closed loops







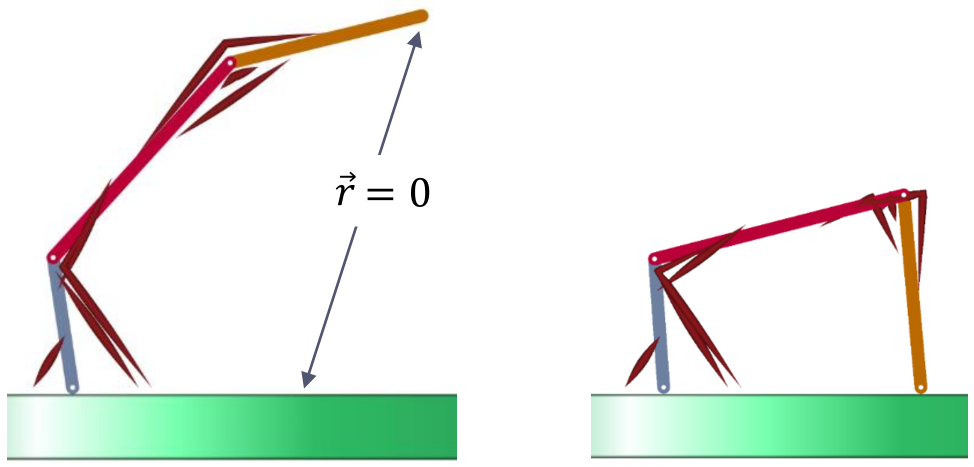
The Man-Machine in AnyBody

How Can Complex Closed loops be created ?

MEASURES AND DRIVERS

Connecting Man & Machine

- Creating closed loops
  - Step 1: Measure $\vec{r}$ — Kinematic Measures
  - Step 2: Constrain $r_x, r_y = 0$ — Drivers

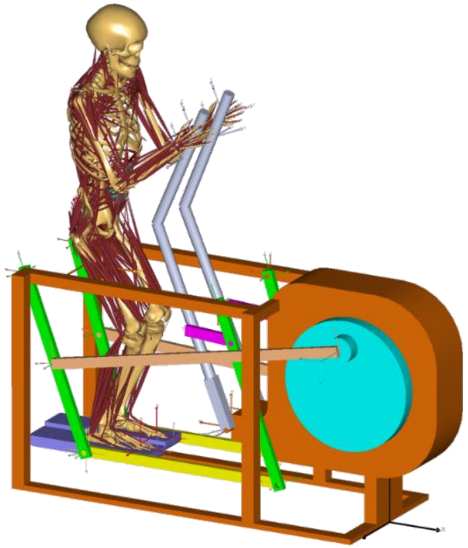


Connecting Man & Machine

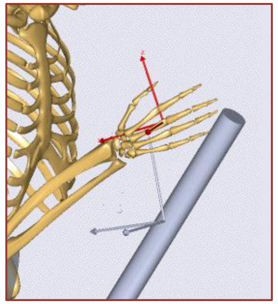
- Creating closed loops
  - Step 1: Measure $\vec{r}$
  - Step 2: Constrain $r_x, r_y = 0$

- Kinematic Measures
  - Point-point translation
  - Seg-seg rotation
  - CoM position
  - Abstract measures

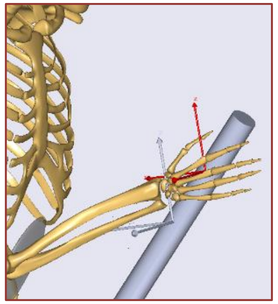
- Drivers
  - Joints
  - Const pos/vel/acc
  - Fourier/polynomial functions
  - Data interpolation



Before



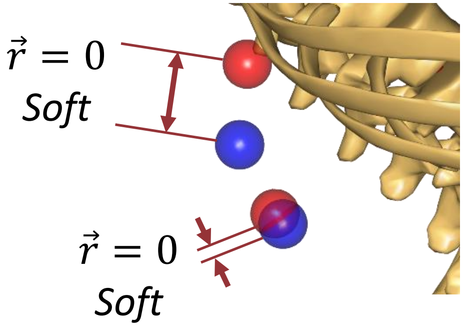
After



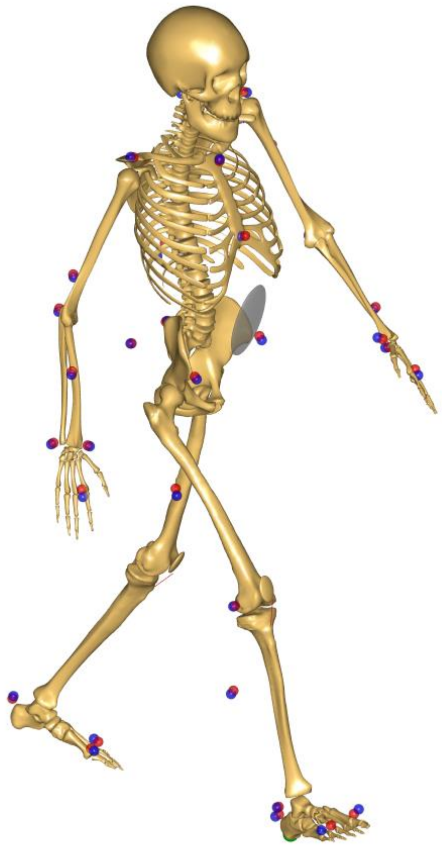
Connecting Man & Machine

- Hard and Soft Drivers
  - Hard drivers’ constraints always fulfilled
  - Soft constraints only to best extent possible

- E.g., MoCap model

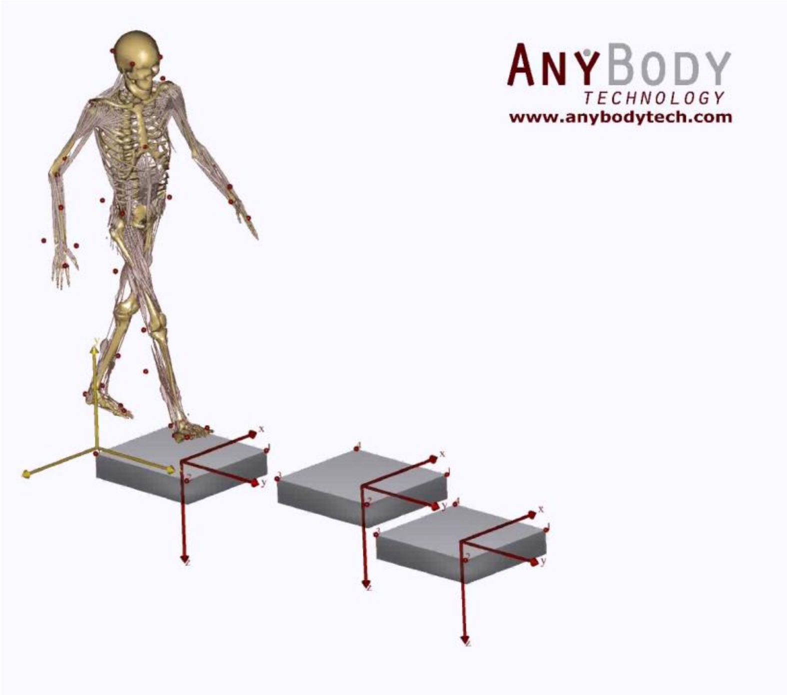


Kinematics Simulation:
- Compute joint angles
- Minimizes soft constraints



Connecting Man & Machine

- Drivers: Hard or soft
  - Hard drivers' constraints always fulfilled
  - Soft constraints only to best extent possible
- E.g., MoCap model

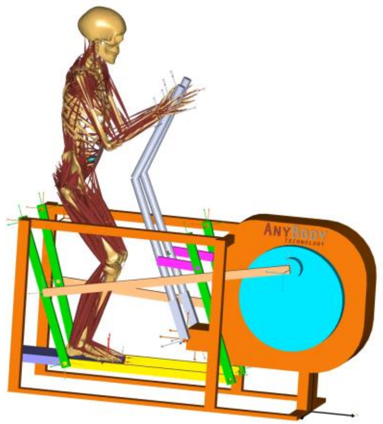


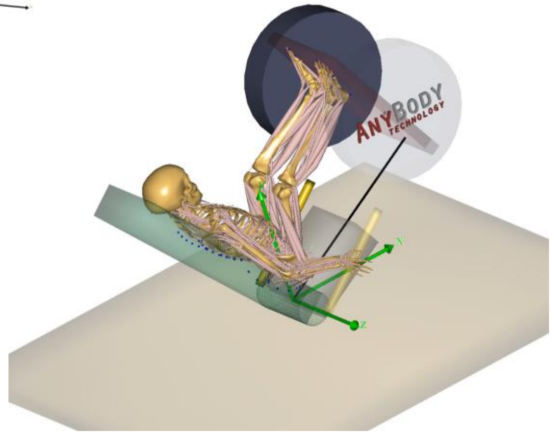
Connecting Man & Machine

- Drivers: Hard or soft
  - Hard drivers' constraints always fulfilled
  - Soft constraints only to best extent possible

- E.g., MoCap model

- **Machine Driven Motion**
  - Complex motions without MoCap!
  - No need to measure human motion





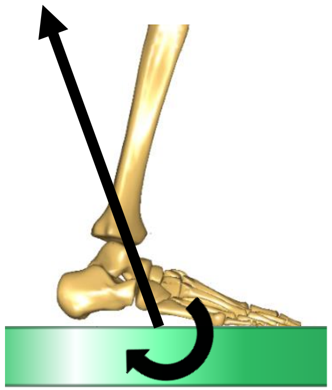
The Man-Machine in AnyBody

How Can Man-Machine Reaction forces be controlled?

SPECIAL FORCE ELEMENTS

Man-Machine Reaction Forces

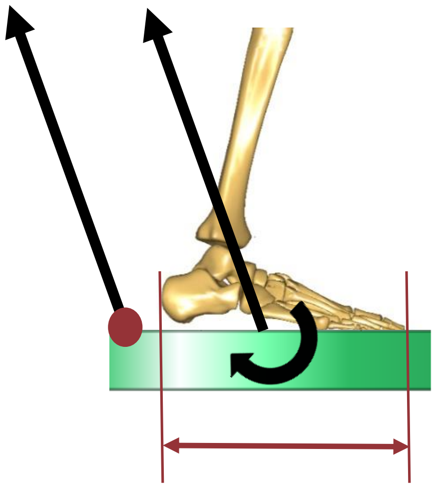
- Simulating double support stance
  - Create closed loop
  - Rigidly weld foot to ground
  - 6DOF - 6 Measures and drivers



- Direct Muscle Recruitment
  - Cost function
  - No control over Man-Machine reactions!

Man-Machine Reaction Forces

- Simulating double support stance
  - Create closed loop
  - Rigidly weld foot to ground
  - 6DOF - 6 Measures and drivers
- Direct Muscle Recruitment
  - Cost function
  - No control over Man-Machine reactions!
  - CoP must like inside foot



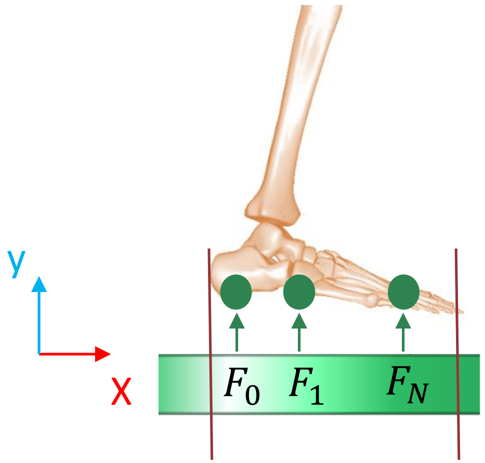
Solution:

- Decouple constraint’s kinematics from kinetics
- Switch off driver’s default reaction forces
- Enforce constraint with Special Force Elements

Special Contact Elements

- Double support stance
  - Ground - Foot constraints
  - Introduce any number of force elements
  - Each element has an optimal force

- Inv Dynamics, Direct muscle recruitment



$$Cost\ Fun = \sum_i {a_i}^3 + \sum_j \left(\frac{F_j}{F_j^{opt}}\right)^3$$

Special Contact Elements

- Double support stance
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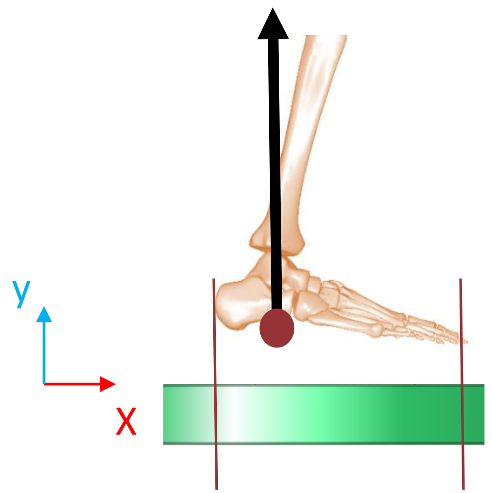

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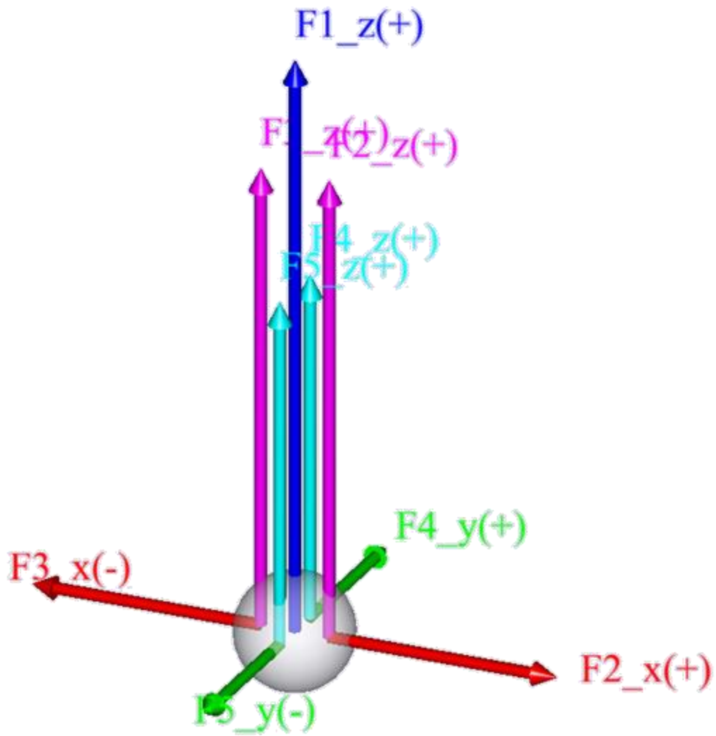
Ground Reaction Force Prediction

- Ground reaction force components
  - Normal
  - Friction

- Possible to couple Normal and friction special force elements
  - Friction ≤ (μ × Normal)

- GRF prediction model



Ground Reaction Force Prediction

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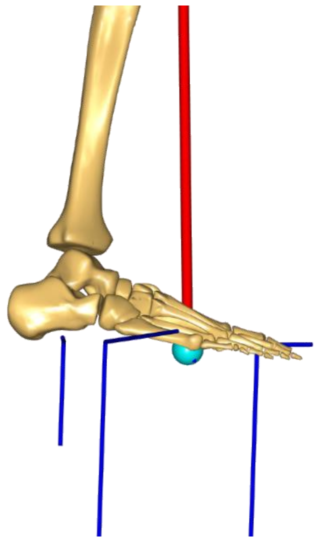
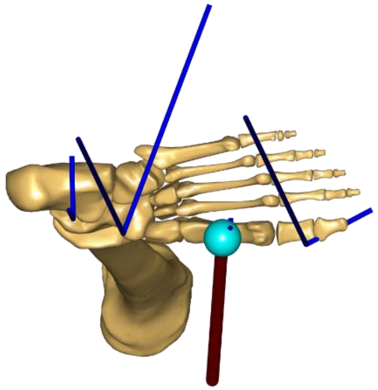
- Webcast by Dr. Michael Skipper Andersen from 6th Oct 2015





The Man-Machine in AnyBody

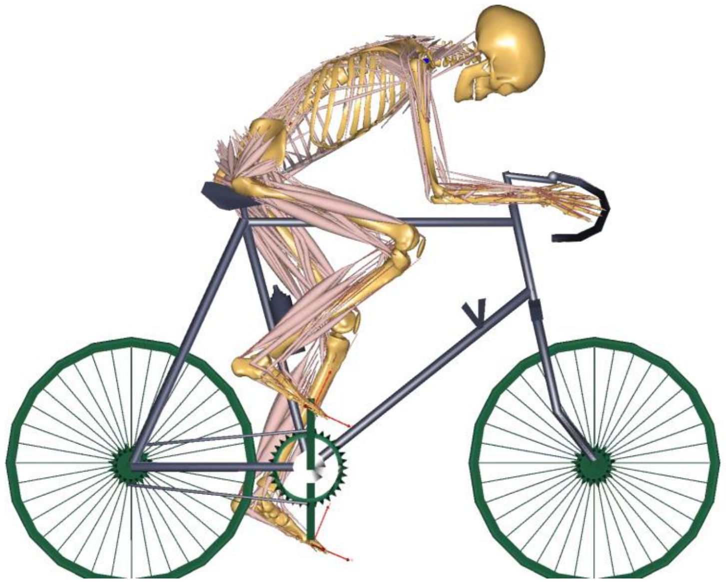
How Can Machine's design be optimized?

OPTIMIZATION STUDIES

Machine Design and Optimization

- What is the best design for a cycle?
  - Best for minimizing quadriceps activation.

- Formulate as optimization
  - Cost function - minimize quad activation
  - Parametrize design of cycle
  - Parameters are optimization unknowns



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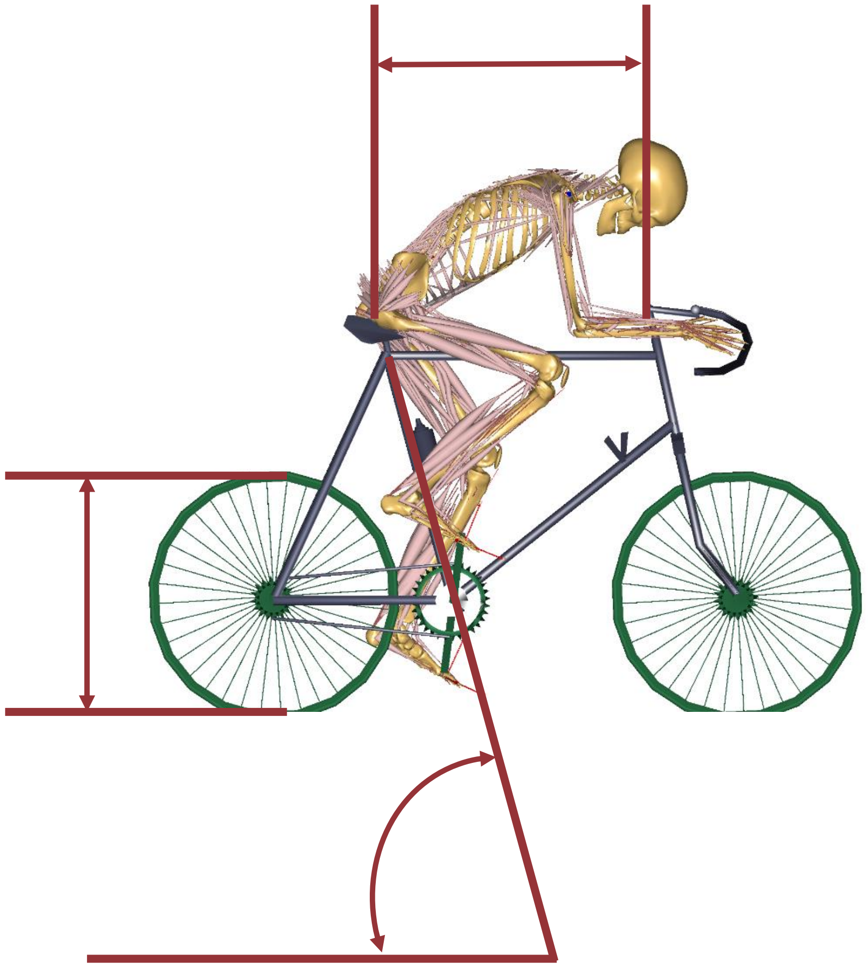
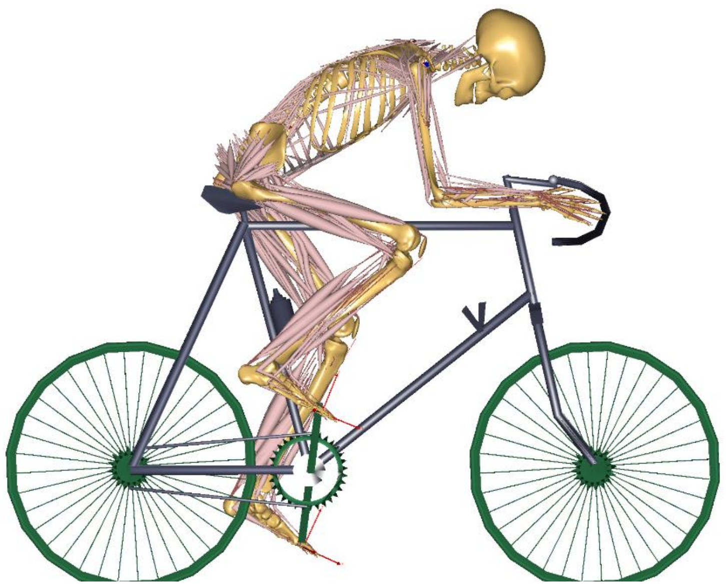


Machine Design and Optimization

- What is the best design for a cycle?
  - Best for minimizing quadriceps activation.

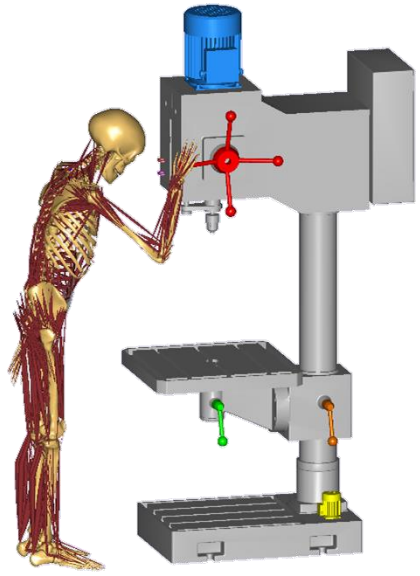
- Formulate as optimization
  - Cost function - minimize quad activation
  - Parametrize design of cycle
  - Parameters are optimization unknowns

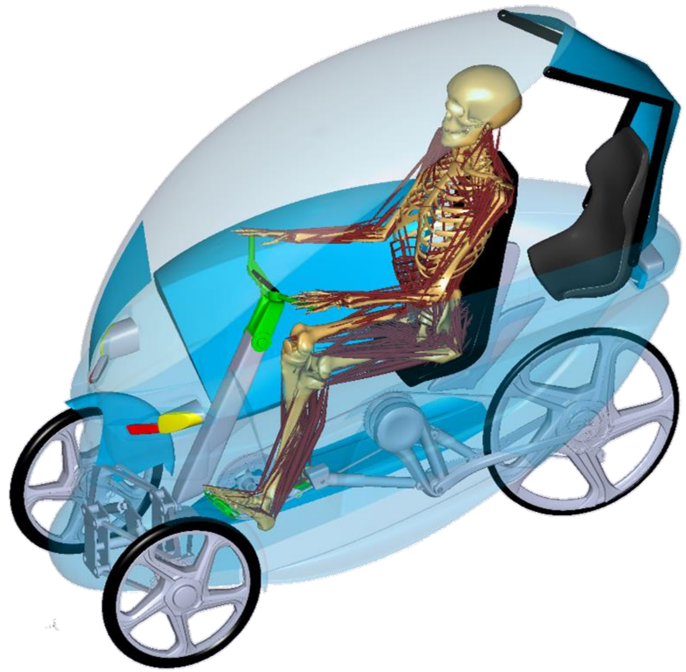
- Run optimization studies within AnyBody



Machine Design and Optimization

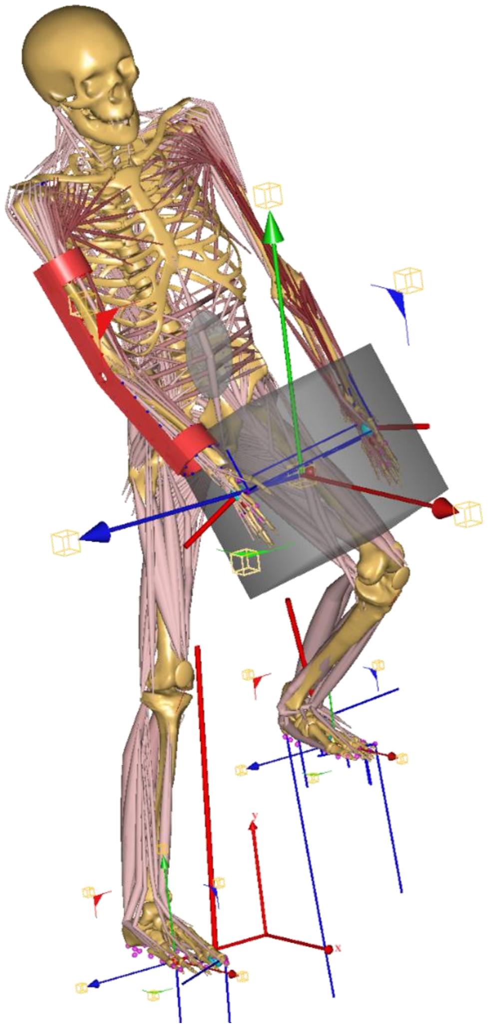
- Solidworks2AnyBody plugin
  - Import your machine's design from SolidWorks
  - Run Man-Machine simulations





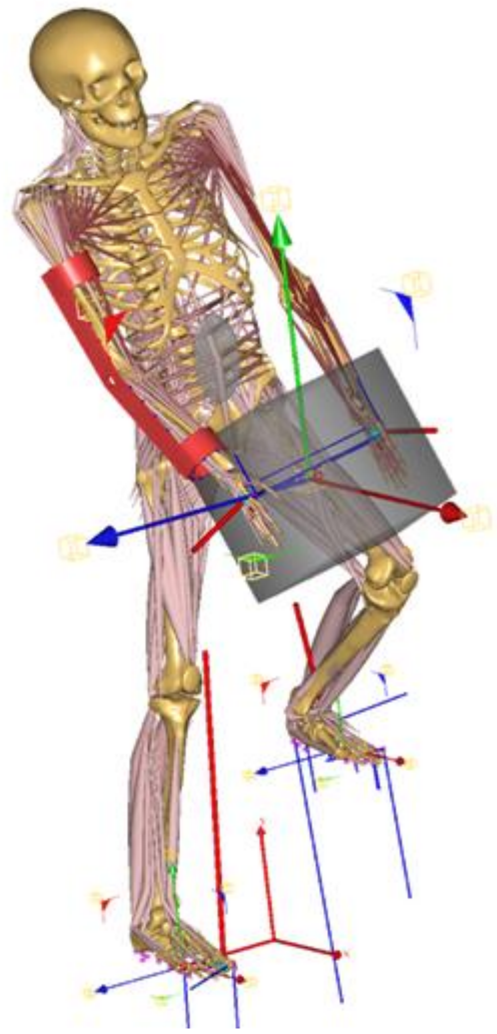
Demo: AnyBody Modeling Systen

- Quick solution to ergonomics problem
  - Widgets for manually positioning feet, box
  - Automatic balance
  - Special force elements
  - Simple arm exoskeleton
  - Data visualization



Trial demo

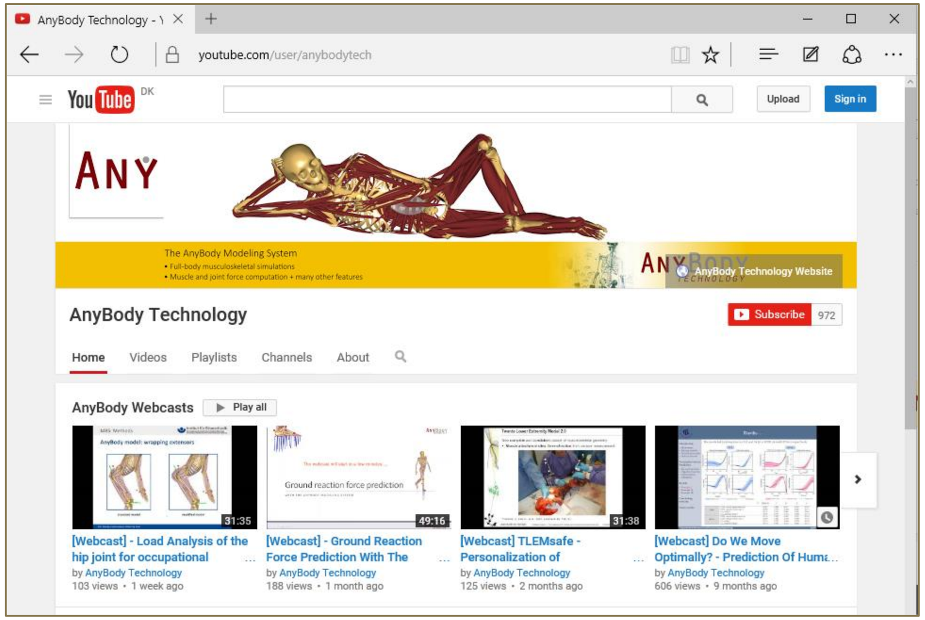
- Try out the model today!
  - Find it on the AnyBody WIKI page



URL: wiki.anyscript.org

Webcasts

- Next webcast 20th April 2016
  - “Personalize your musculoskeletal models using medical image data”
- Check our YouTube channel for previous webcast
  - Search channels for ‘AnyBody Technology’



www.anybodytech.com

- Events, dates, publication list, ...

www.anyscript.org

- Wiki, Forum

Events

- **ESB 2016, 22nd Congress of the European Society of Biomechanics, Lyon, France, 10-13 Jul.**
  - **Free Workshop – Crowne Plaza Lyon-Cité Internationale. Location**
  - **10th Jul 2016, 12:00 – 16:00 hours**
  - **Come visit us at our Booth**

- ICRA 2016 - IEEE International Conference on Robotics and Automation, Stockholm, Sweden, 16-21 May.

- Musculoskeletal modeling course at Aalborg Uni, Denmark, 6-9 Sep, registrations open now.

Time for questions: