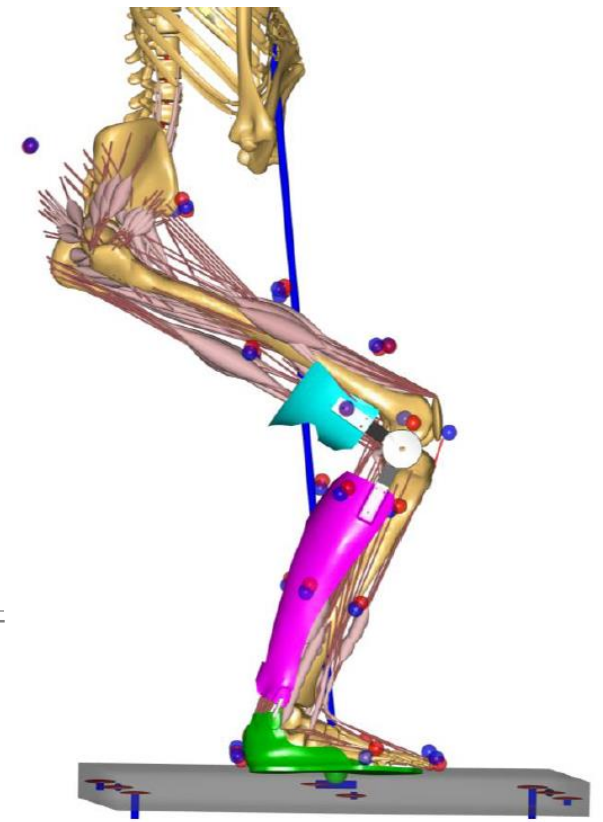


The webcast will start in a few minutes....

Simulations as a tool for human-centered exoskeleton design



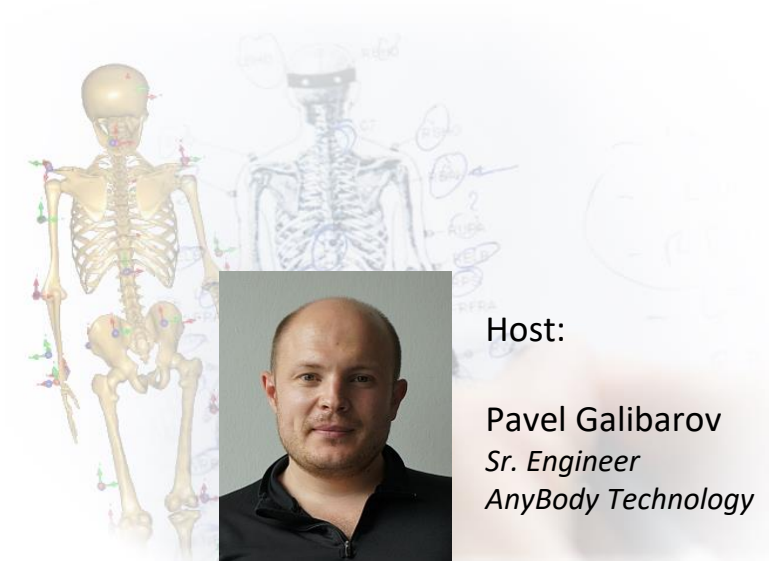
Outline

- Brief introduction
- Today's webcast:
 - Simulations and exoskeleton design
 - AnyBody and exo simulations
 - Case studies
- Questions and answers



Presenter:

Ananth Gopalakrishnan, PhD,
Product specialist
AnyBody Technology (DK)



Host:

Pavel Galibarov
Sr. Engineer
AnyBody Technology

Control Panel

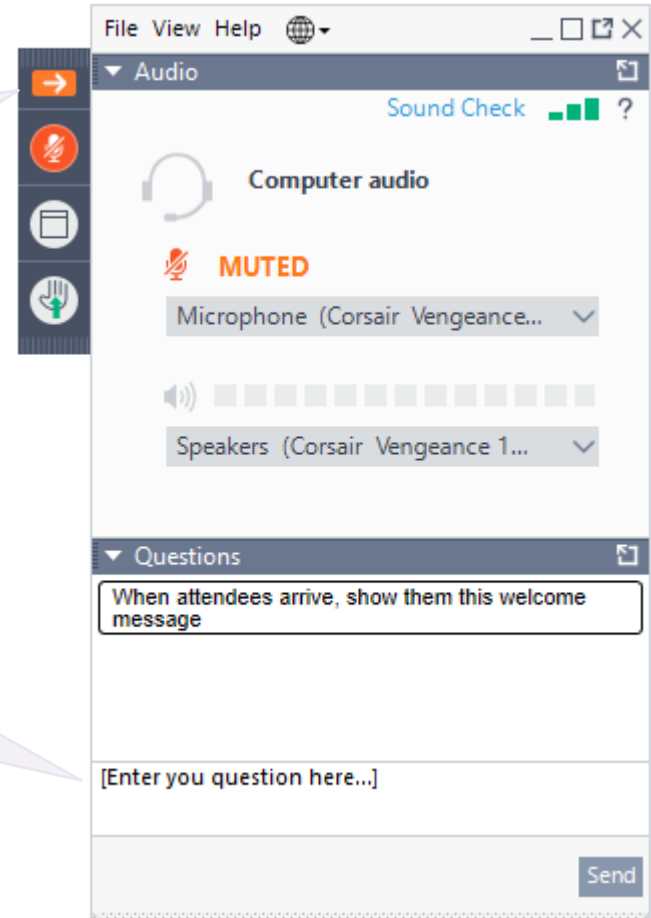
The Control Panel appears on the right side of your screen.

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.

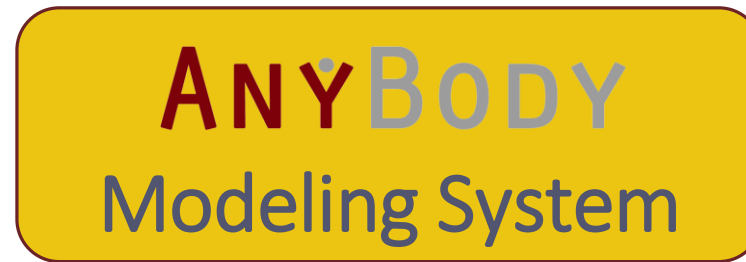
Expand/Collapse the Control Panel

Ask a question during the presentation



Musculoskeletal Simulation

Motion data
Kinematics + Forces

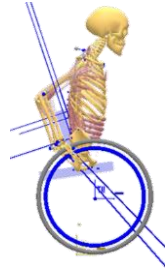


Body Loads

- Joint moments
- Muscle forces
- Joint reaction forces



Movement
Analysis

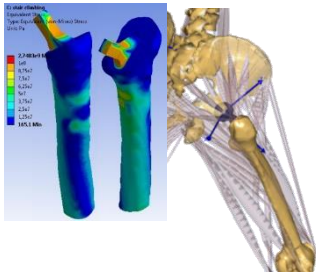


Product Design
Optimization



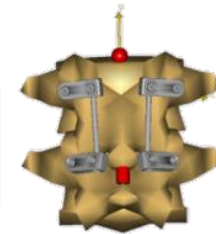
Ergonomic
Analysis

ANYBODY Modeling System



Load Cases for
Finite Element
Analysis

Surgical Planning and
Outcome Evaluation



Simulations for Human-Centered Exoskeleton Design

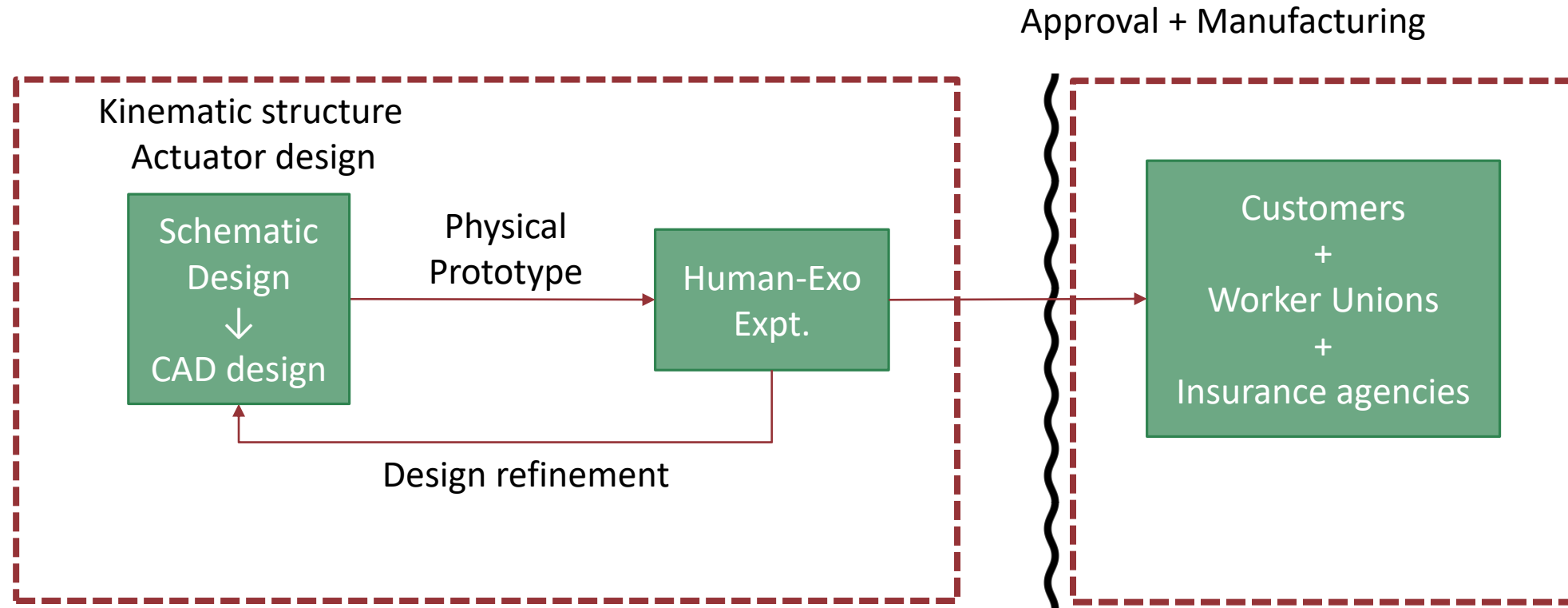
Outline

- **Act 1:** The 'Pain points' and Human-Exo Simulations
- **Act 2:** Intro to simulations in AnyBody
- **Act 3:** Case studies

Act 1

The 'Pain points' and Human Exo-Simulations

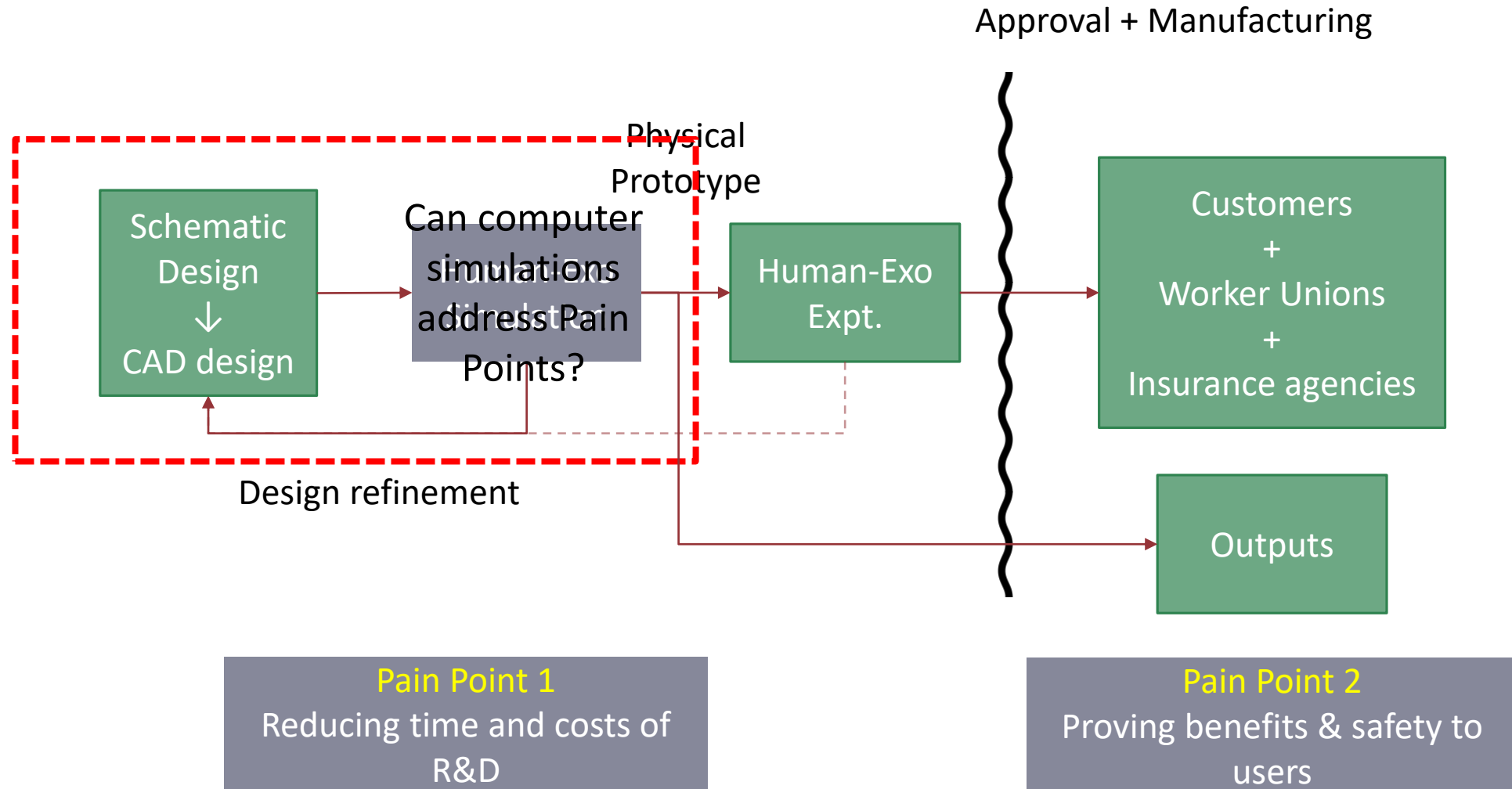
The Design Cycle



Pain Point 1
Reducing time and costs of
R&D

Pain Point 2
Proving benefits & safety to
users

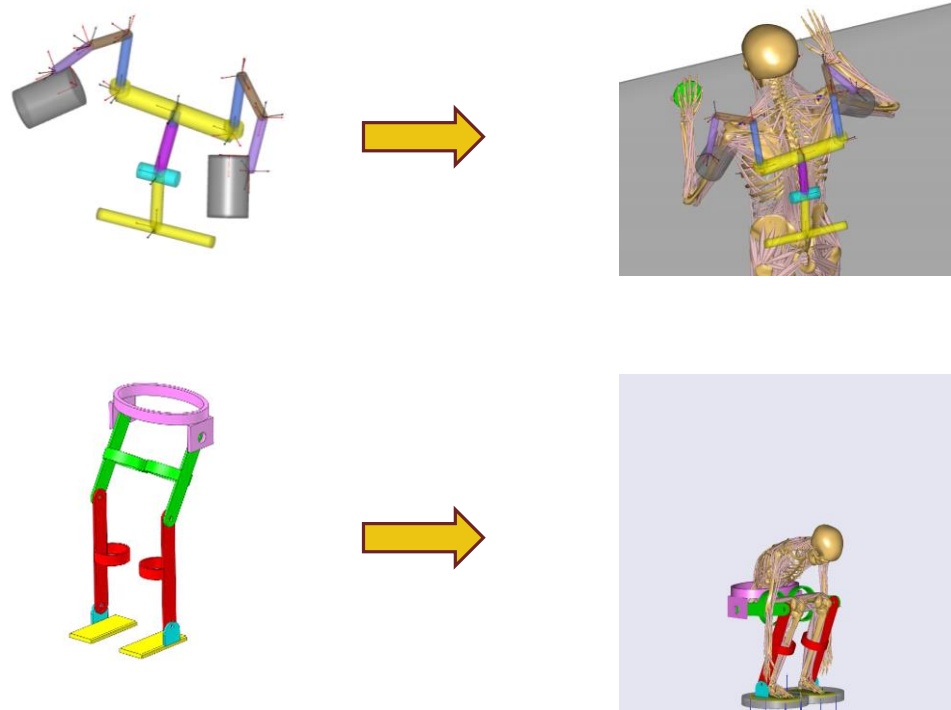
The Design Cycle



Human-Exo Simulation



Human-Exo Simulation



Musculoskeletal Simulation



ANYBODY
Modeling System

Human

- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

Human-Exo Interaction

- Forces (straps, pads etc)

Exo

- Actuator forces & power
- Kinematics

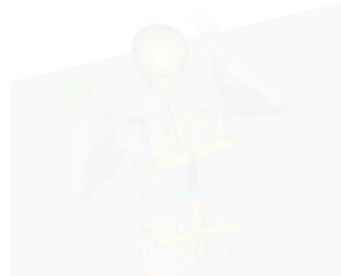
Human-Exo Simulation

Schematic Design
↓
CAD design

Human-Exo Simulation

Output

AnyBody Modeling System™ Simulation Outputs



Musculoskeletal Simulation



Human

- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

Human-Exo Interaction

- Forces (straps, pads etc)

Exo

- Actuator forces & power
- Kinematics

Webcast Goals

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefits & safety to users

How can Pain Points be addressed by simulation outputs



AnyBody Modeling System™ Simulation Outputs

Human

- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

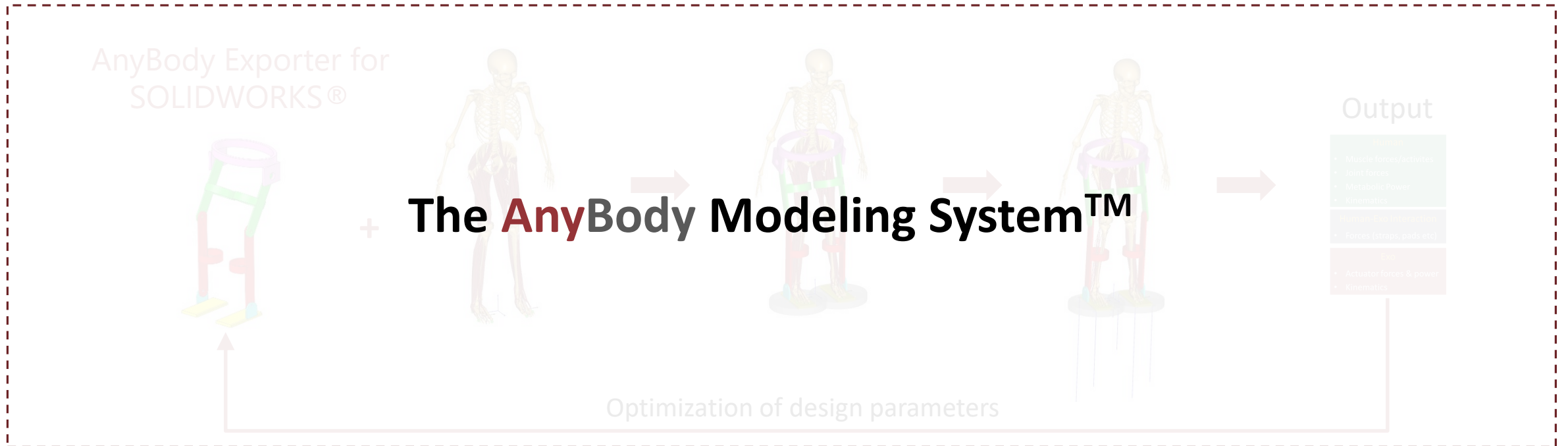
Human-Exo Interaction

- Forces (straps, pads etc)

Exo

- Actuator forces & power
- Kinematics

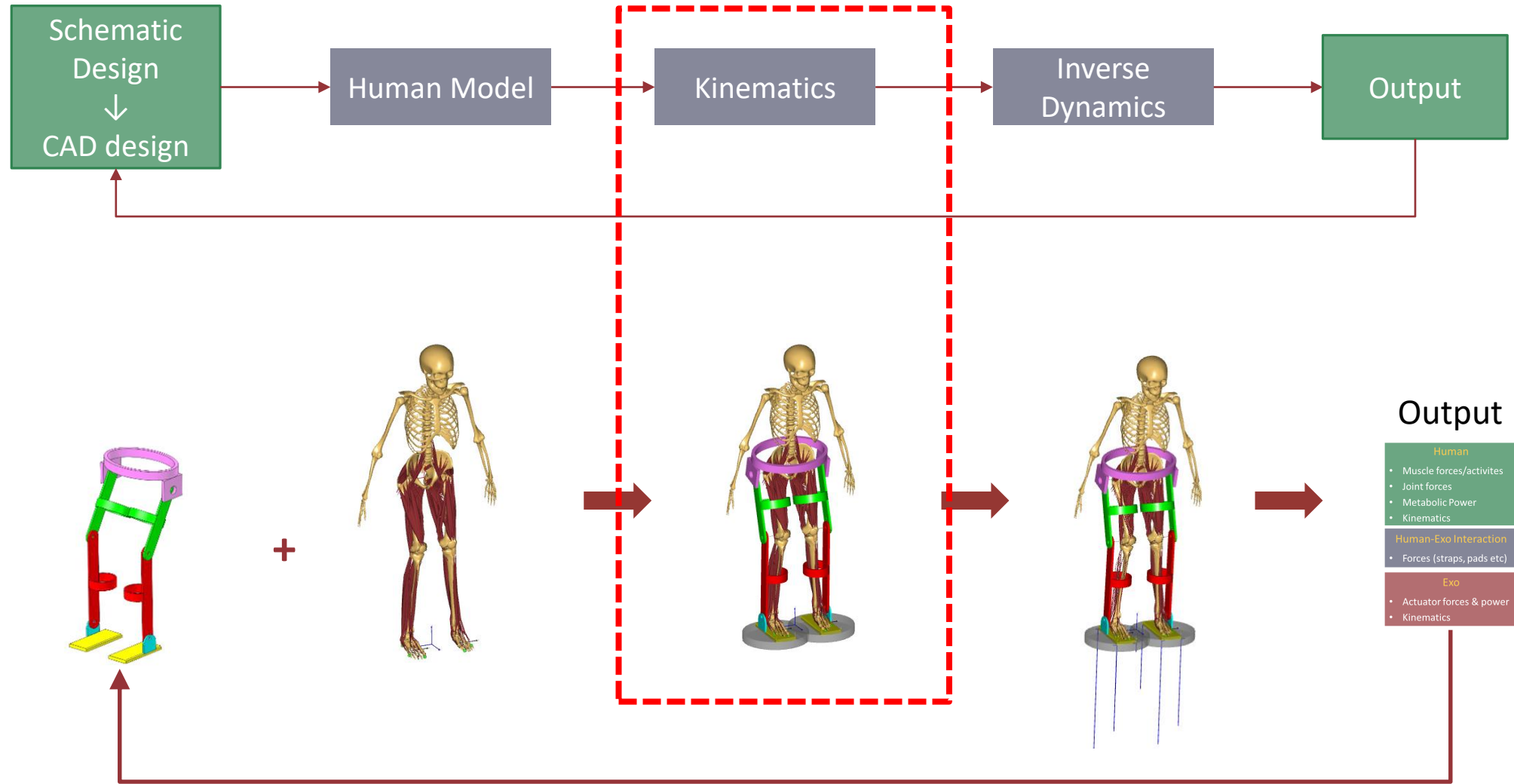
Human-Exo Simulation



Act 2

Simulations in the AnyBody Modeling System

Human-Exo Simulation



Kinematics in AnyBody

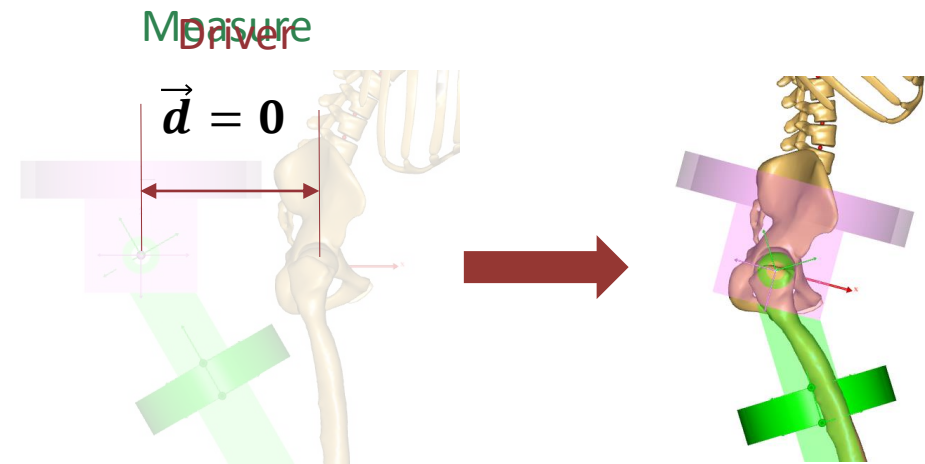
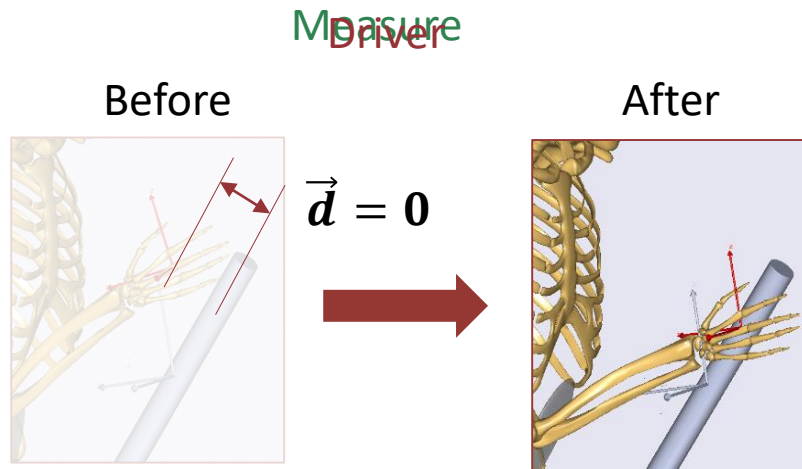
- **Step 1** - Assembling Exo on Human
 - Create constraints at attachment points
 - Human-Exo Joint alignment

ANYBODY
Modeling System

Measures & Drivers

Measures specific geometry

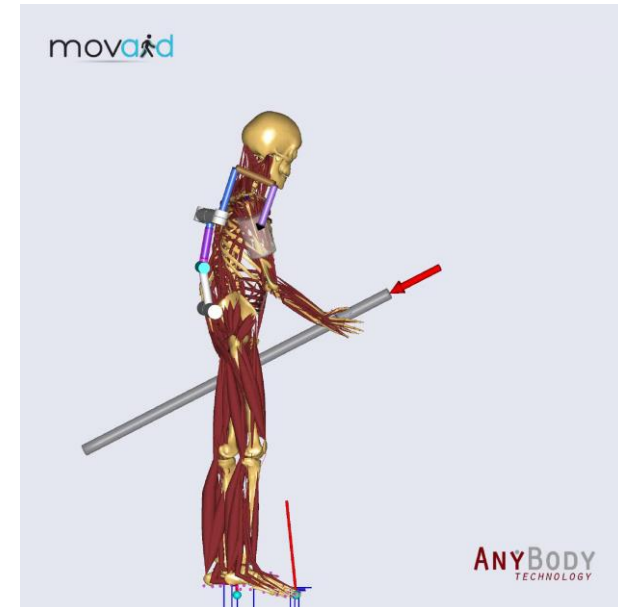
Constrains measured values to 0 or $f(t)$



Kinematics in AnyBody

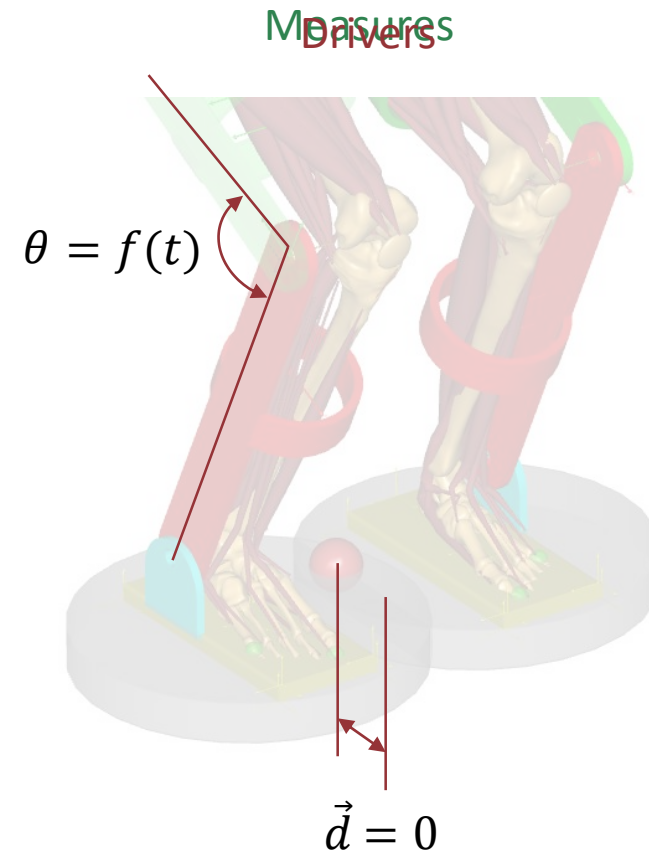
- **Step 1** - Assembling Exo on Human
 - Create constraints at attachment points
 - Human-Exo Joint alignment

- **Step 2** - Prescribing Motion
 - Motion Capture data (.c3d or BVH files)



Kinematics in AnyBody

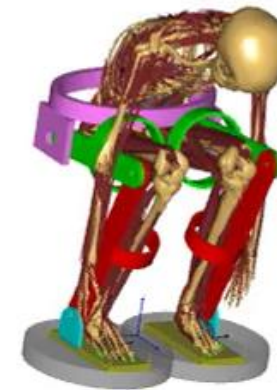
- **Step 1** - Assembling Exo on Human
 - Create constraints at attachment points
 - Human-Exo Joint alignment
- **Step 2** - Prescribing Motion
 - Motion Capture data (.c3d or BVH files)
 - Synthesize motion



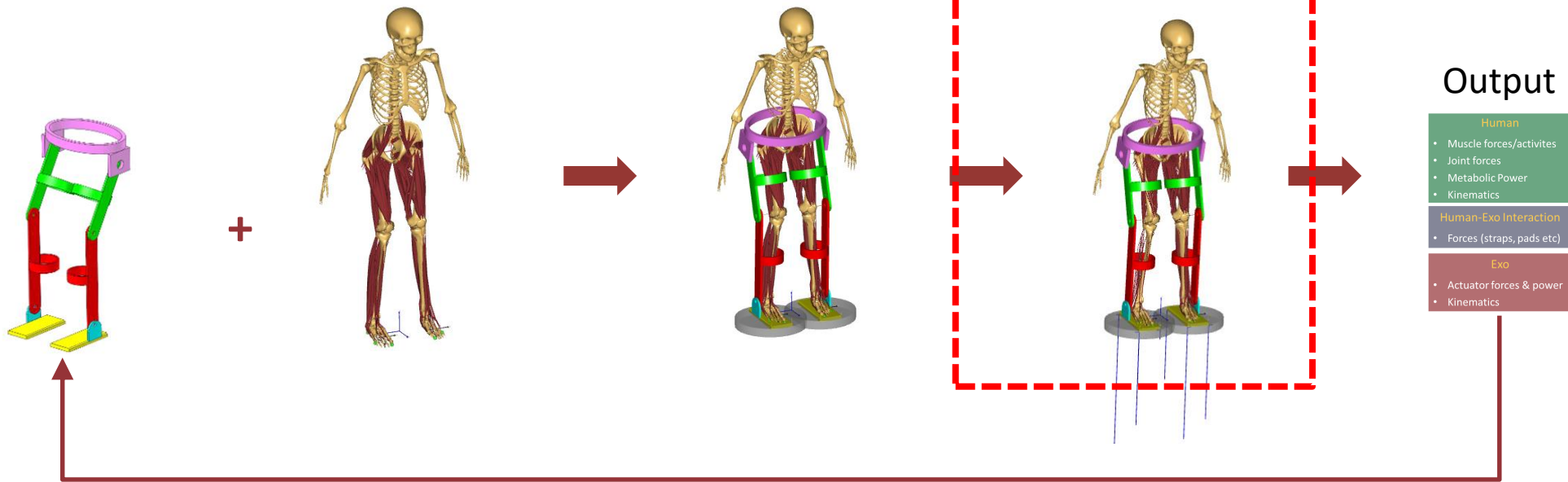
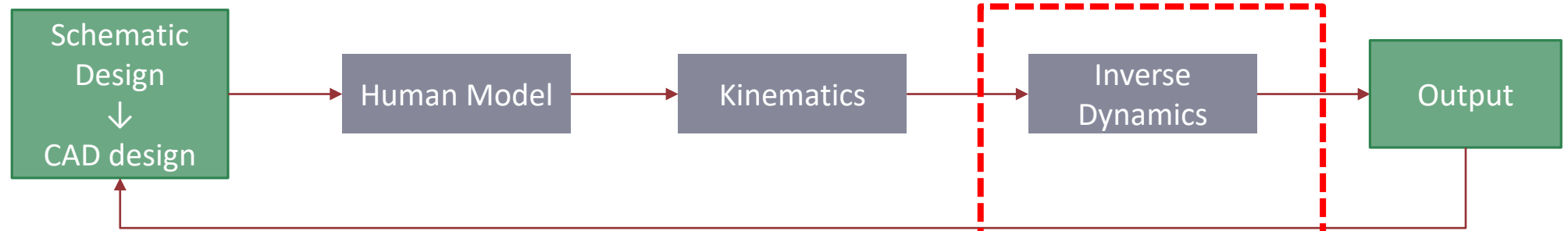
Kinematics in AnyBody

- **Step 1** - Assembling Exo on Human
 - Create constraints at attachment points
 - Human-Exo Joint alignment

- **Step 2** - Prescribing Motion
 - Motion Capture data (.c3d or BVH files)
 - Synthesize motion

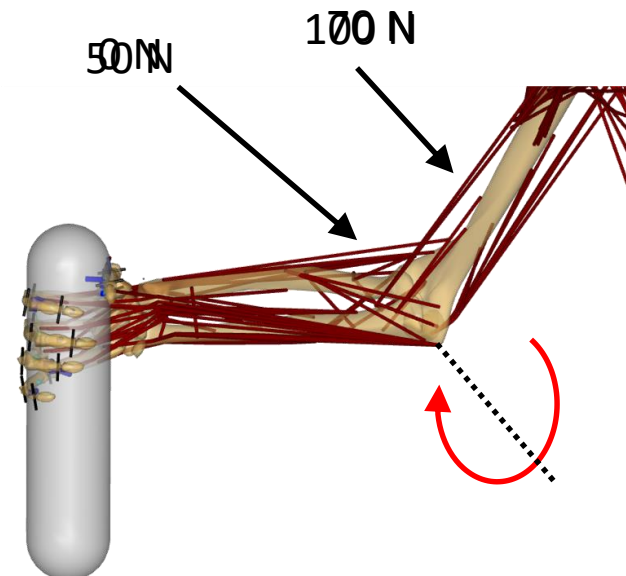


Human-Exo Simulation



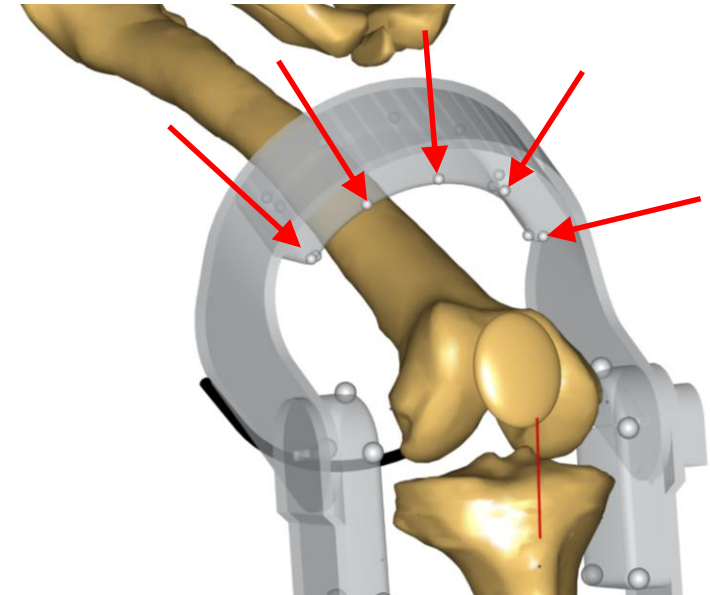
Inverse Dynamics in AnyBody

- Inverse dynamics: Motion (Kinematics) → Forces
- Calculate all forces
 - Human – eg. muscles, joints
 - Exo – eg. motors, actuators
 - Human-Exo interface - eg. straps
- Force redundancy in Human-Exo system
 - Muscle redundancy



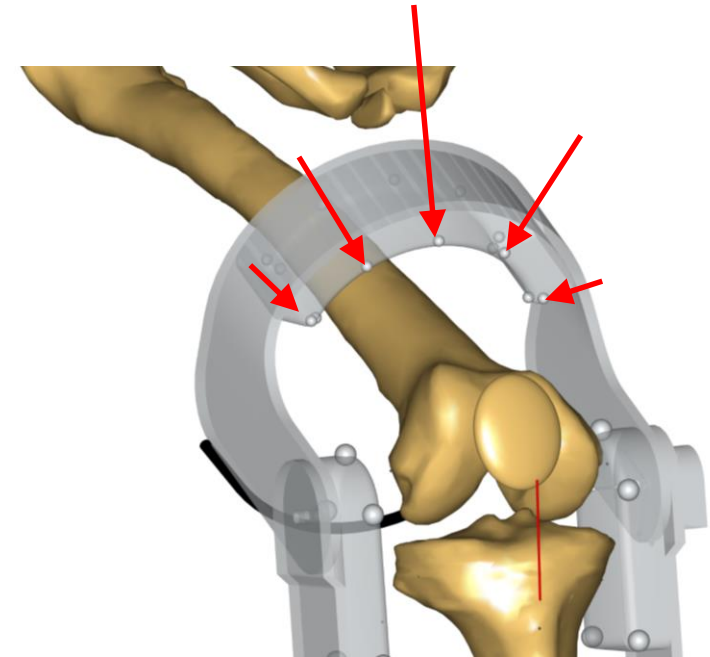
Inverse Dynamics in AnyBody

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- Force redundancy in Human-Exo system
 - Muscle redundancy
 - Human-Exo reaction forces

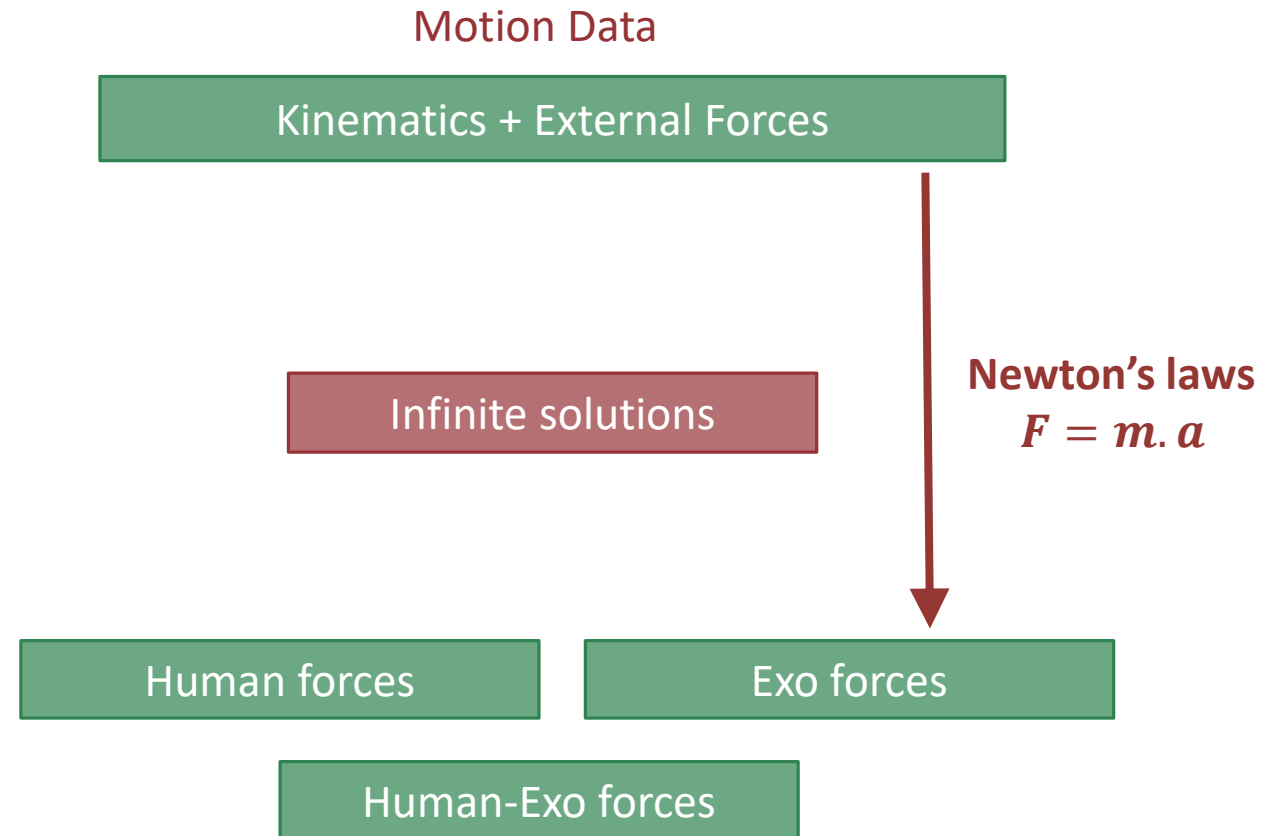
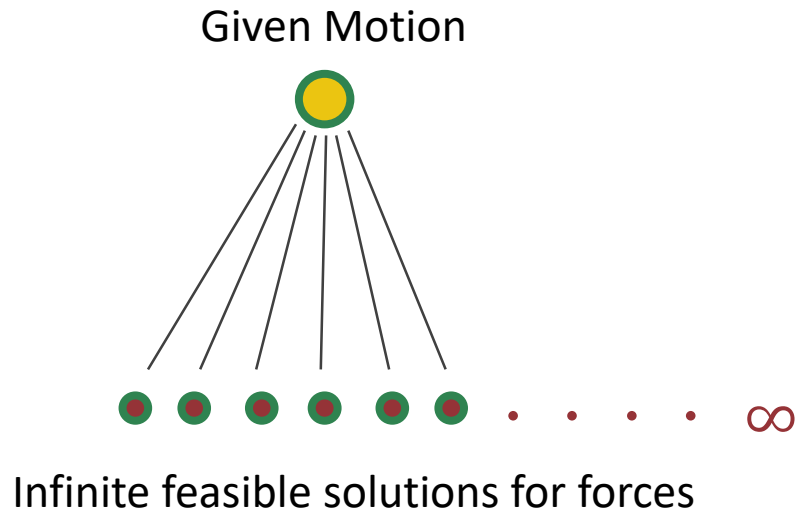


Inverse Dynamics in AnyBody

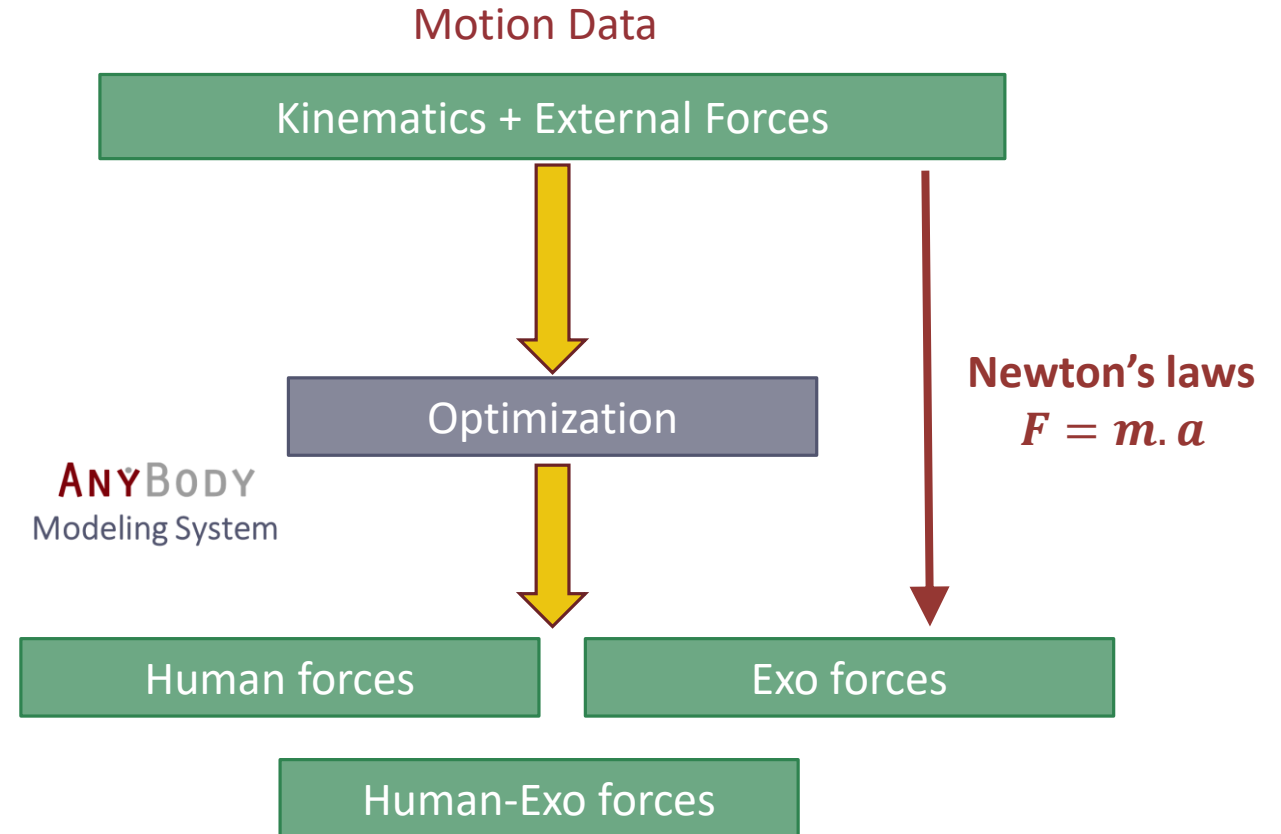
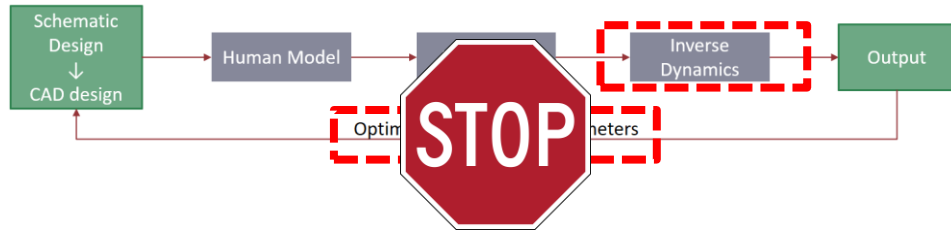
- Inverse dynamics: Motion (Kinematics) → Forces
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 - Human – eg. muscles, joints
 - Exo – eg. motors, actuators
 - Human-Exo interface - eg. straps
- Force redundancy in Human-Exo system
 - Muscle redundancy
 - Human-Exo reaction forces
 - **How unique Forces be predicted?**



Inverse Dynamics in AnyBody

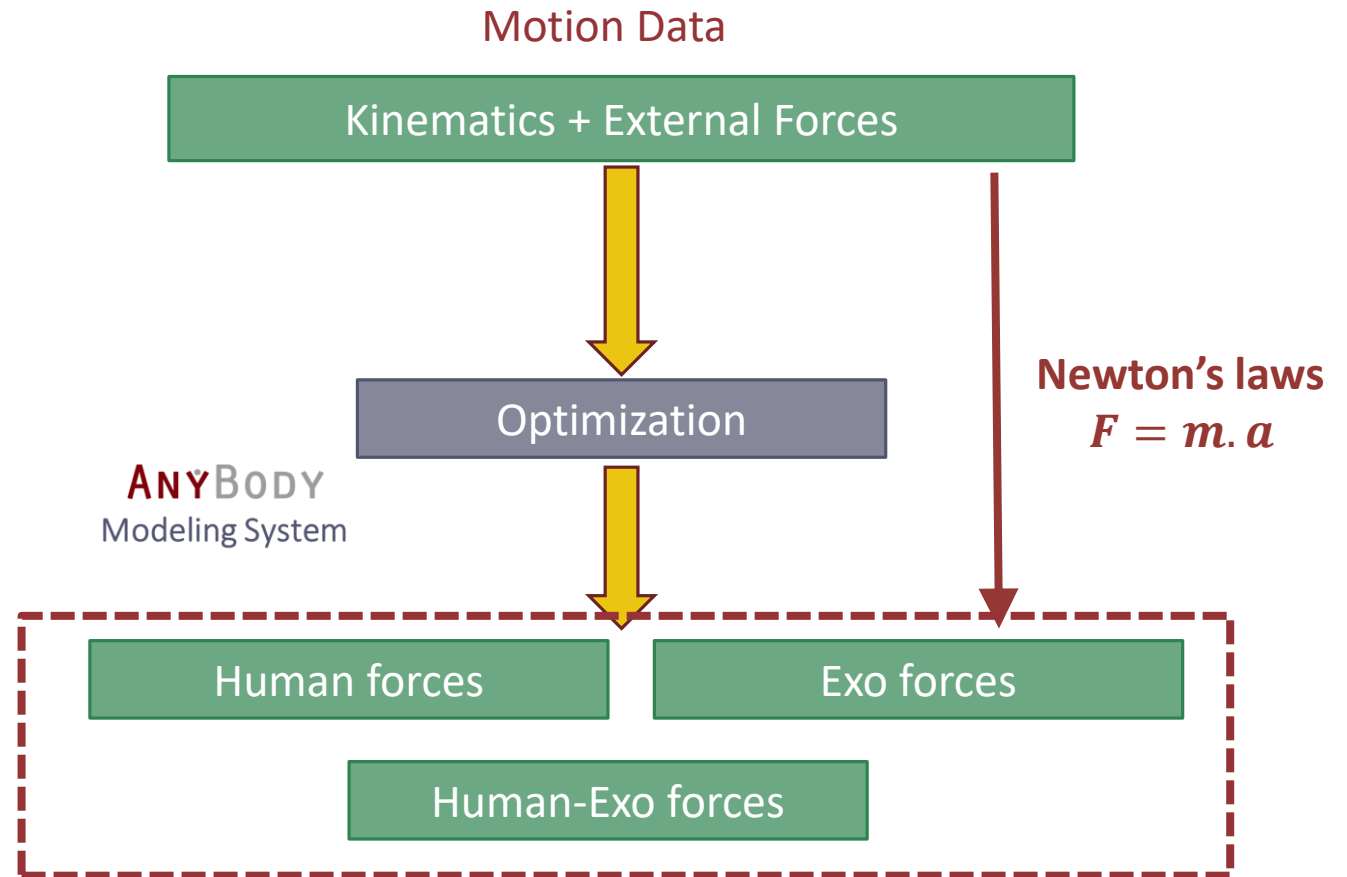


Inverse Dynamics in AnyBody

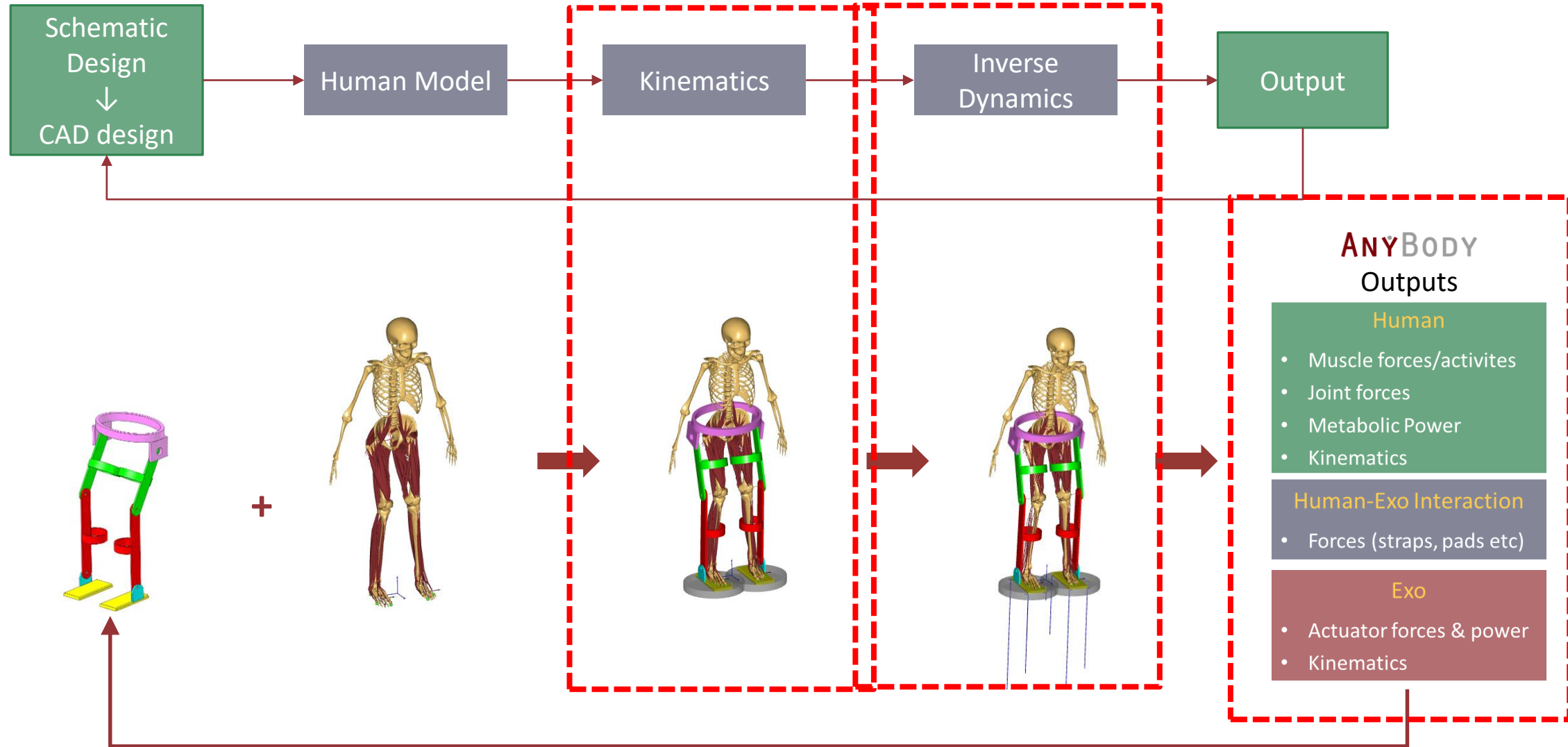


Inverse Dynamics in AnyBody

How can Exo/Environment be best used to minimize muscle effort



Human-Exo Simulation



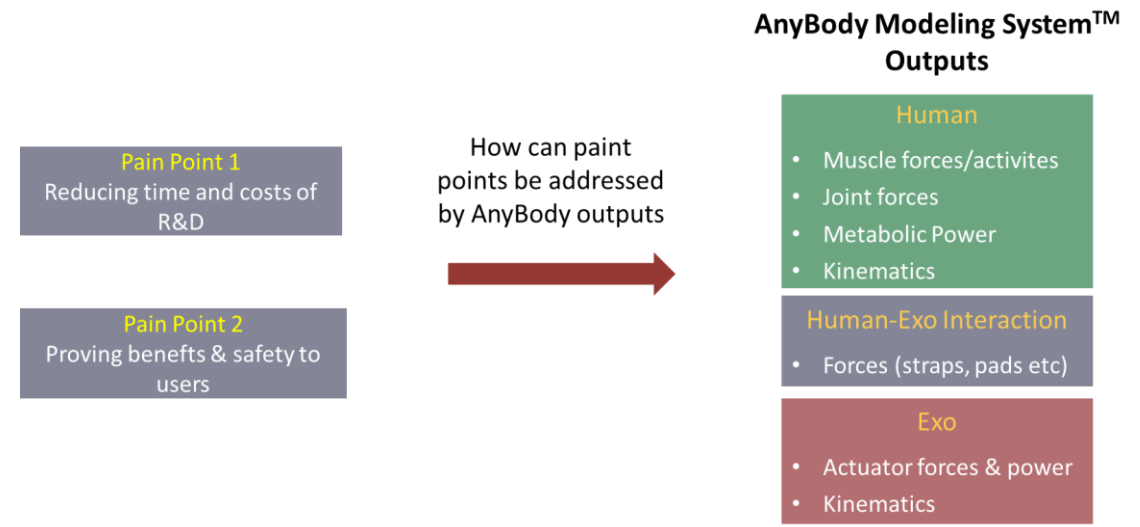
Act 3

Case Studies

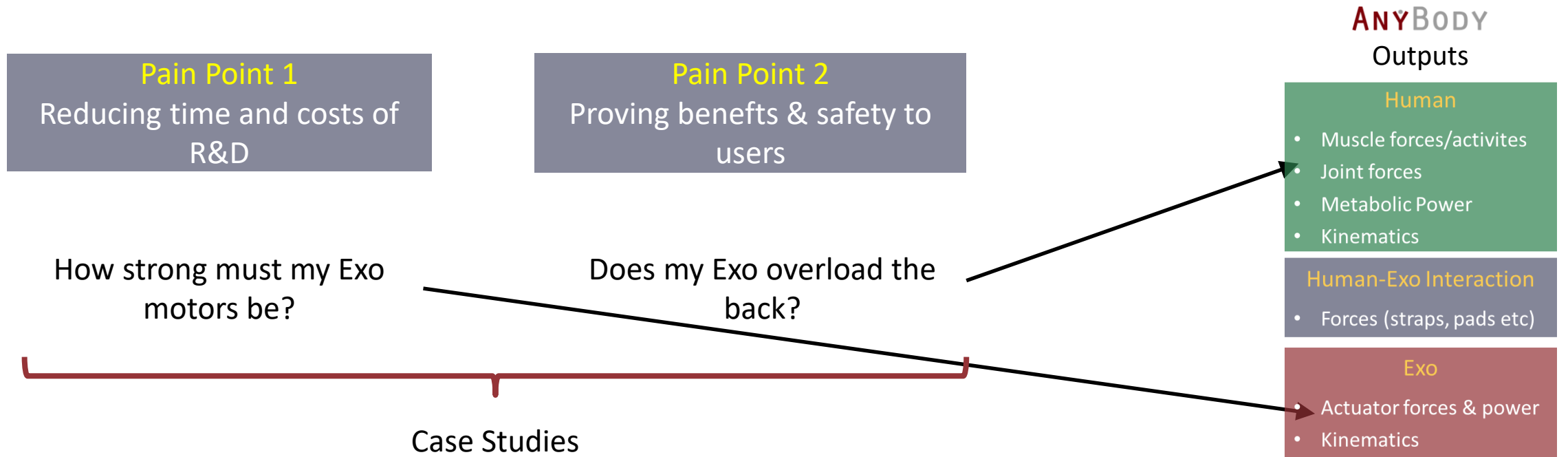
Case Studies

- Customer cases
 - **Case 1:** Passive, gravity-compensating arm exoskeleton
 - **Case 2:** Soft-Active, waist exoskeleton

- Internal cases
 - **Case 3:** Passive, Waist assisting device
 - Metabolic energy savings



Human-Exo Simulation



Case 1: Arm Exoskeleton

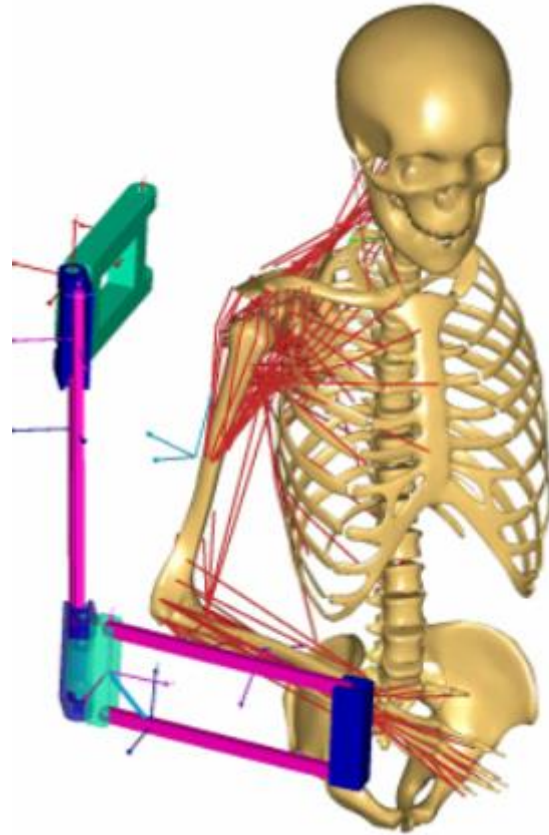
"A human-centered design optimization approach for robotic exoskeletons through biomechanical simulation", (2017)

Zhou et al., Robotics and Autonomous Systems, Vol 91, Pgs 337-347

Dr. Shaoping Bai
Aalborg University, Denmark

<http://homes.m-tech.aau.dk/shb/>

Case 1: Arm Exoskeleton

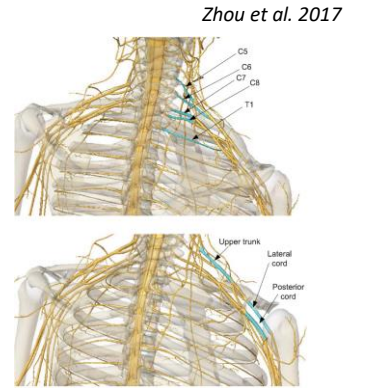
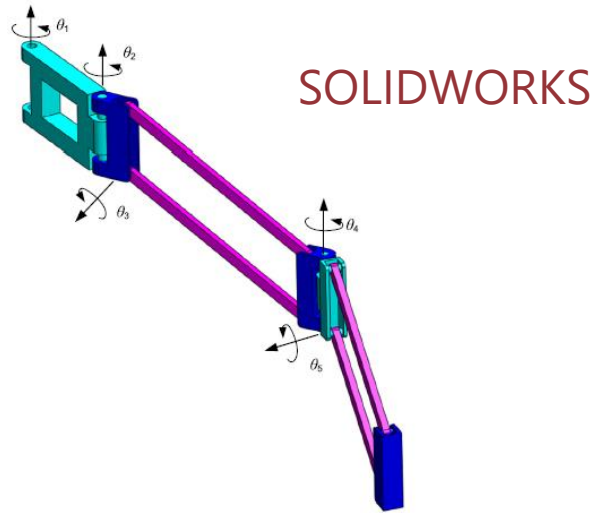
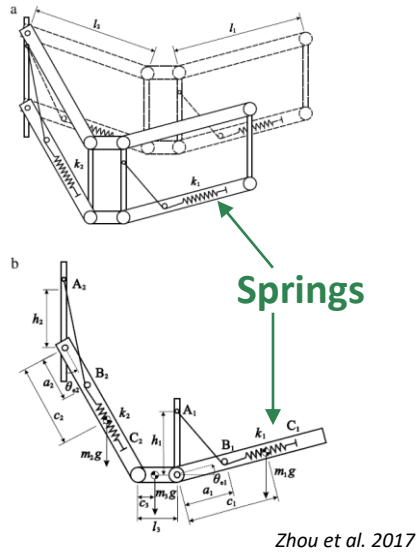


Case 1: Arm Exoskeleton

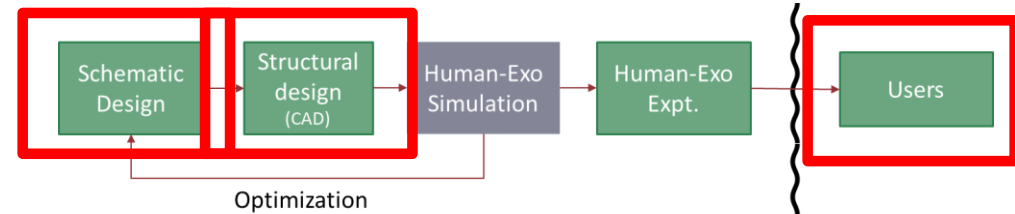
What are the ideal spring stiffnesses for the Exoskeleton?

Case 1: Arm Exoskeleton

Gravity compensation

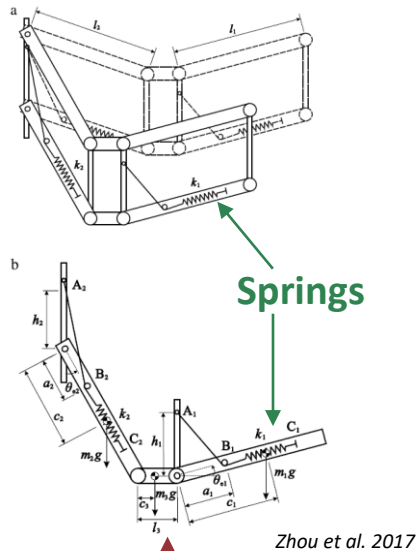


Paralysis of C7 nerve
Drinking motions

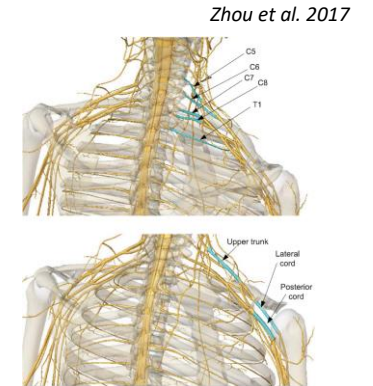
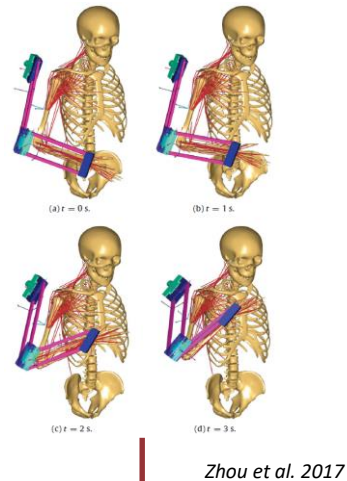


Case 1: Arm Exoskeleton

Gravity compensation



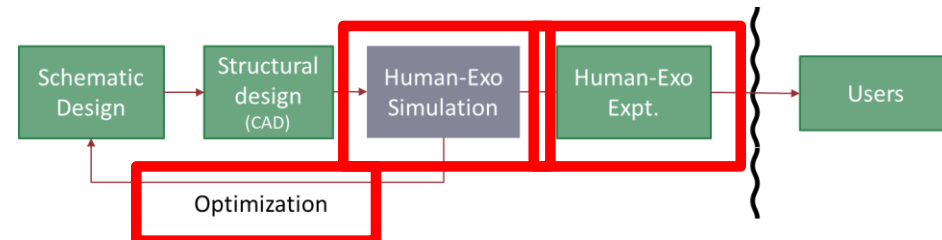
Weakened muscles, C7 injury



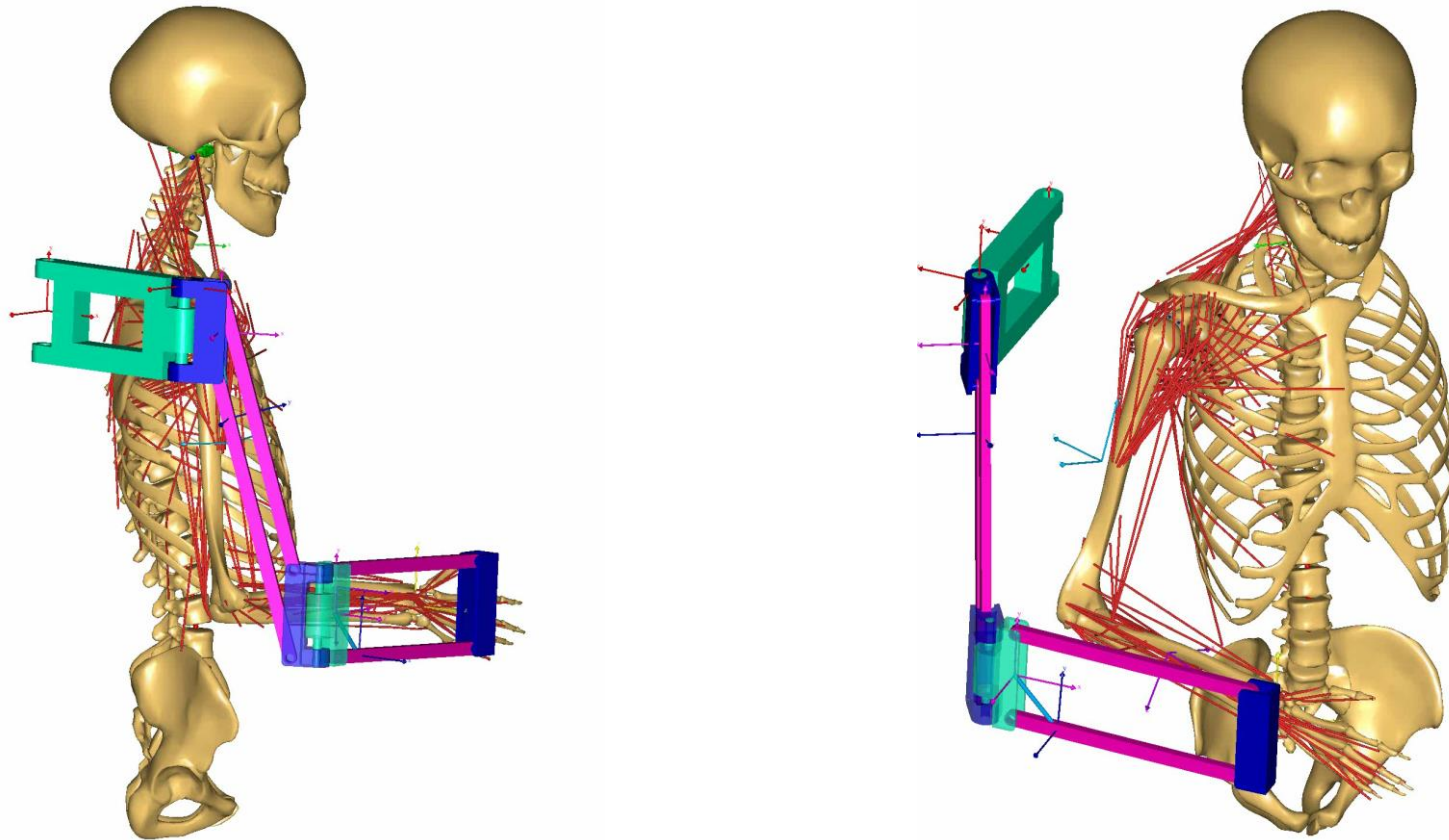
Paralysis of C7 nerve
Drinking motions

Optimize (External tool): Spring stiffness

Goal: Min muscle effort/activity



Case 1: Arm Exoskeleton



Courtesy Dr. Shaoping Bai, Aalborg University

Case 1: Arm Exoskeleton

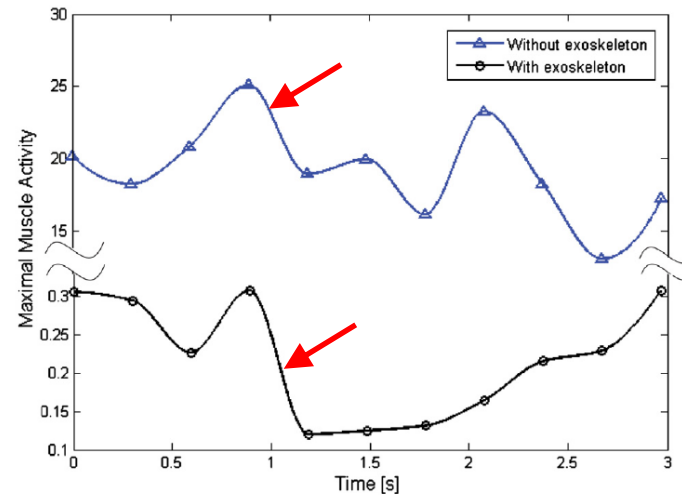
Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefits & safety to users

- Do optimized springs reduce muscle effort?

ANYBODY
Outputs

- Human**
 - Muscle forces/activities
 - Joint forces
 - Metabolic Power
 - Kinematics
- Human-Exo Interaction**
 - Forces (straps, pads etc)
- Exo**
 - Actuator forces & power
 - Kinematics



Zhou et al. 2017

Case 1: Arm Exoskeleton

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefits & safety to users

- Do optimized springs reduce muscle effort?
- How are Exo & Human motions coordinated?

ANYBODY
Outputs

Human

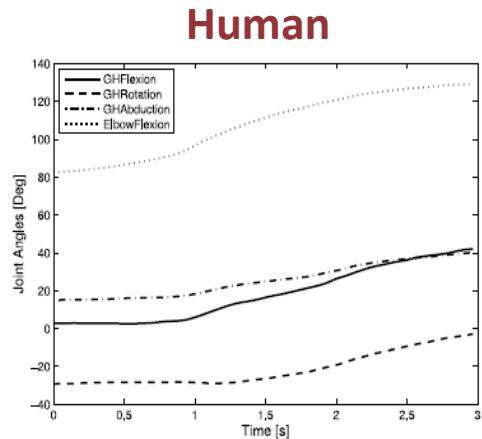
- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

Human-Exo Interaction

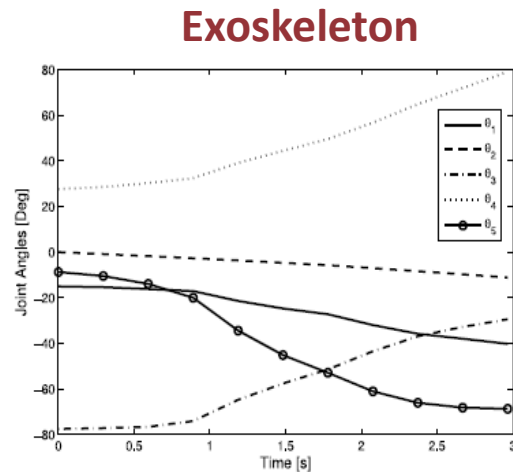
- Forces (straps, pads etc)

Exo

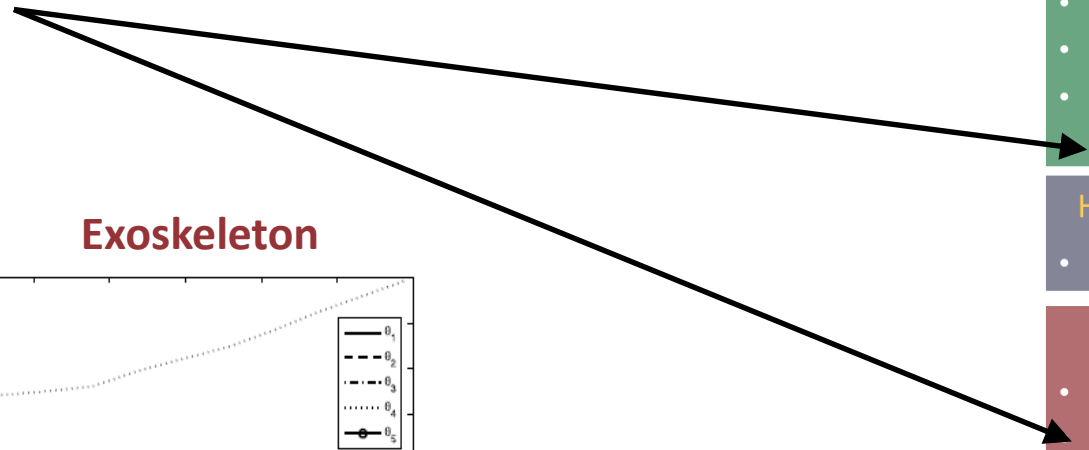
- Actuator forces & power
- Kinematics



Zhou et al. 2017



Zhou et al. 2017



Case 1: Arm Exoskeleton

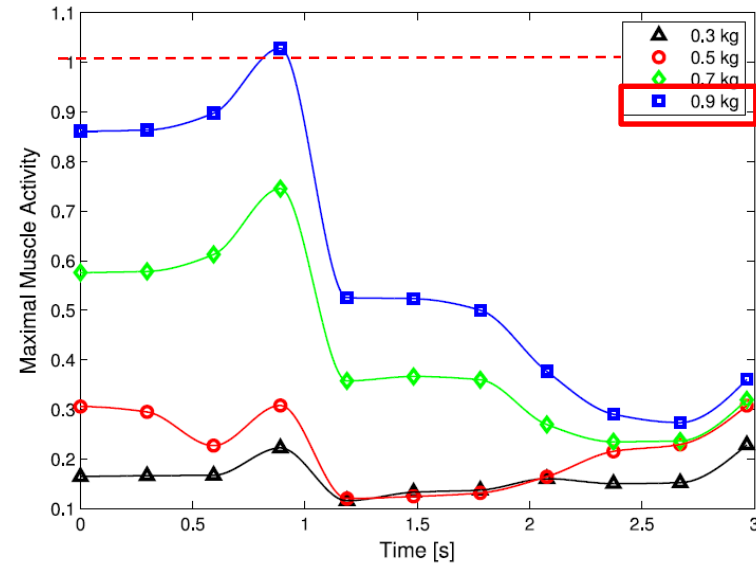
Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefits & safety to users

- Do optimized springs reduce muscle effort?
- How are Exo & Human motions coordinated?
- Maximum lifting load?

ANYBODY
Outputs

- Human**
 - Muscle forces/activities
 - Joint forces
 - Metabolic Power
 - Kinematics
- Human-Exo Interaction**
 - Forces (straps, pads etc)
- Exo**
 - Actuator forces & power
 - Kinematics



Case 1: Arm Exoskeleton

Pain Point 1
Reducing time and costs of R&D

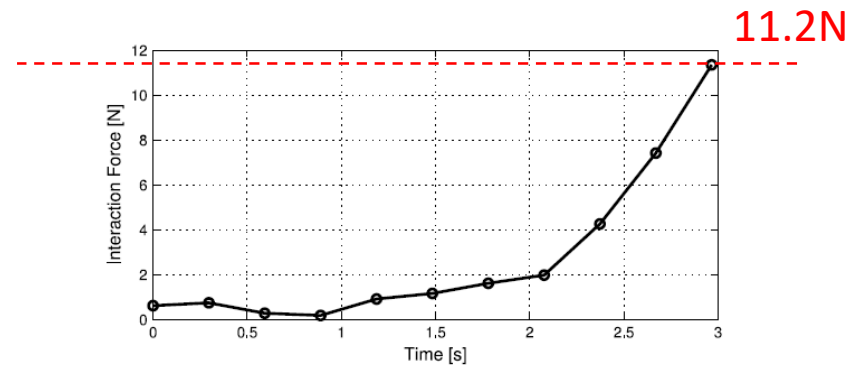
- Do optimized springs reduce muscle effort?
- How are Exo & Human motions coordinated?
- Maximum lifting load?

Pain Point 2
Proving benefits & safety to users

- Is the Exo comfortable to use?

ANYBODY
Outputs

- Human**
 - Muscle forces/activities
 - Joint forces
 - Metabolic Power
 - Kinematics
- Human-Exo Interaction**
 - Forces (straps, pads etc)
- Exo**
 - Actuator forces & power
 - Kinematics



Zhou et al. 2017

$P_{max} \cdot A_{contact} = 16.7N > 11.2N$

↓

Max comfortable pressure

Device is comfortable to use

Case 1: Arm Exoskeleton

Pain Point 1

Reducing time and costs of R&D

- Do optimized springs reduce muscle effort?
- How are Exo & Human motions coordinated?
- Maximum lifting load?

Pain Point 2

Proving benefits & safety to users

- Is the Exo comfortable to use?

ANYBODY Outputs

Human

- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

Human-Exo Interaction

- Forces (straps, pads etc)

Exo

- Actuator forces & power
- Kinematics

Case 2: Soft Waist Exoskeleton

“Semi-Endoskeleton-Type Waist Assist AB-Wear Suit Equipped with Compressive Force Reduction Mechanism”, (2017)

Inose et al., 2017 IEEE International Conference on Robotics and Automation (ICRA)

Nakamura Lab
Chuo University, Japan

<http://www.mech.chuo-u.ac.jp/~nakalab/>

Case 2: Soft Waist Exoskeleton

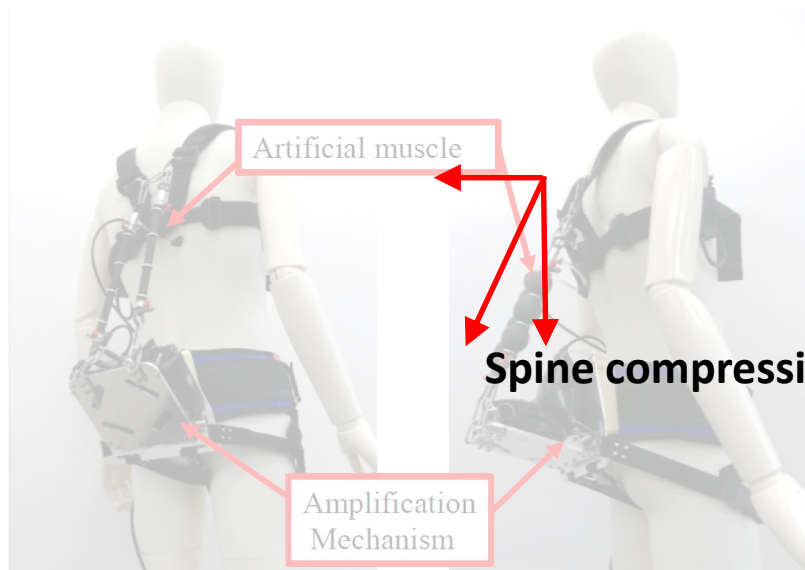
Effectiveness of existing Exo designs, verified using AnyBody



Courtesy Dr. Taro Nakamura, Chuo University

Case 2: Soft Waist Exoskeleton

Effectiveness of existing Exo designs, verified using AnyBody

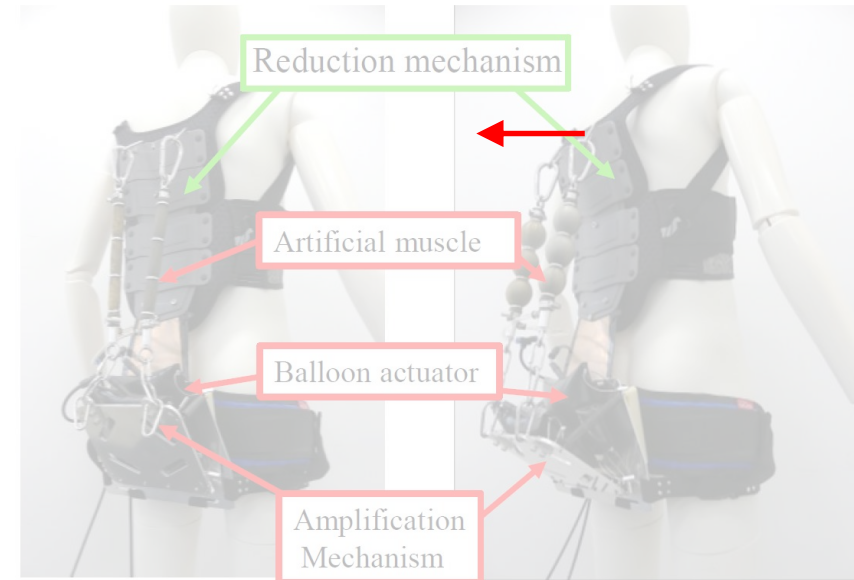


Non-pressurized

Pressurized

Inose et al. 2017

Old Design



Non-pressurized

Pressurized

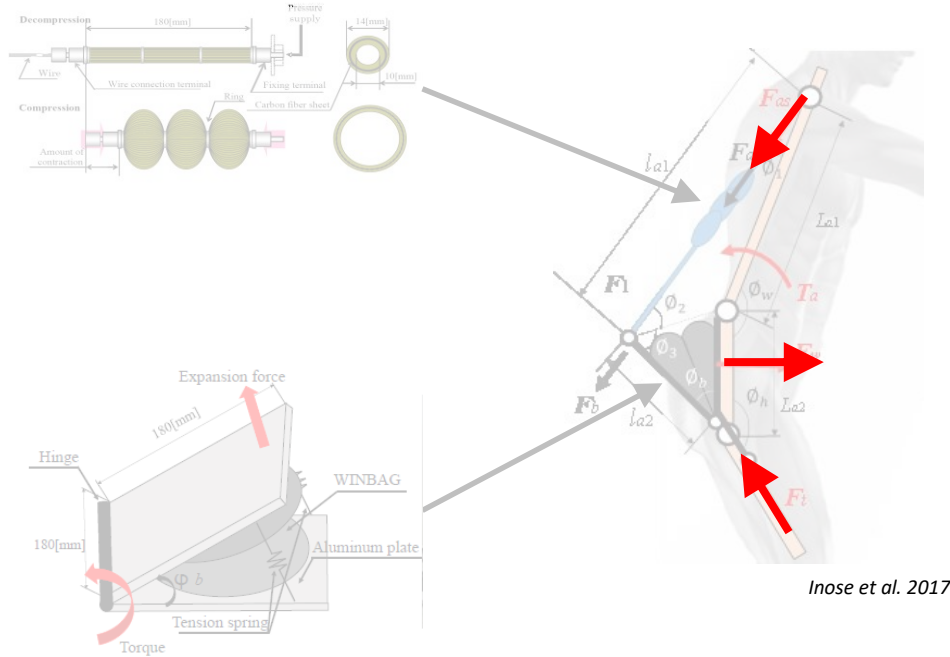
Inose et al. 2017

New Design

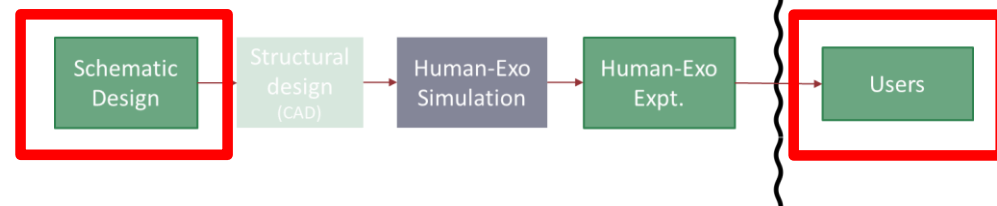
Case 2: Soft Waist Exoskeleton

Is the Exoskeleton safe for the user?

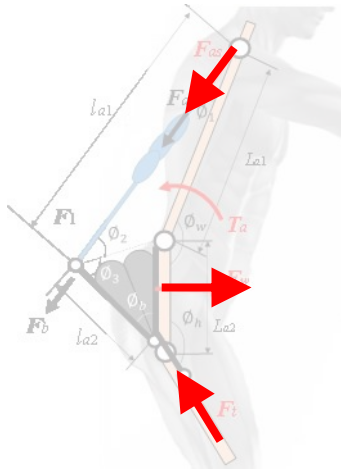
Case 2: Soft Waist Exoskeleton



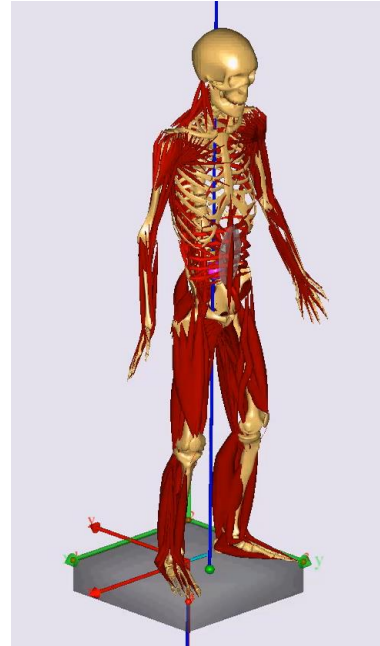
Stoop lifting



Case 2: Soft Waist Exoskeleton



Inose et al. 2017

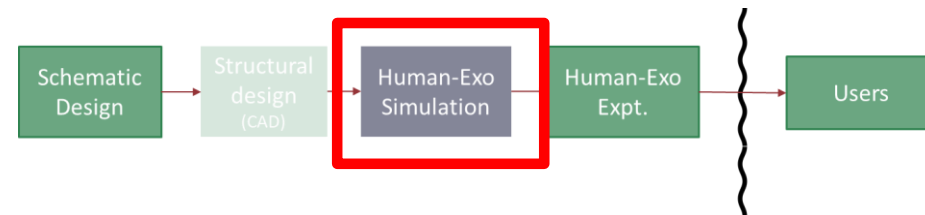


Courtesy Dr. Taro Nakamura, Chuo University

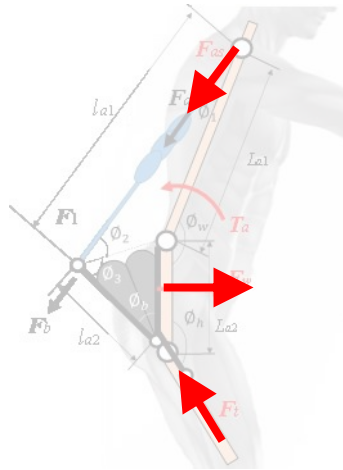
Same Motion
Different Conditions
1: No Exo



Stoop lifting



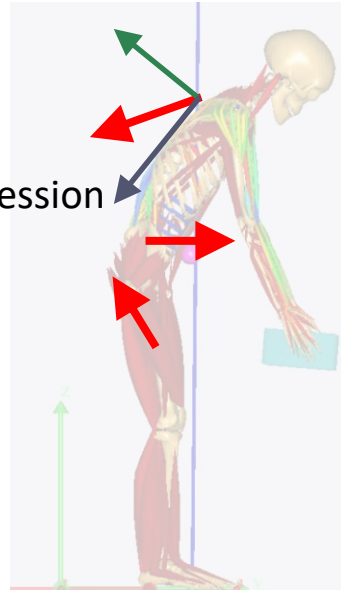
Case 2: Soft Waist Exoskeleton



Inose et al. 2017



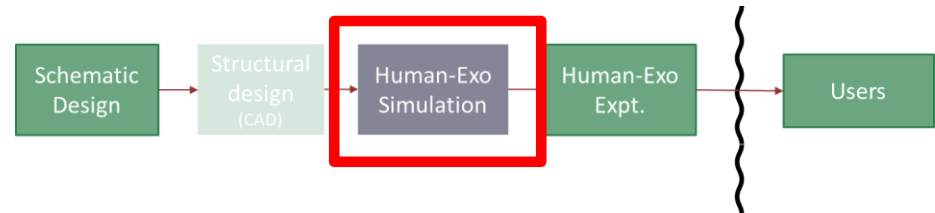
Compression



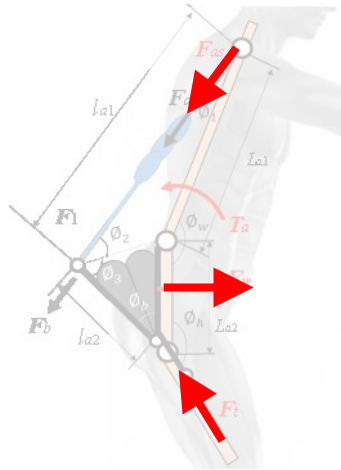
Same Motion
Different Conditions
1: No Exo
2: Old design



Stoop lifting



Case 2: Soft Waist Exoskeleton



Inose et al. 2017



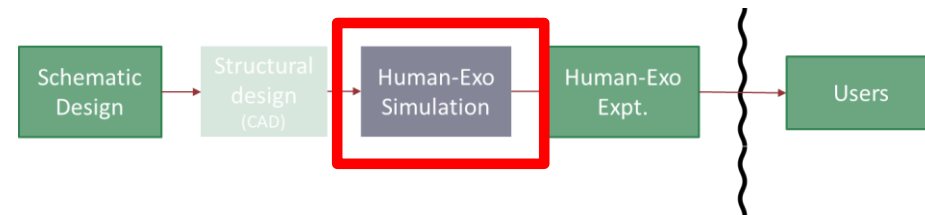
No Compression



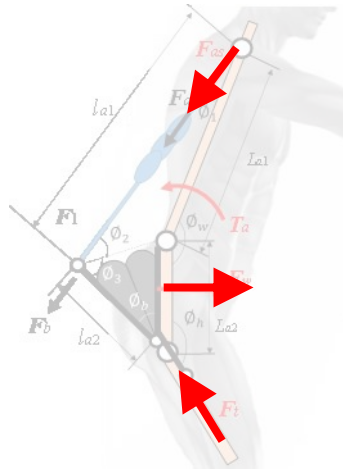
- Same Motion
Different Conditions
- 1: No Exo
 - 2: Old design
 - 3: New design



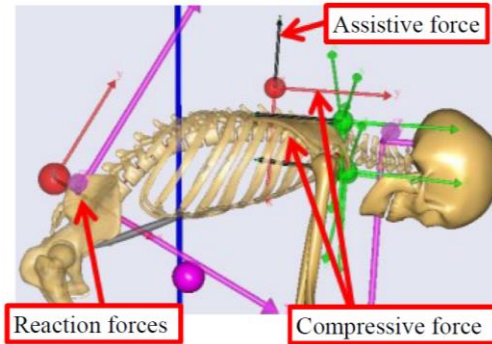
Stoop lifting



Case 2: Soft Waist Exoskeleton



Inose et al. 2017



Inose et al. 2017

Three conditions

- 1: No device
- 2: Old device
- 3: New device

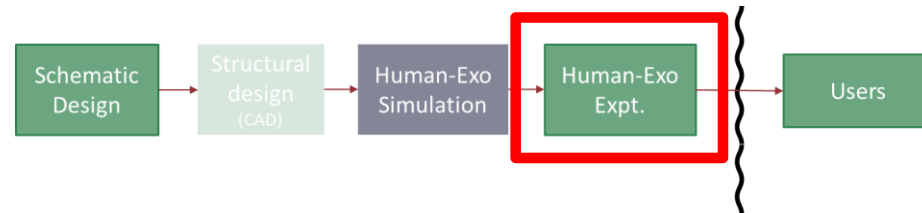


Inose et al. 2017

EMG measured



Stoop lifting



Case 2: Soft Waist Exoskeleton

Pain Point 1

Reducing time and costs of R&D

Pain Point 2

Proving benefits & safety to users

- Does New Design reduce compressive spinal force?

ANYBODY
Outputs

Human

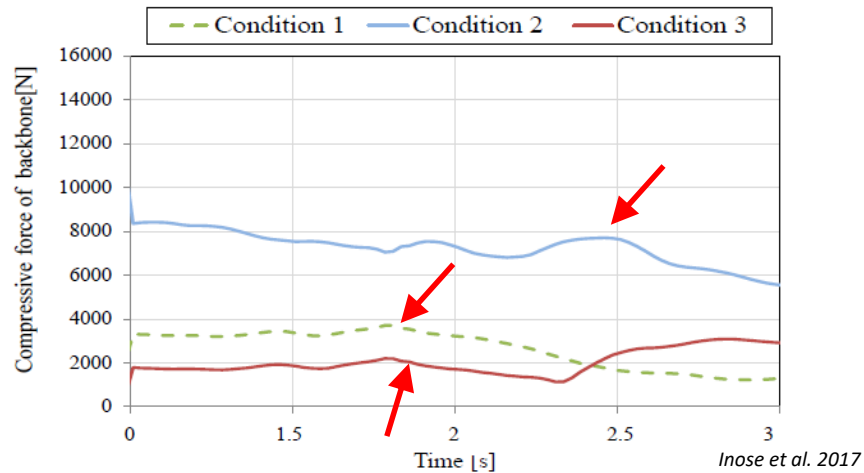
- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

Human-Exo Interaction

- Forces (straps, pads etc)

Exo

- Actuator forces & power
- Kinematics



Case 2: Soft Waist Exoskeleton

Pain Point 1

Reducing time and costs of R&D

Pain Point 2

Proving benefits & safety to users

- Does New Design reduce compressive spinal force?
- Does New Design reduce muscle effort?

ANYBODY
Outputs

Human

- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

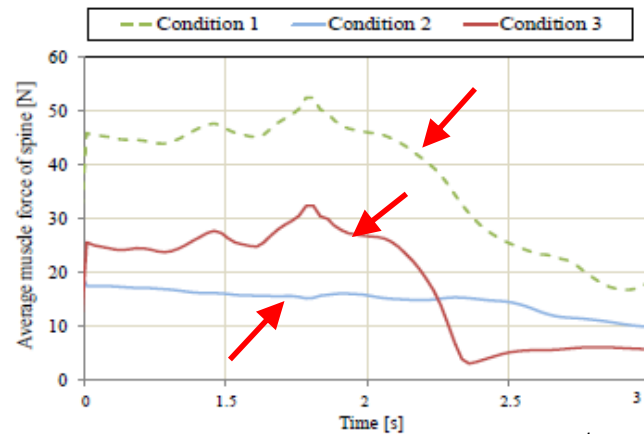
Human-Exo Interaction

- Forces (straps, pads etc)

Exo

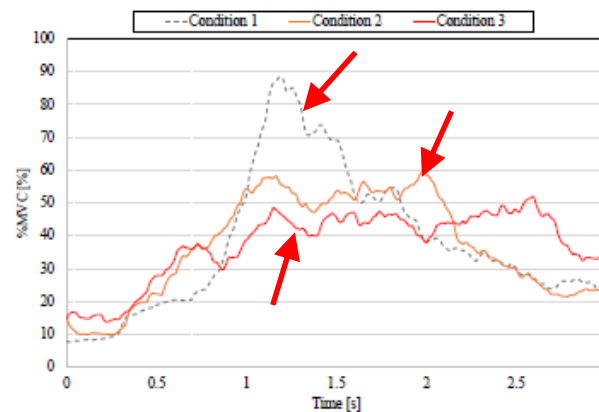
- Actuator forces & power
- Kinematics

Average spinal muscle force



Inose et al. 2017

Erector Spinae EMG



Inose et al. 2017

Case 2: Soft Waist Exoskeleton

Pain Point 1

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ANYBODY
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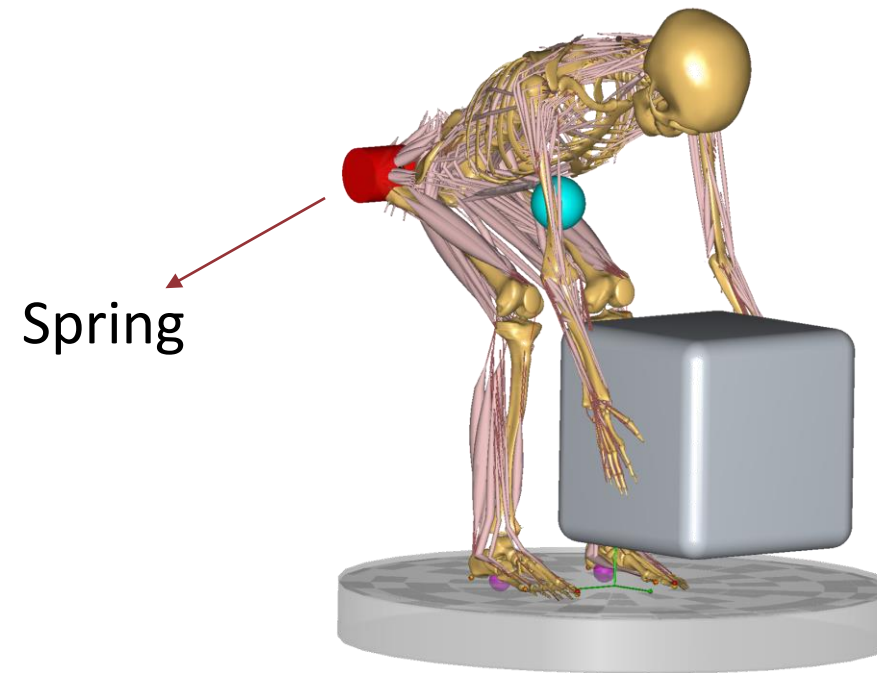
Exo

- Actuator forces & power
- Kinematics

Case 3: Waist Assist Exoskeleton

Internal study done at AnyBody Technology

Case 3: Waist Assist Exoskeleton

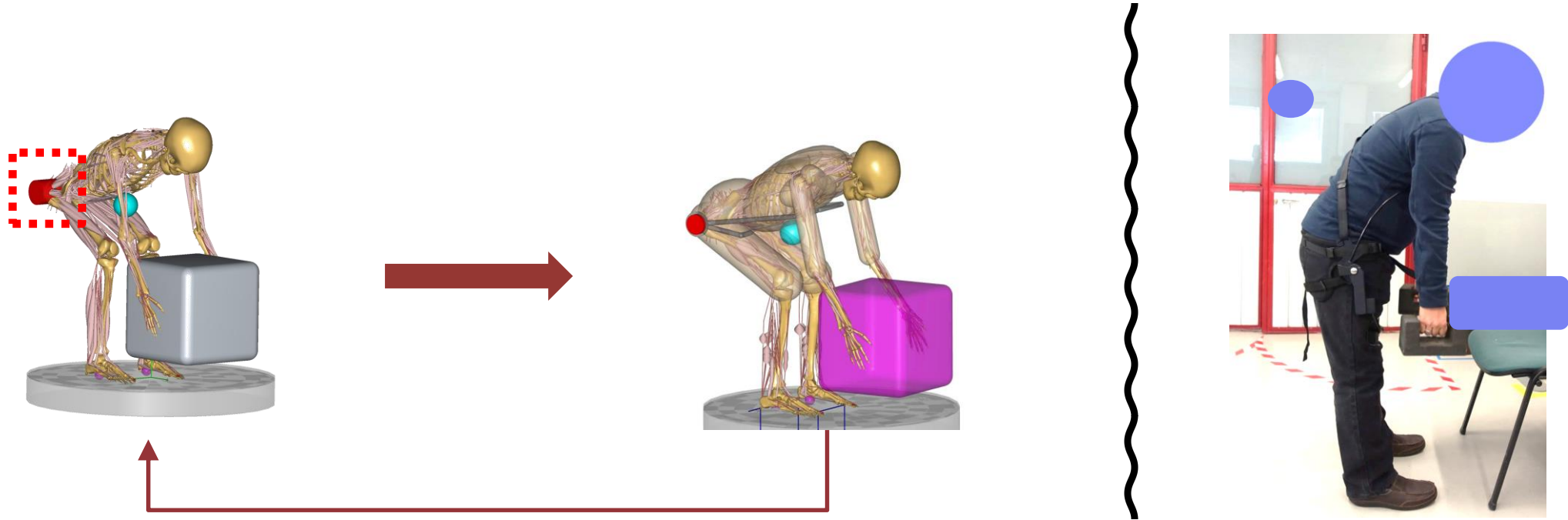


Case 3: Waist Assist Exoskeleton

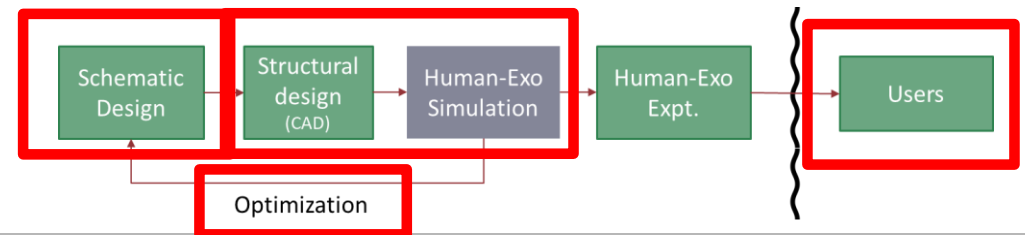
What spring stiffness value minimizes
Metabolic cost?



Case 3: Waist Assist Exo



Parameter Study (in AnyBody): Hip spring stiffness



Case 3: Waist Assist Exo

Pain Point 1

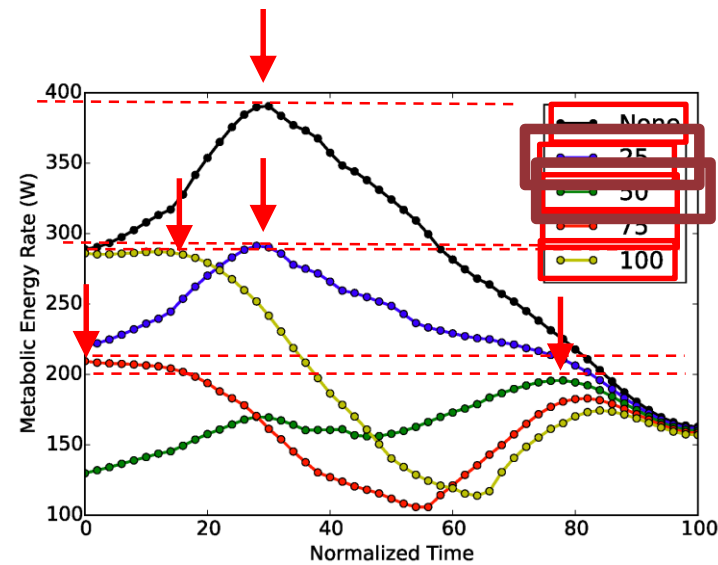
Reducing time and costs of R&D

Pain Point 2

Proving benefits & safety to users

- Exo reduces metabolic energy cost? By How much?

- Higher stiffness does not guarantee lower Metabolic power
- Low metabolic cost must be combined with other criterion



ANYBODY
Outputs

- Human**
 - Muscle forces/activities
 - Joint forces
 - Metabolic Power
 - Kinematics
- Human-Exo Interaction**
 - Forces (straps, pads etc)
- Exo**
 - Actuator forces & power
 - Kinematics

Case 3: Waist Assist Exo

Pain Point 1

Reducing time and costs of R&D

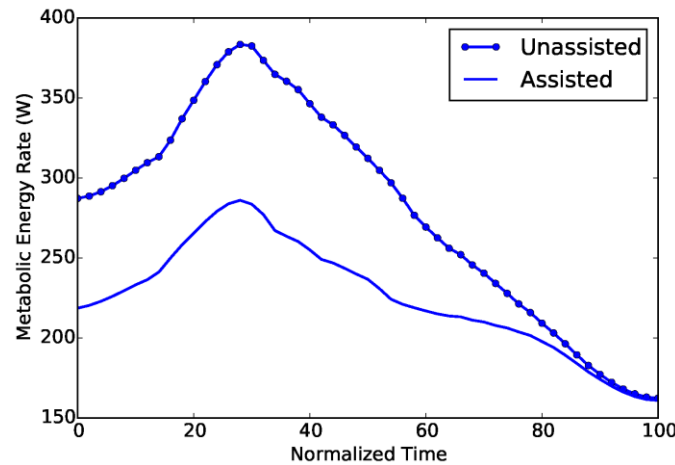
Pain Point 2

Proving benefits & safety to users

- Exo reduces metabolic energy cost? By How much?

$K = 25 \text{ Nm/rad}$

% Device Benefit	Joint Reaction (L4/L5)	Metabolic Cost
Box-lifting	21.4	19.6



ANYBODY
Outputs

- Human**
 - Muscle forces/activities
 - Joint forces
 - Metabolic Power
 - Kinematics
- Human-Exo Interaction**
 - Forces (straps, pads etc)
- Exo**
 - Actuator forces & power
 - Kinematics

Case 3: Waist Assist Exo

Pain Point 1

Reducing time and costs of R&D

Pain Point 2

Proving benefits & safety to users

- Exo reduces metabolic energy cost? By How much?
- Simulations unravel unintuitive relationships between Exo performance metrics

ANYBODY Outputs

Human

- Muscle forces/activities
- Joint forces
- Metabolic Power
- Kinematics

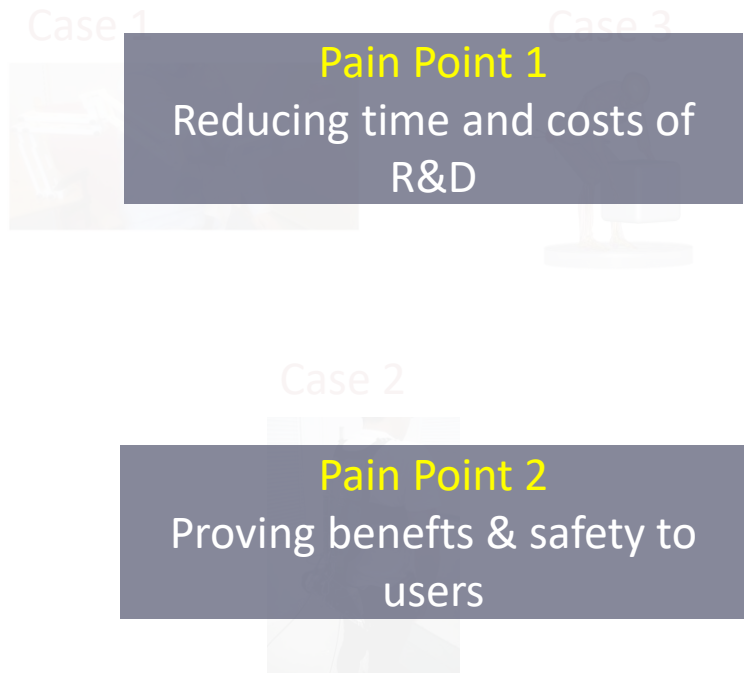
Human-Exo Interaction

- Forces (straps, pads etc)

Exo

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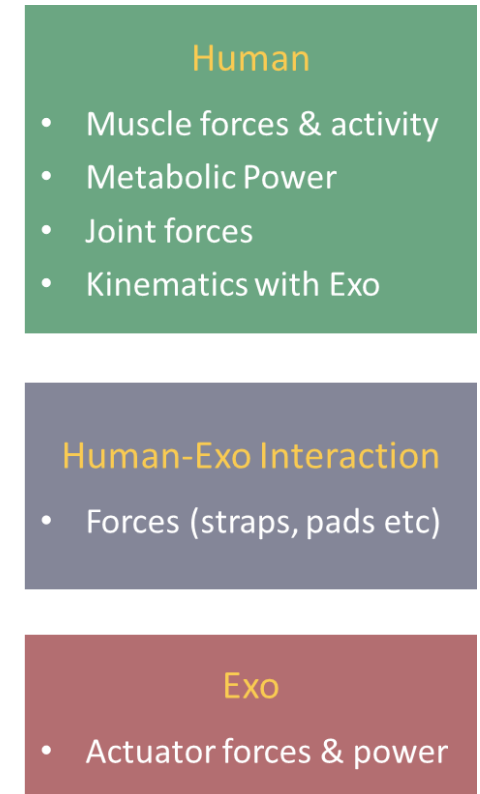
Take Home Messages



Pain Points facing Exo designers can be addressed by musculoskeletal simulation



Value of simulation outputs

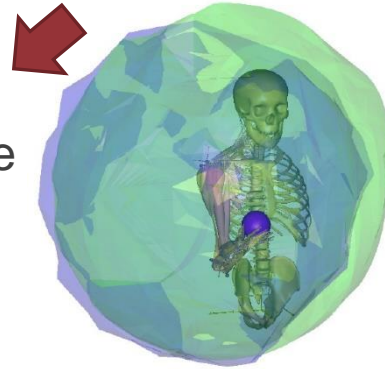


Acknowledgements

- Exoskeleton and Simulation videos
- Dr. Shaoping Bai, Aalborg University
- Dr. Taro Nakamura, Chuo University

Upcoming webcasts

26 Apr: Model validation using the anatomical reachable 3-D workspace



www.anybodytech.com

- Events, dates, publication list, ...

Events:

21-23 Mar: WearRAcon 2018, Scottsdale, AZ

26-29 Mar: CMBBE 2018 in Lisbon

30 Apr- 4 May: Advanced PhD course on Musculoskeletal modeling. Aalborg University, Denmark.

The screenshot shows the AnyBody Technology website. The navigation menu includes: ANYBODY TECHNOLOGY, INDUSTRIES, SOFTWARE, SERVICES, EVENTS, DOWNLOADS, CONTACT, and a search bar. The main content area is titled "Industry" and lists various categories: orthopedics, automotive, exoskeleton, aerospace, defense, work place ergonomics, consumer products, furniture, and sports. Below this is "Body part" with categories: hand, wrist, upper extremity, shoulder, trunk, spine, hip, lower extremity, knee, ankle, foot, mandible, elbow, and leg. The "Research area" section lists: seating, gait, methods, FEA, animal, occupational health, validation, sensitivity analysis, and rehab. A "Year" filter is set to "565 Publications". The "Keywords" section lists: upper extremity, validation, spine, hip, knee, and gait. The main content area displays a list of publications:

Year	Publications	Keywords
2018	Chander DS, Cavatorta MP (2018), "Multi-directional one-handed strength assessments using AnyBody Modeling Systems", Appl. Ergon., vol. 67, pp. 225-236. [DOI, WWW]	NEW upper extremity validation
2017	Angelini L, Damm P, Zander T, Arshad R, Di Puccio F, Schmidt H (2017), "Effect of arm swinging on lumbar spine and hip joint forces", J. Biomech.. [DOI]	spine hip knee gait
2017	Arshad R, Angelini L, Zander T, Di Puccio F, El-Rich M, Schmidt H (2017), "Spinal loads and	spine gait

 **Meet us?** Send email to sales@anybodytech.com

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WearRAcon 18

SEE WHAT LEADS

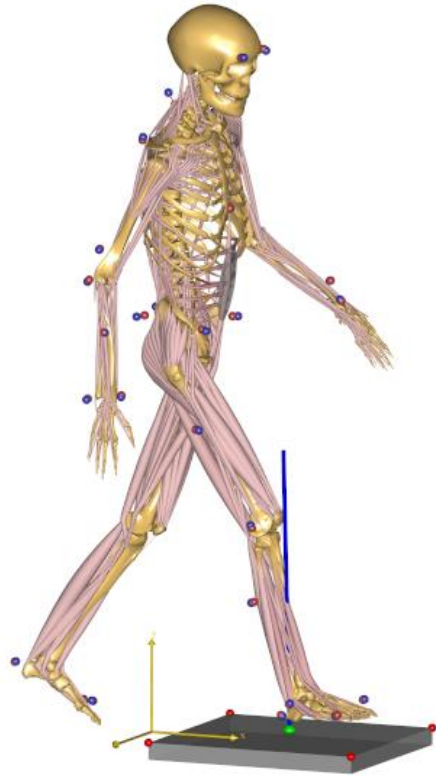
Jørgen Rosenkilde, CEO
AnyBody Technology

*March 21 – 23, 2018.
Scottsdale Plaza Resort
Scottsdale, AZ (USA)*



Meet us? Send email to sales@anybodytech.com

Time for questions:



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