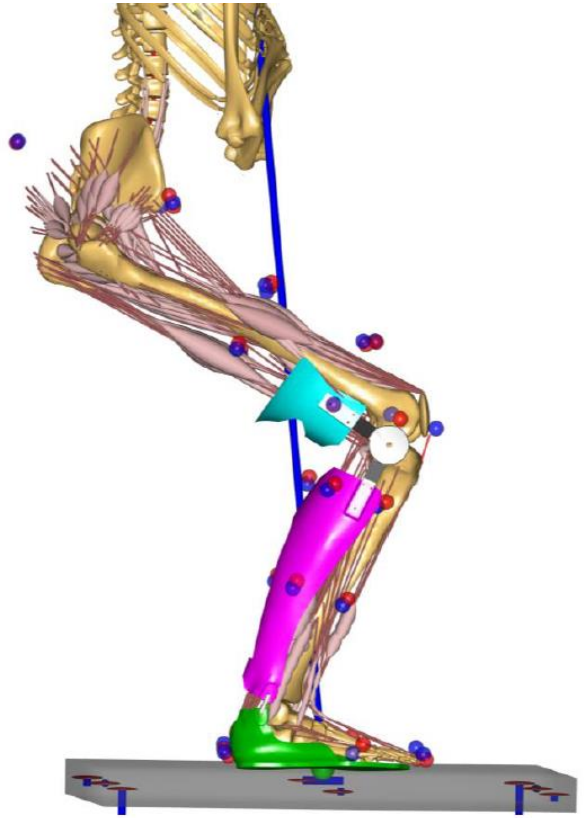
The webcast will start in a few minutes….

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:

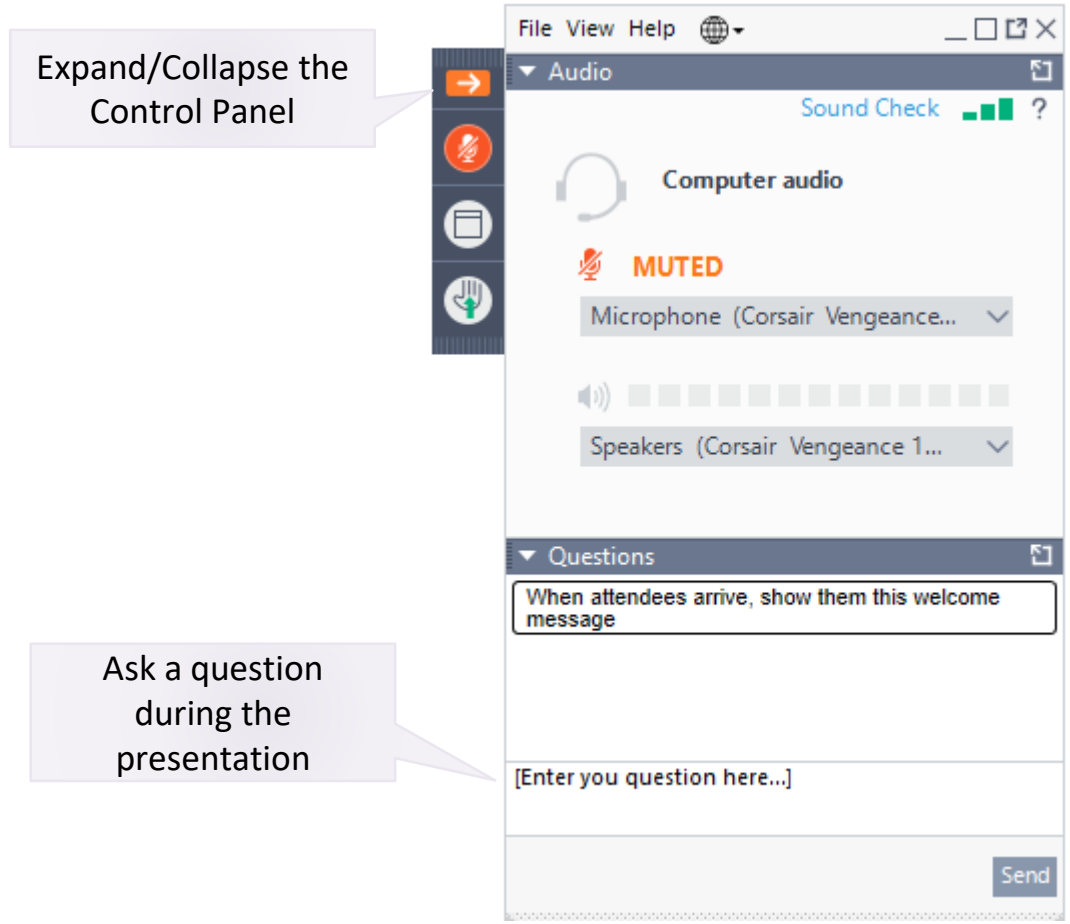
Pavel Galibarov
Sr. Engineer
AnyBody Technology

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.



Musculoskeletal Simulation

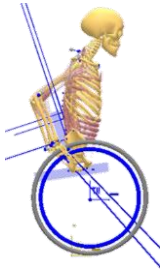
Motion data

Kinematics + Forces

ANYBODY Modeling System

Body Loads

- Joint moments
- Muscle forces
- Joint reaction forces

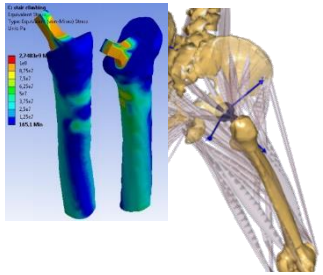


Product Design Optimization

Movement Analysis

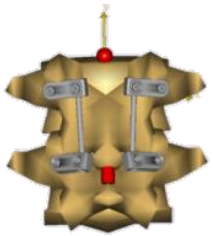
ANYBODY Modeling System

Ergonomic Analysis



Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation



ANYBODY TECHNOLOGY

Simulations for Human-Centered Exoskeleton Design

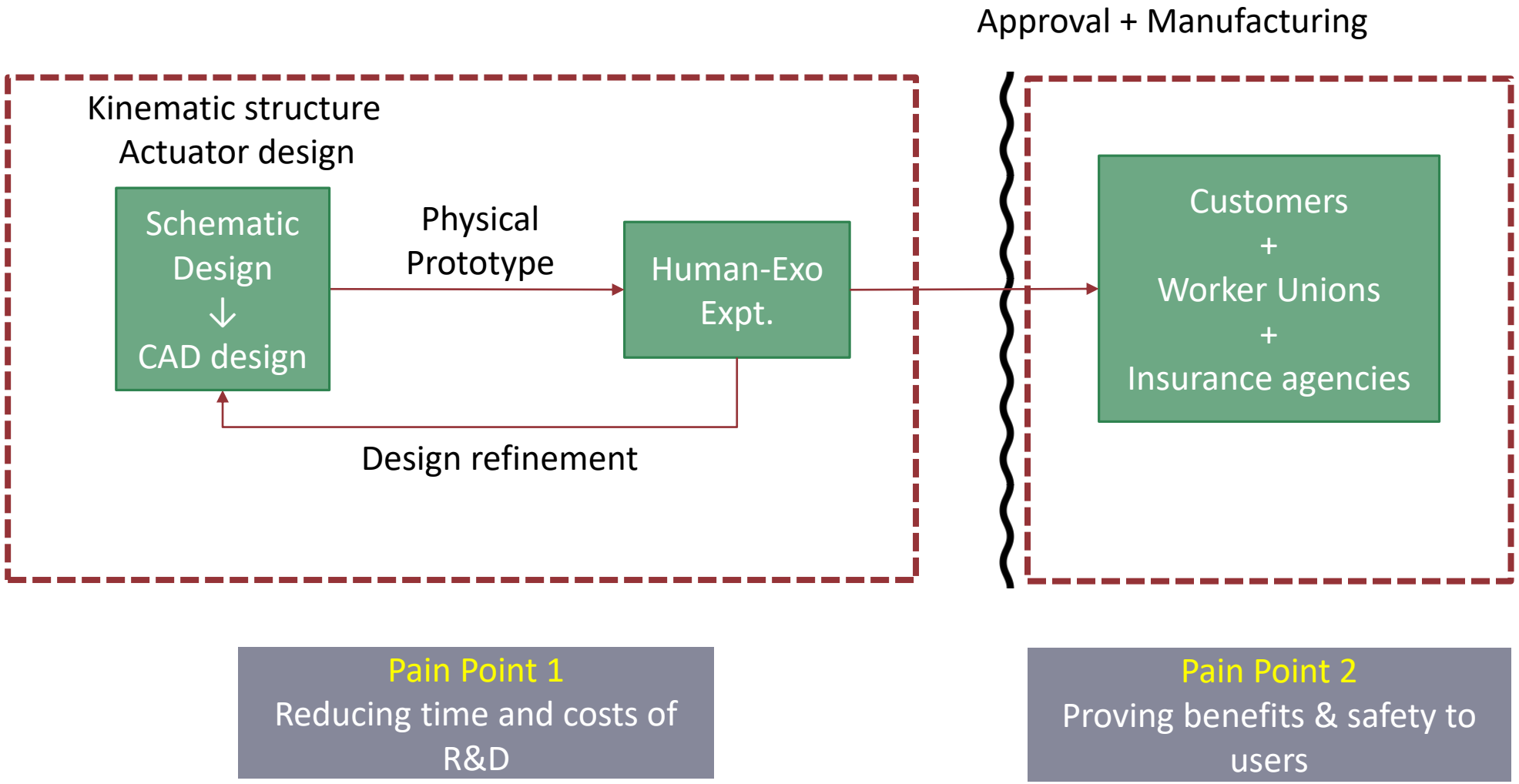
Outline

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

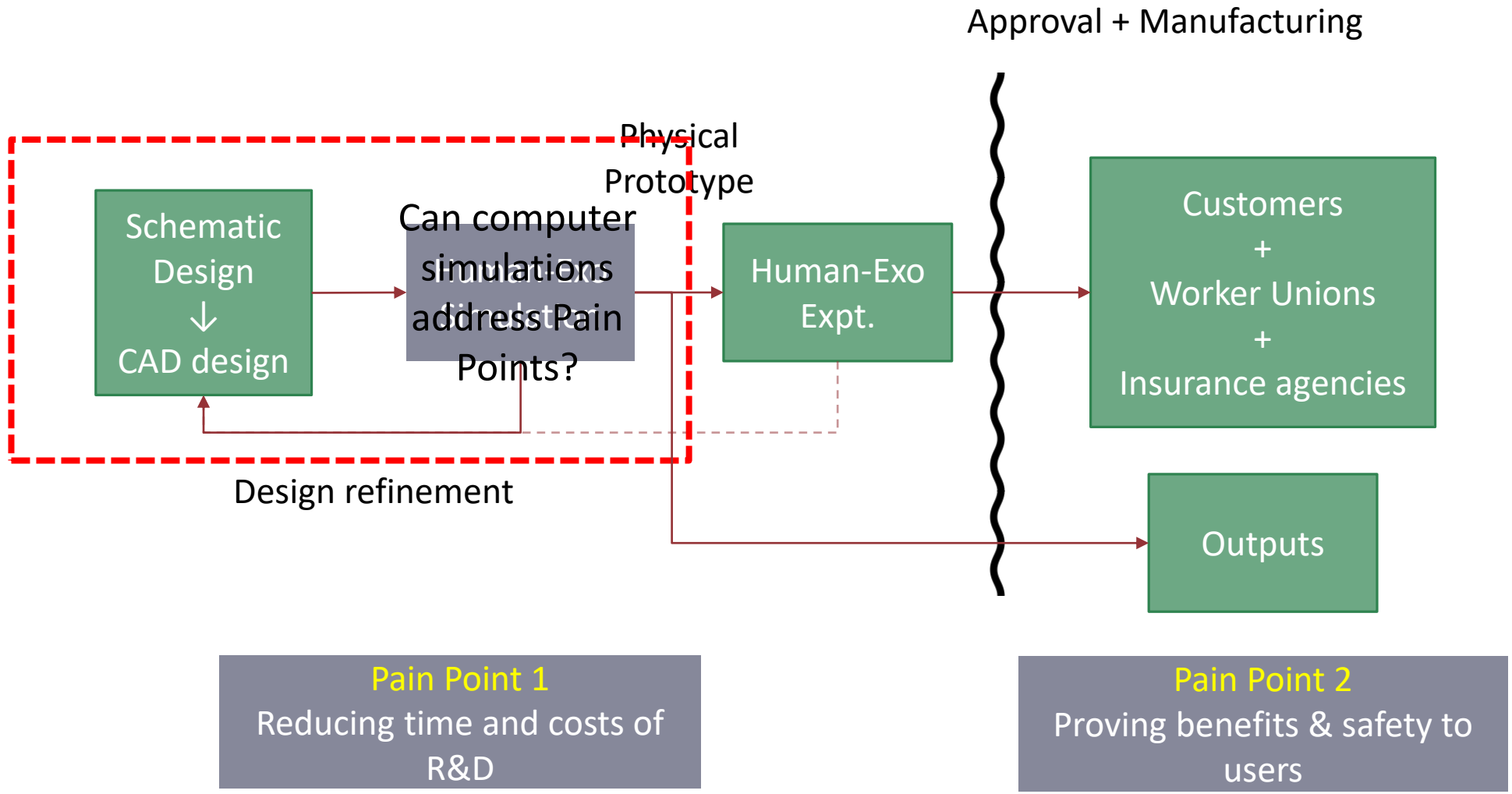
Act 1

The ‘Pain points’ and Human Exo-Simulations

The Design Cycle



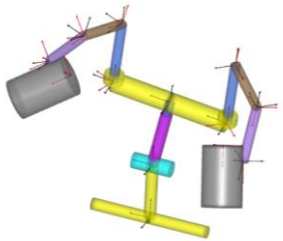
The Design Cycle

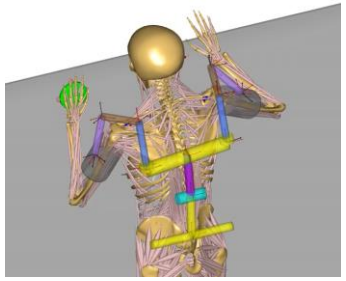


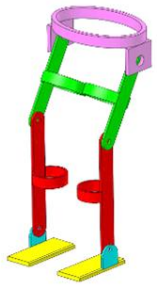
Human-Exo Simulation

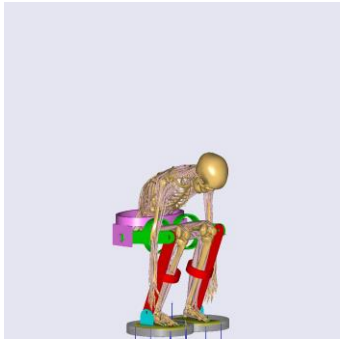
Human-Exo Simulation

Schematic Design ↓ CAD design → Human-Exo Simulation → Output









Musculoskeletal Simulation →

ANYBODY Modeling System

Human

- Muscle forces/activites
- 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

Musculoskeletal Simulation

AnyBody Modeling System™ Simulation Outputs

Human

- Muscle forces/activites
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Human-Exo Interaction

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Exo

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- Kinematics

Webcast Goals

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefts & safety to users

How can Pain Points be addressed by simulation outputs

AnyBody Modeling System™ Simulation Outputs

Human

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

Human-Exo Interaction

- Forces (straps, pads etc)

Exo

- Actuator forces & power
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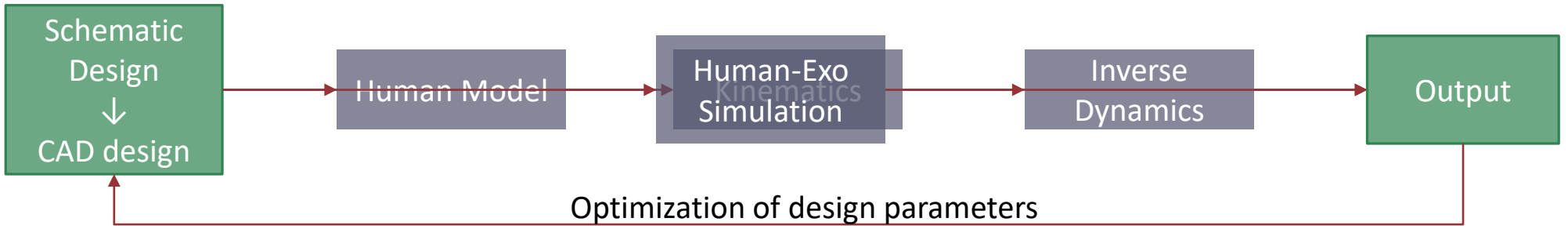
Human-Exo Simulation

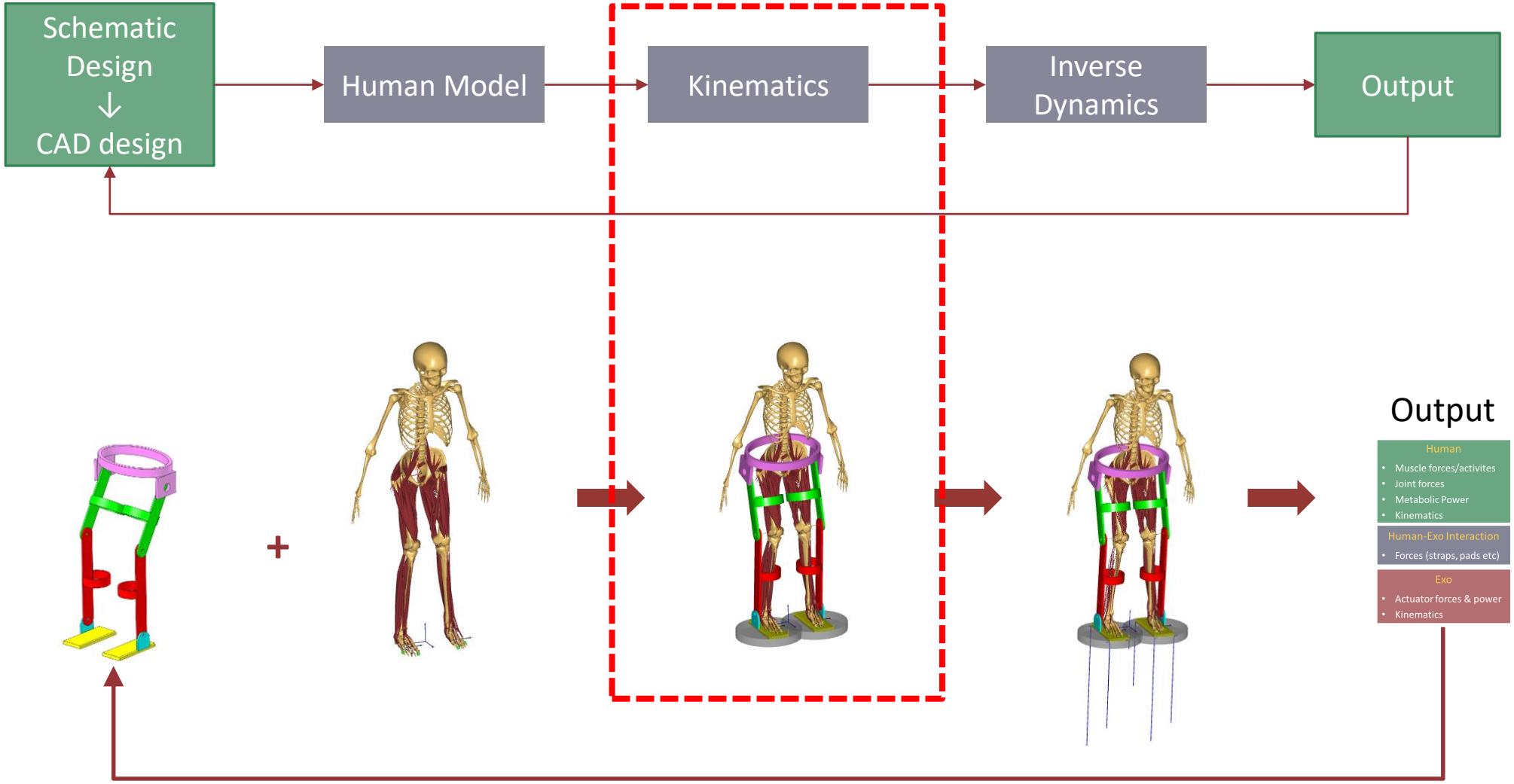


The AnyBody Modeling System™

Act 2

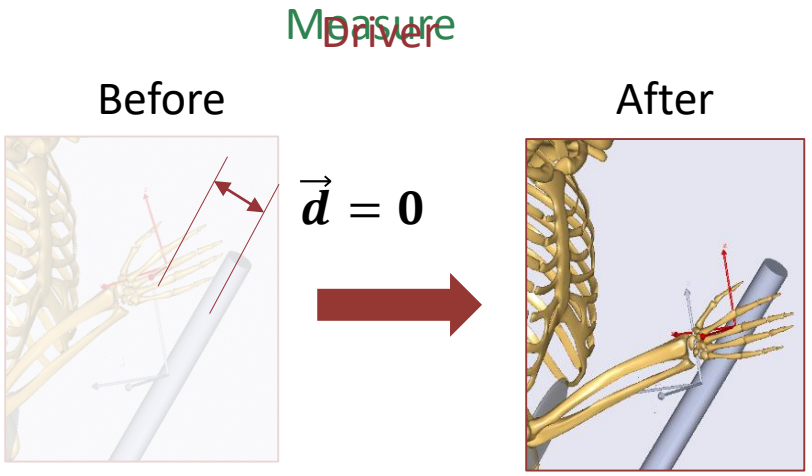
Simulations in the AnyBody Modeling System

Human-Exo Simulation



Kinematics in AnyBody

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

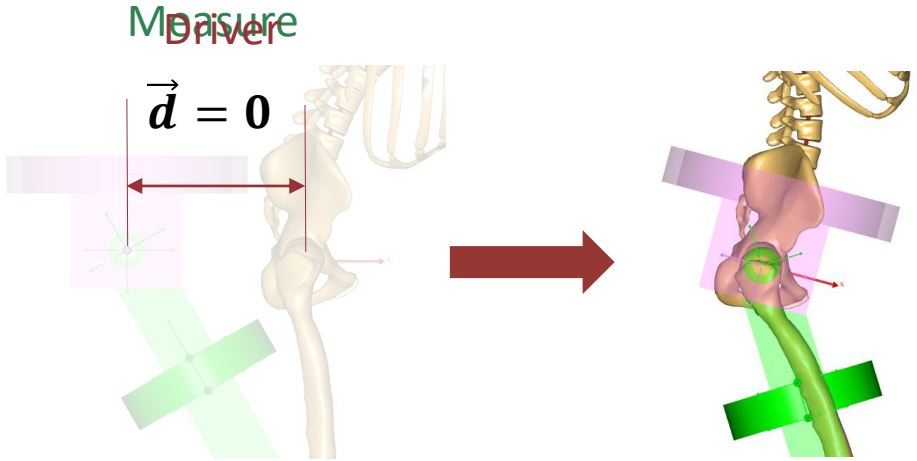


AnyBody Modeling System

Measures & Drivers

Measures specific geometry

Constrains measured values to 0 or f(t)



Kinematics in AnyBody

- **Step 1** - Assembling Exo on Human
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- **Step 2** - Prescribing Motion
  - Motion Capture data (.c3d or BVH files)

Kinematics in AnyBody

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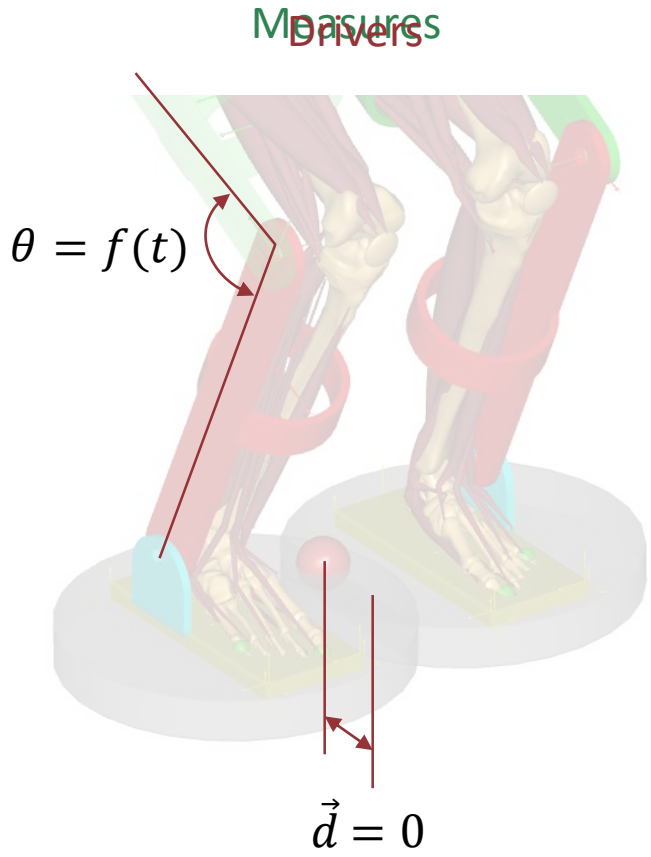
  - Synthesize motion



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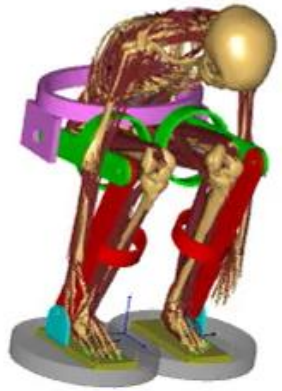
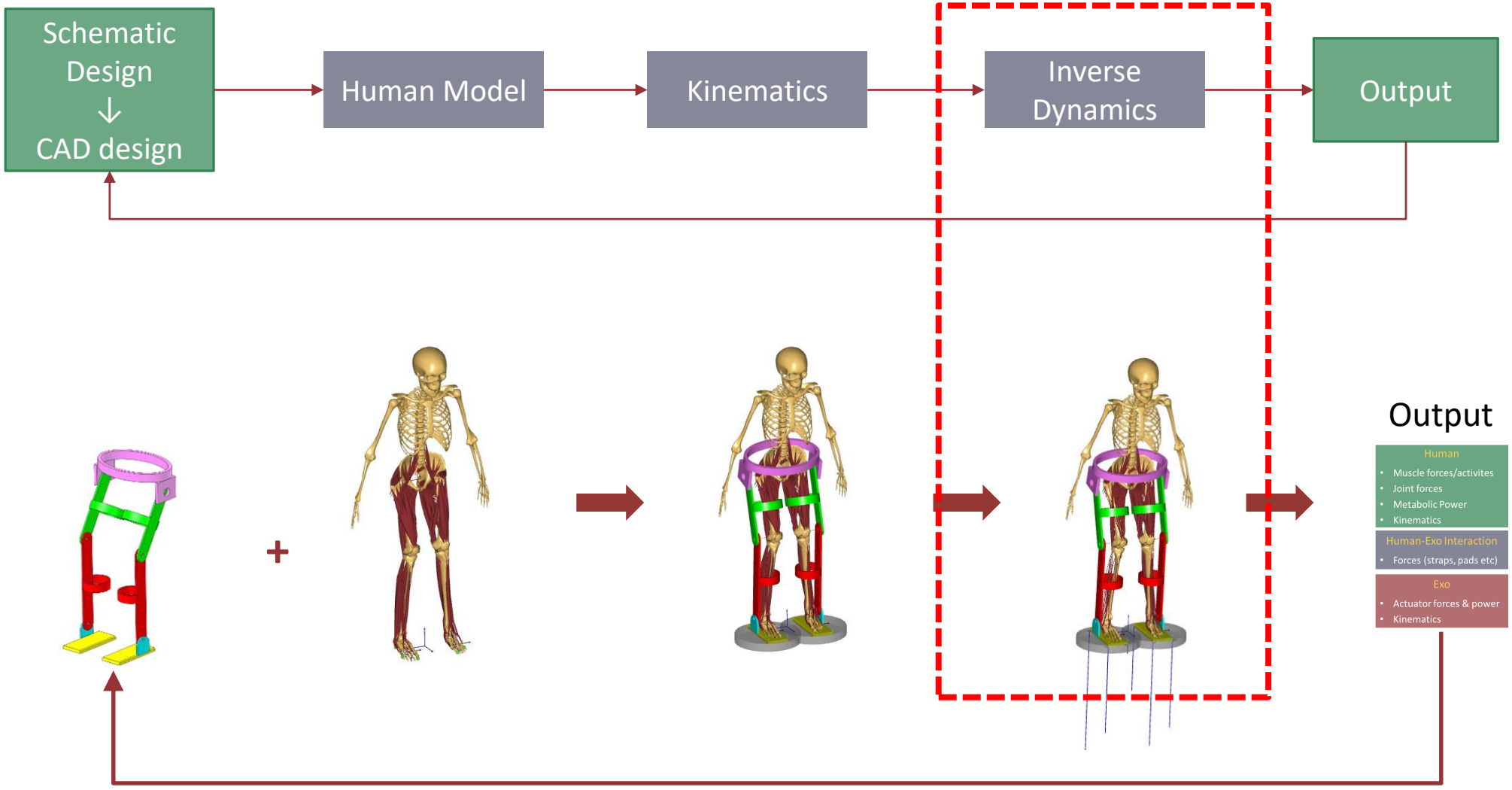
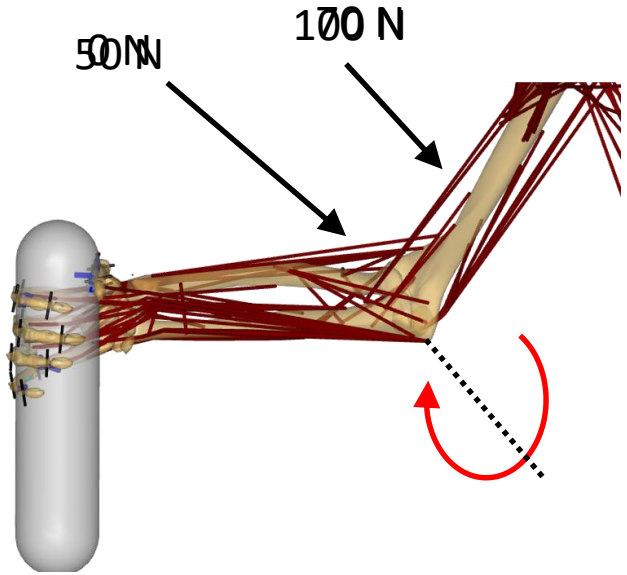


Human-Exo Simulation



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



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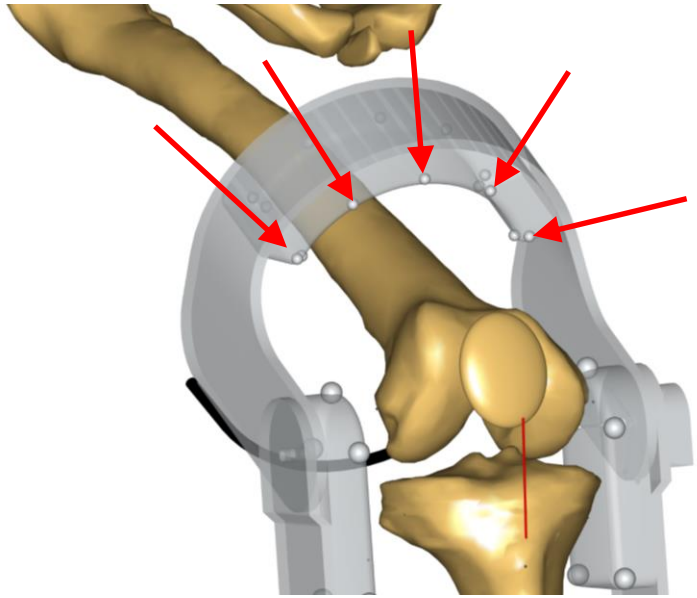

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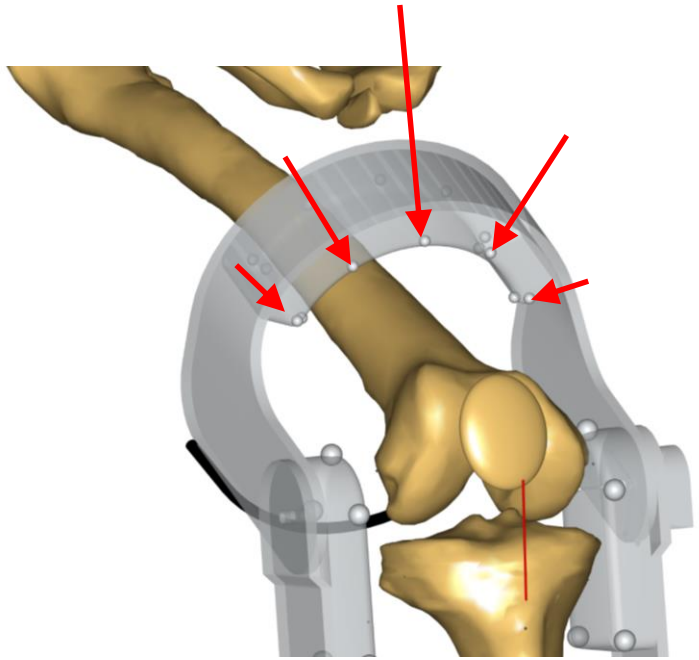
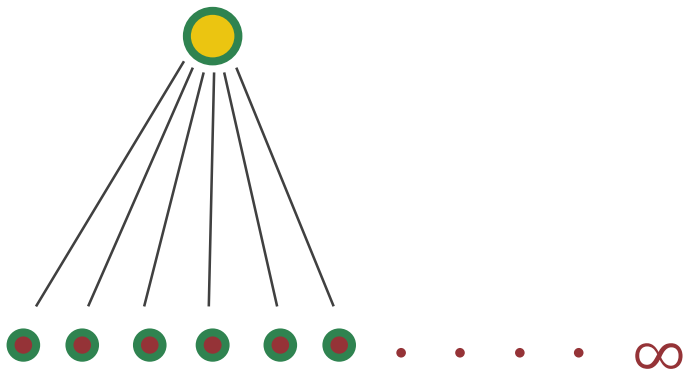
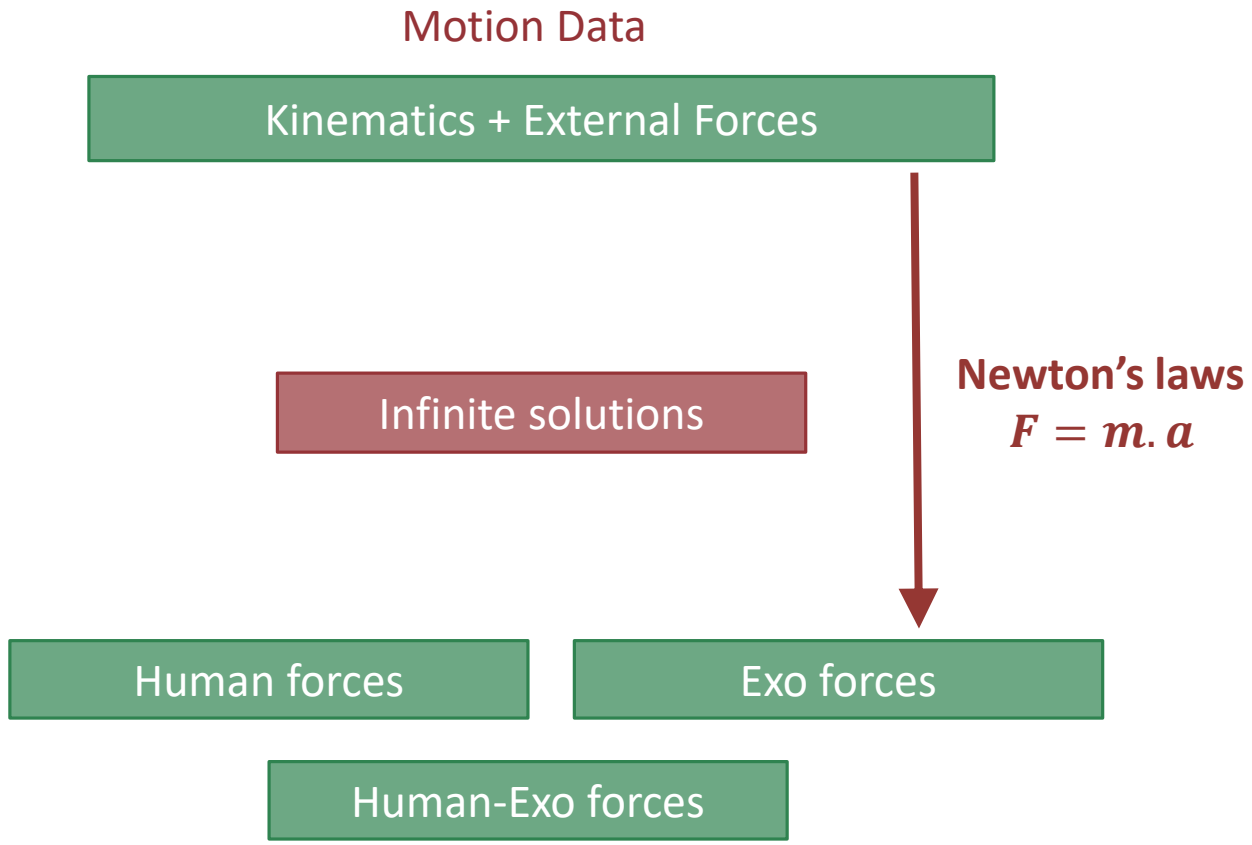
  - Muscle redundancy
  - Human-Exo reaction forces
  - How unique Forces be predicted?



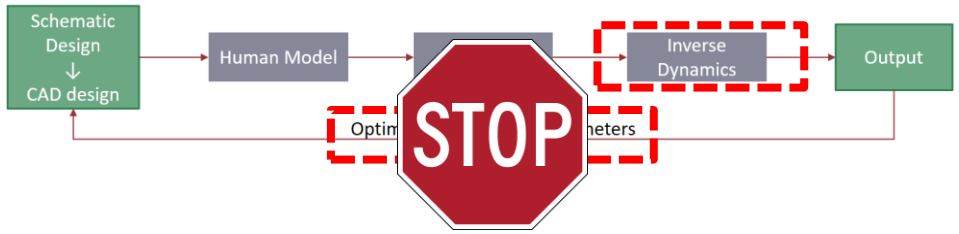
Inverse Dynamics in AnyBody

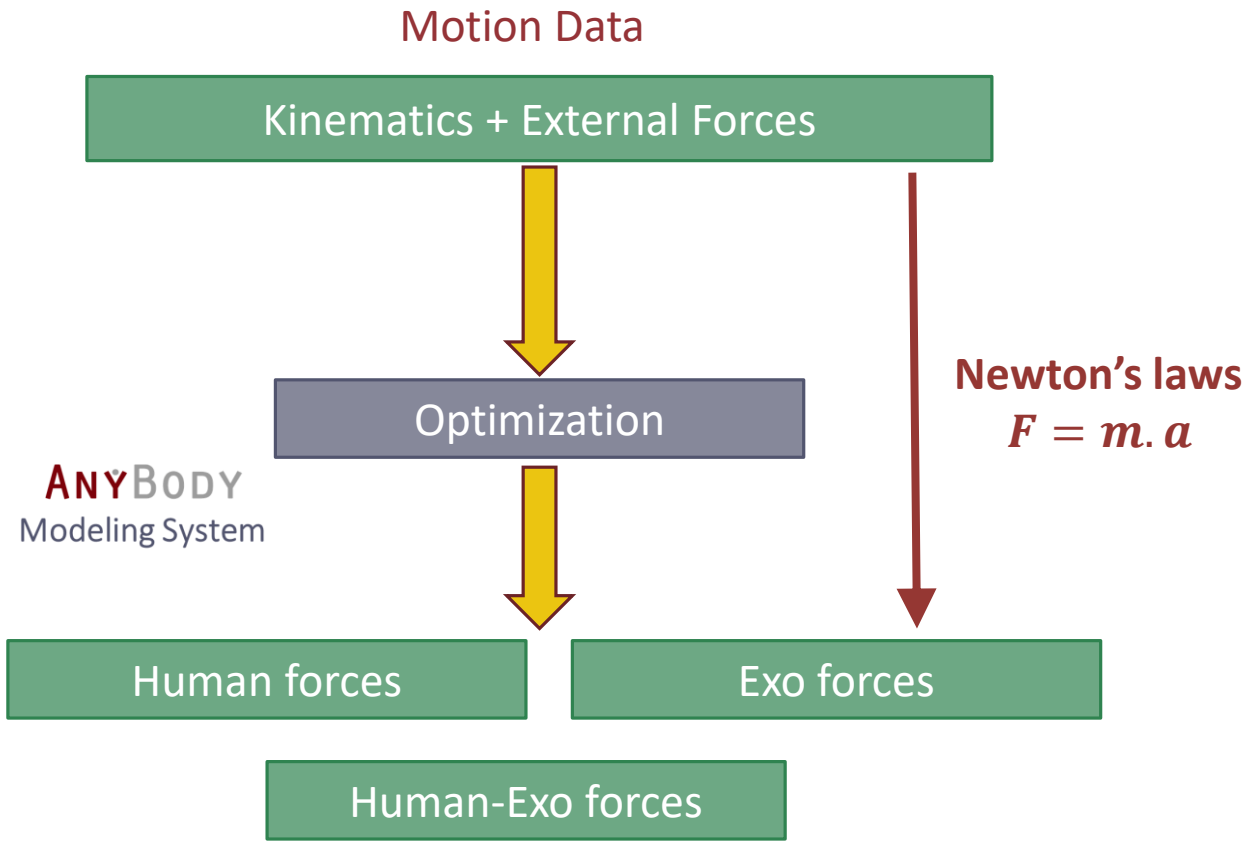


Infinite feasible solutions for forces



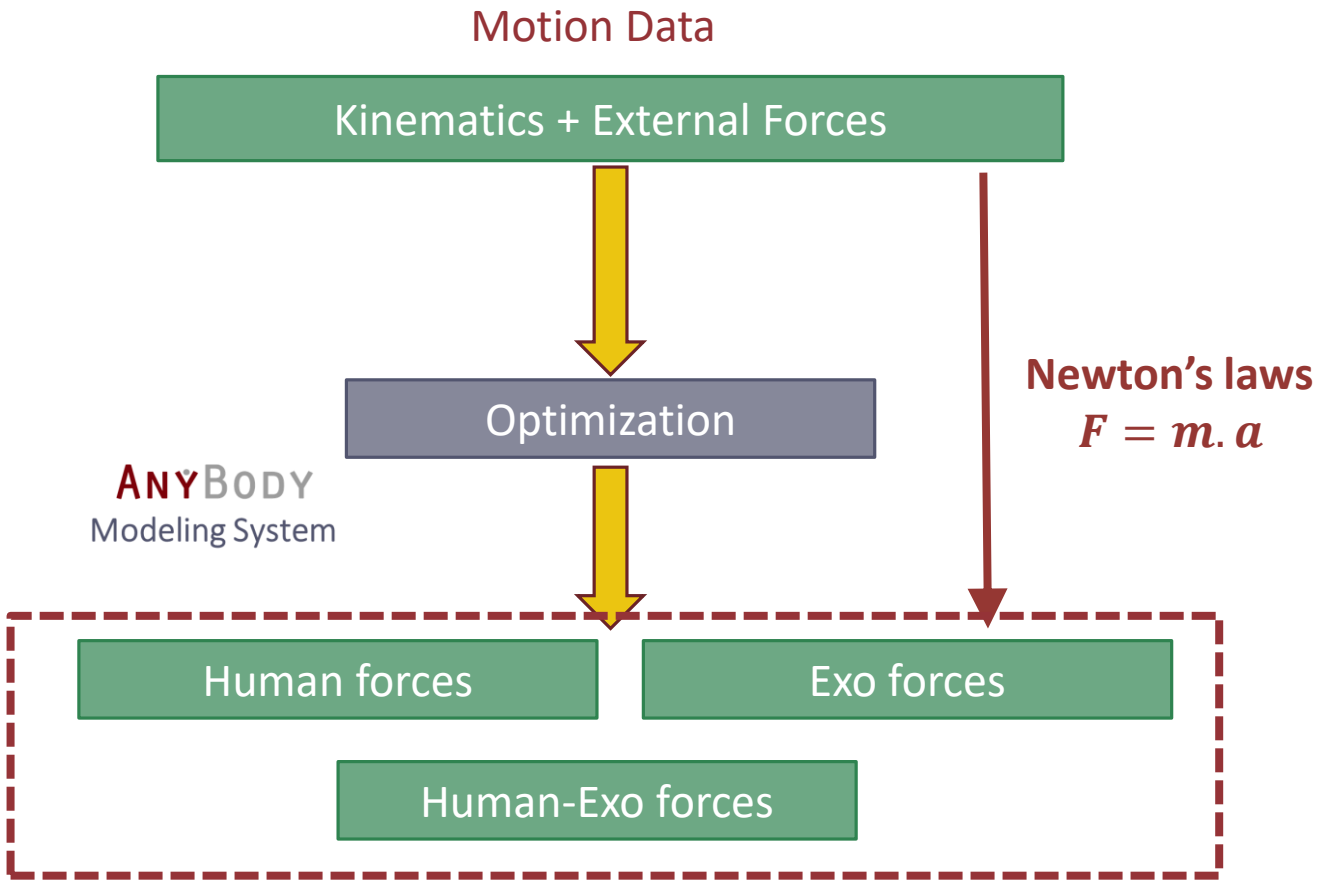
Inverse Dynamics in AnyBody



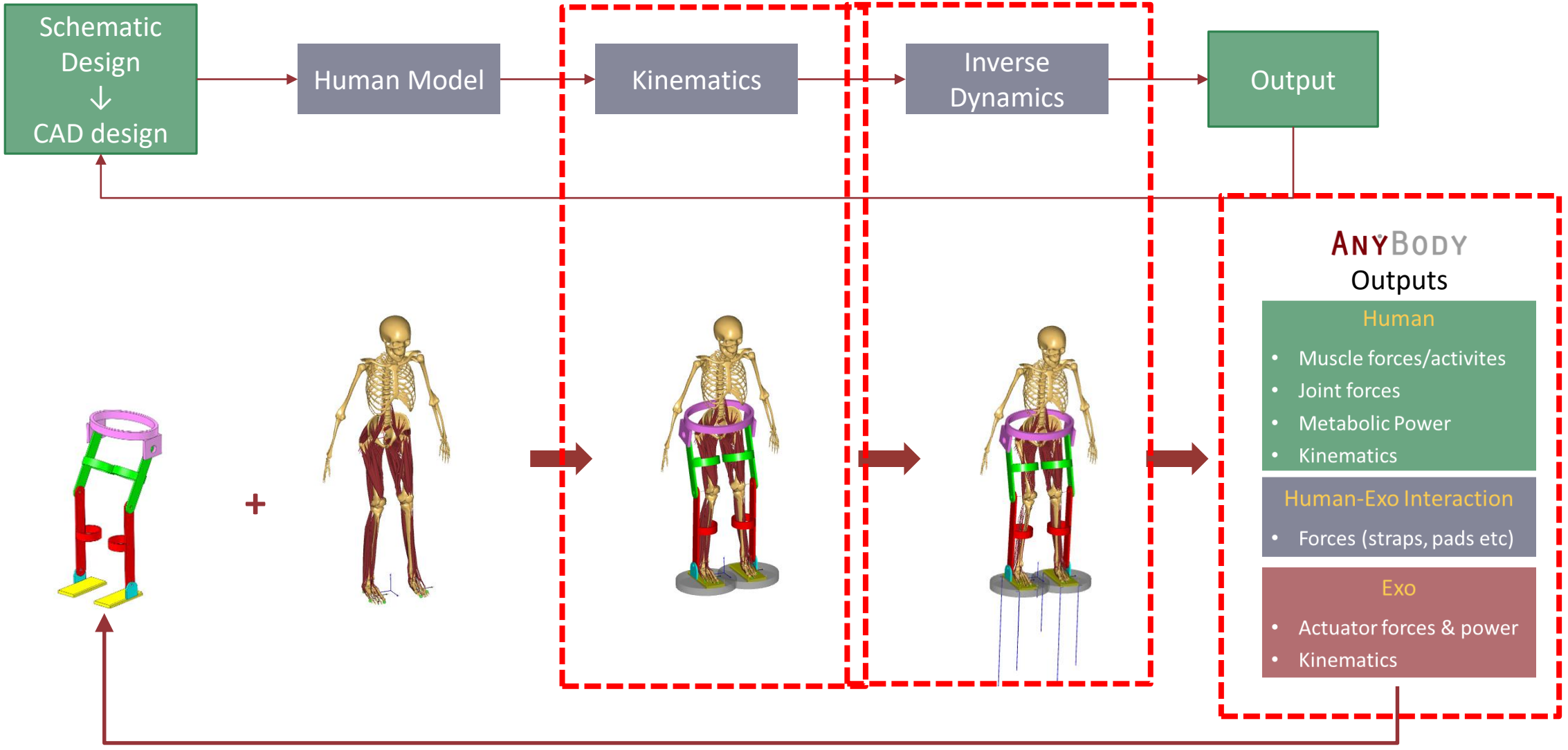


Inverse Dynamics in AnyBody

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



Human-Exo Simulation

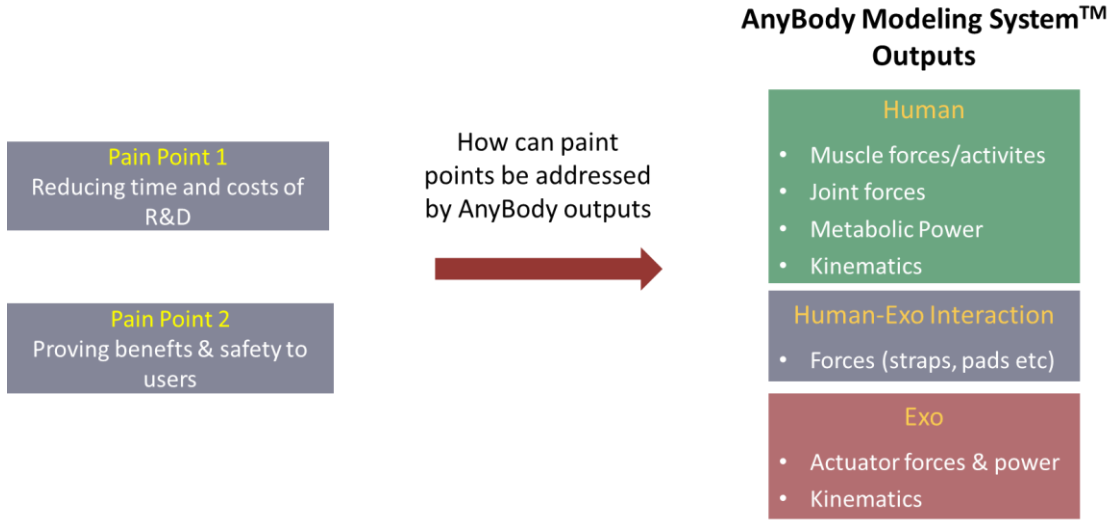


Act 3

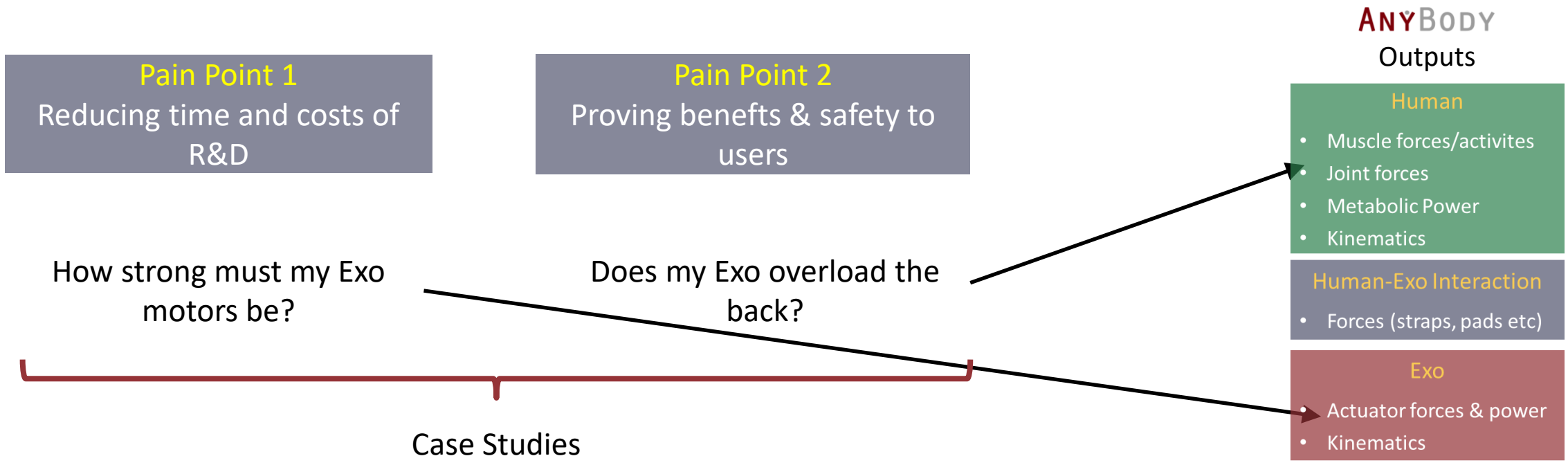
Case Studies

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

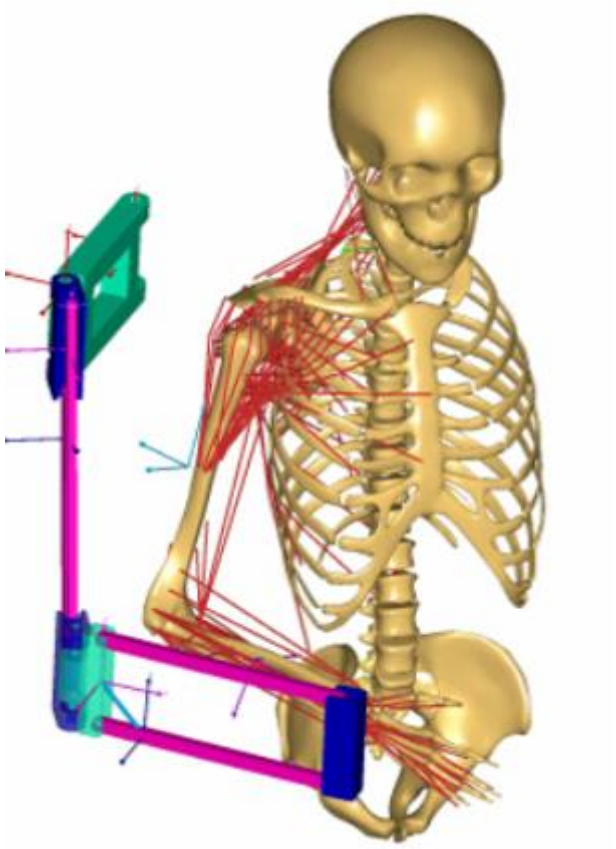
”A human-centered design optimization approach for robotic exoskeletons through biomechanical simulation”, (2017)

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

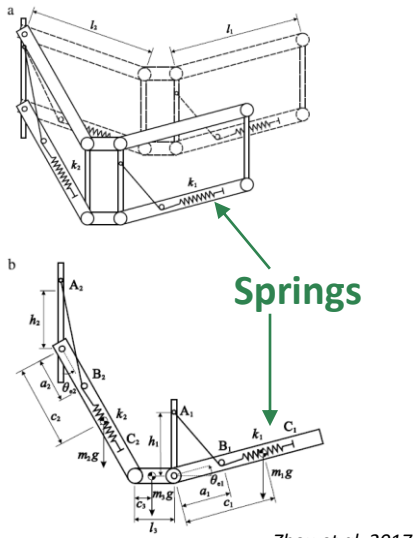


Case 1: Arm Exoskeleton

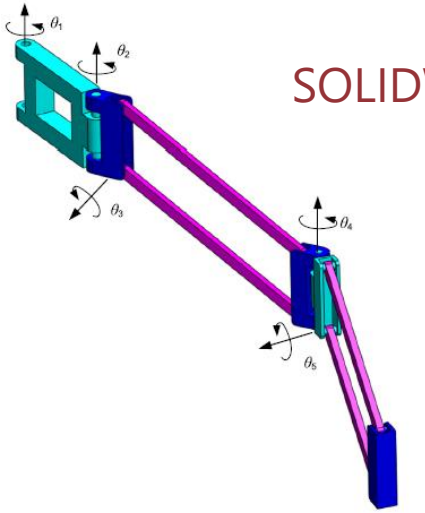
What are the ideal spring stiffnesses for the Exoskeleton?

Case 1: Arm Exoskeleton

Gravity compensation



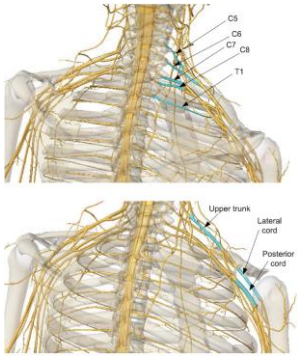
Zhou et al. 2017



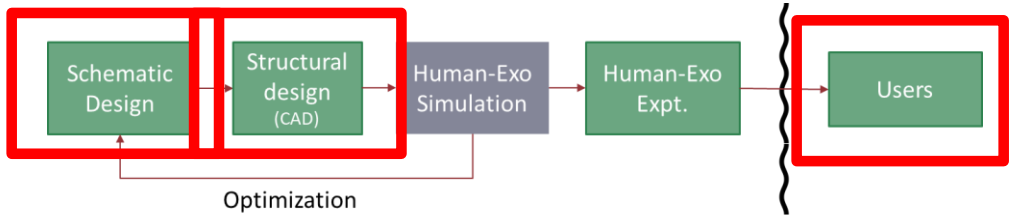
SOLIDWORKS

Zhou et al. 2017

Zhou et al. 2017

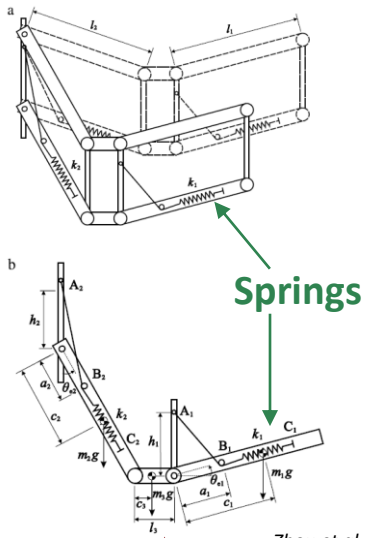


Paralysis of C7 nerve
Drinking motions



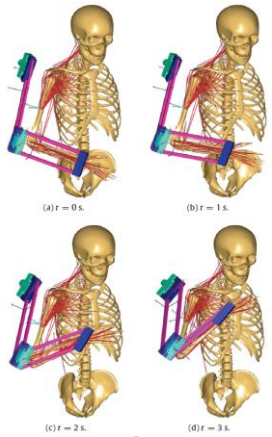
Case 1: Arm Exoskeleton

Gravity compensation



Zhou et al. 2017

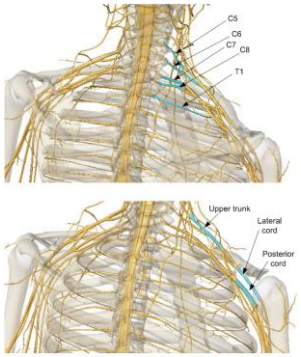
Weakened muscles, C7 injury



Zhou et al. 2017

Zhou et al. 2017

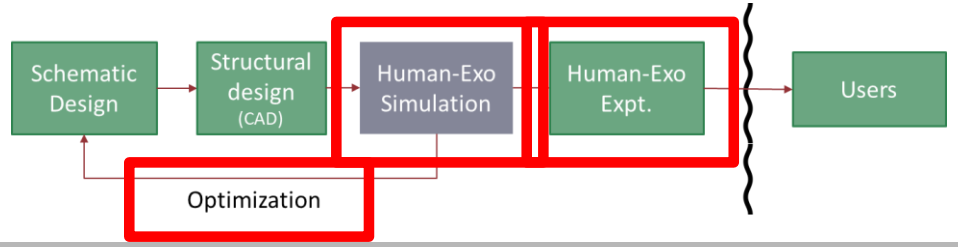
Zhou et al. 2017



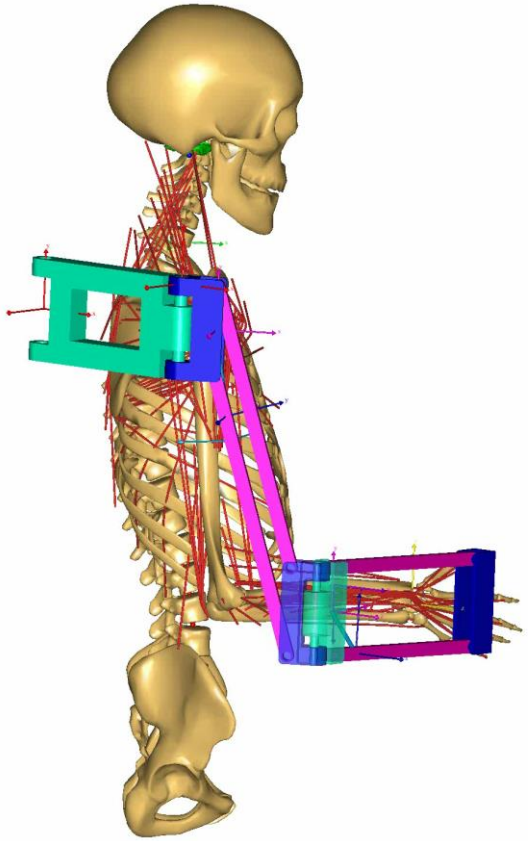
Paralysis of C7 nerve
Drinking motions

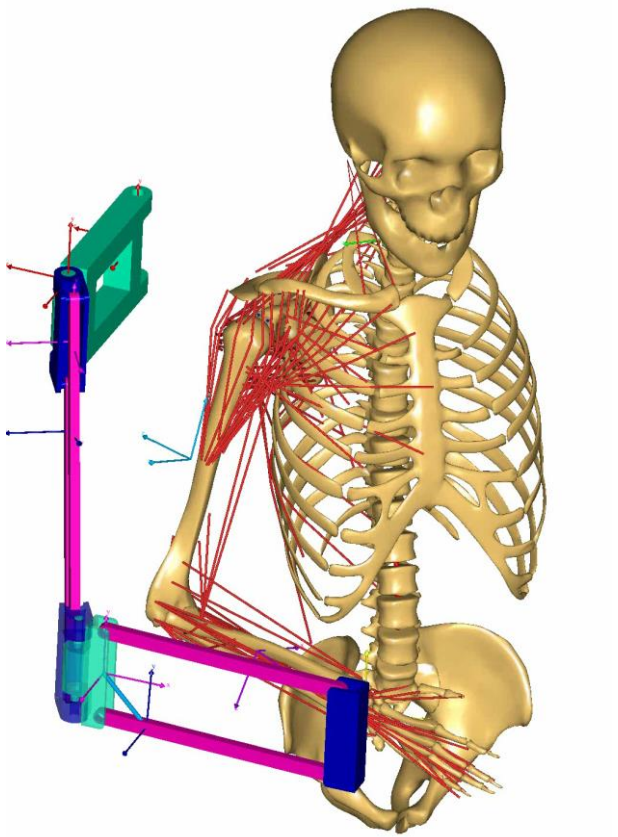
Optimize (External tool): Spring stiffness

Goal: Min muscle effort/activity



Case 1: Arm Exoskeleton





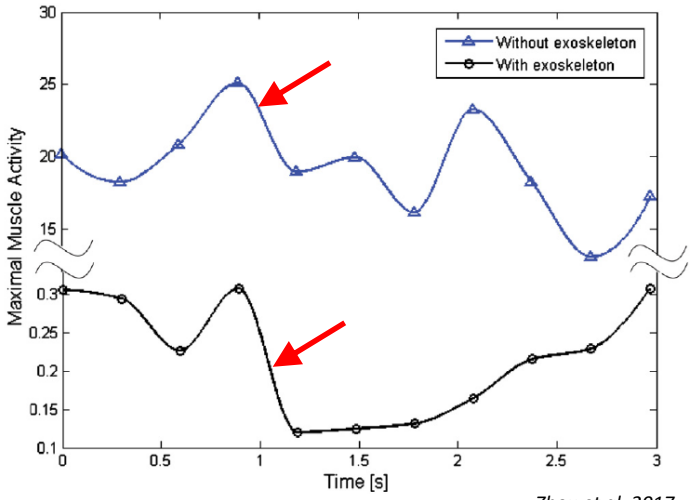
Courtesy Dr. Shaoping Bai, Aalborg University

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?



Zhou et al. 2017

ANYBODY

Outputs

Human
- Muscle forces/activites
- 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

Pain Point 2
Proving benefits & safety to users

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

ANYBODY
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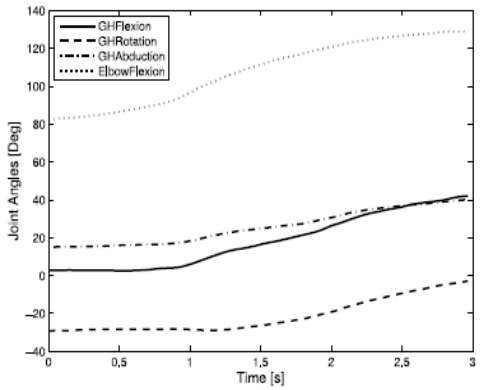
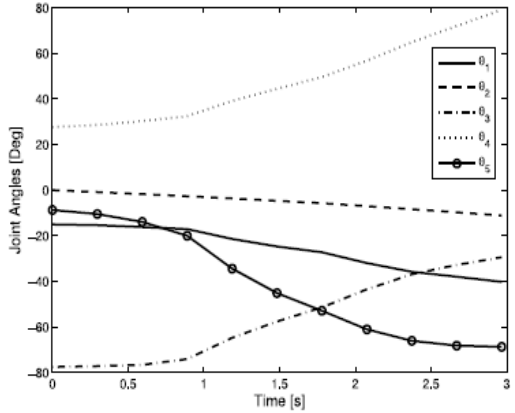
Human



Zhou et al. 2017

Exoskeleton



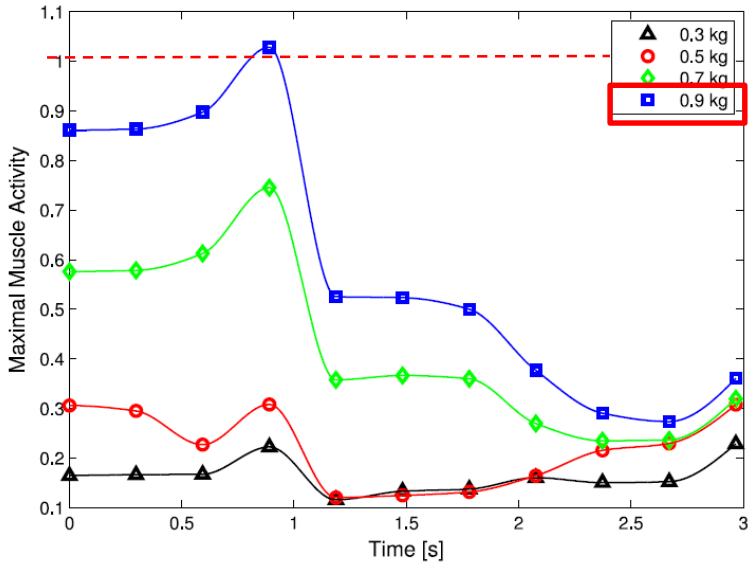
Zhou et al. 2017

Case 1: Arm Exoskeleton

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefts & safety to users

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



ANYBODY

Outputs

Human
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Human-Exo Interaction
- Forces (straps, pads etc)

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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?

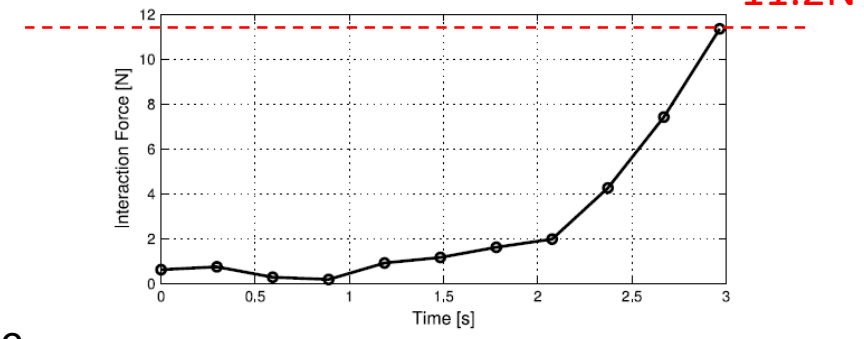
$$P_{max} \cdot A_{contact} = 16.7N > 11.2N$$

Max comfortable pressure

Device is comfortable to use

Pain Point 2
Proving benefts & safety to users

- Is the Exo comfortable to use?



Zhou et al. 2017

ANYBODY

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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/activites
- 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/

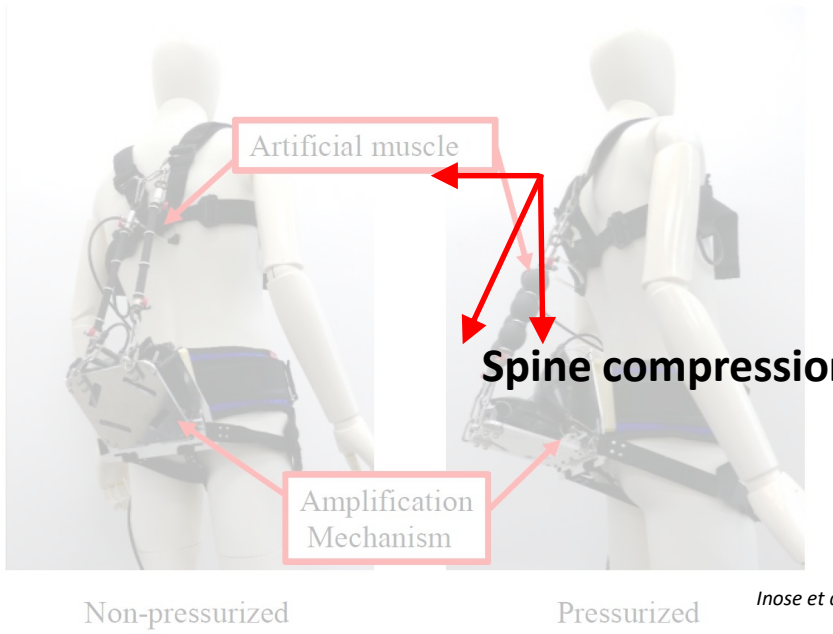
Case 2: Soft Waist Exoskeleton

Effectiveness of existing Exo designs, verified using AnyBody

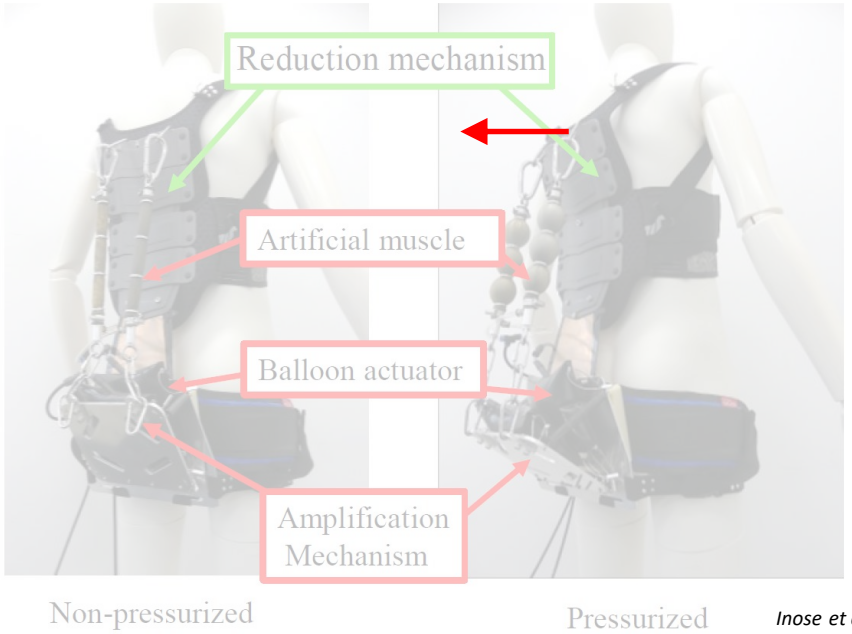
Courtesy Dr. Taro Nakamura, Chuo University

Case 2: Soft Waist Exoskeleton

Effectiveness of existing Exo designs, verified using AnyBody



Inose et al. 2017



Inose et al. 2017

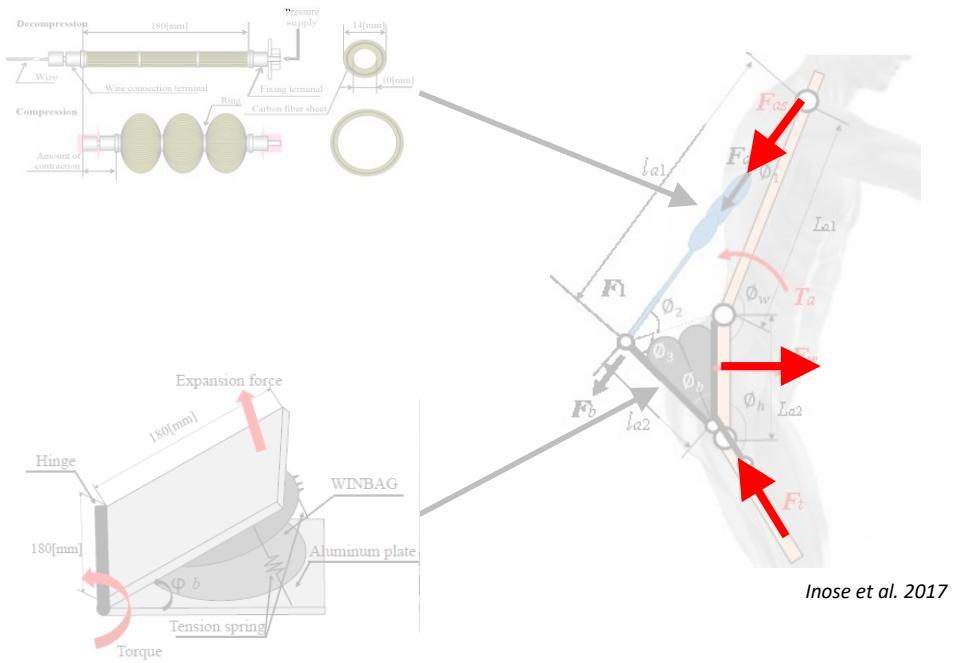
Old Design

New Design

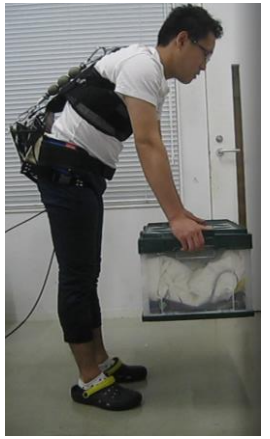
Case 2: Soft Waist Exoskeleton

Is the Exoskeleton safe for the user?

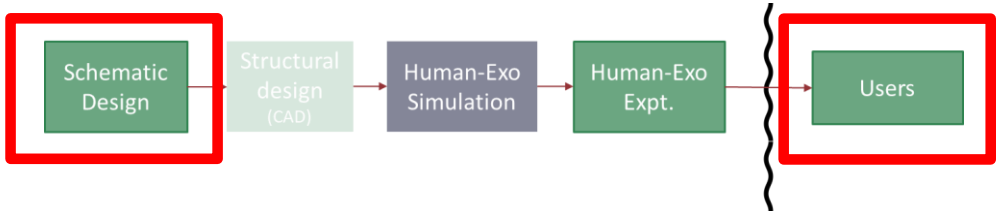
Case 2: Soft Waist Exoskeleton



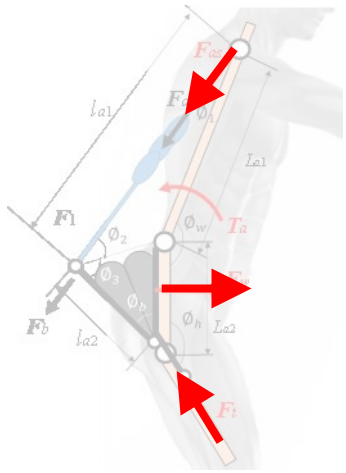
Inose et al. 2017



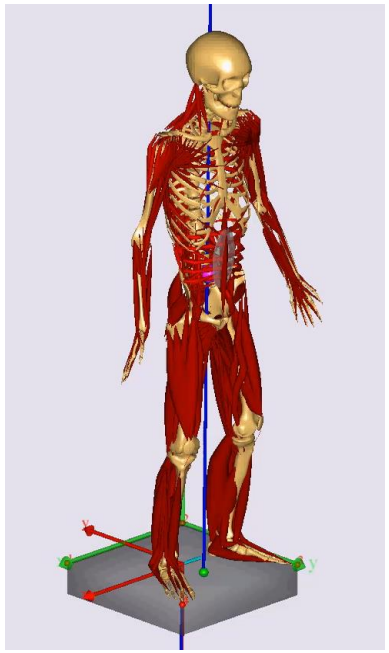
Stoop lifting



Case 2: Soft Waist Exoskeleton

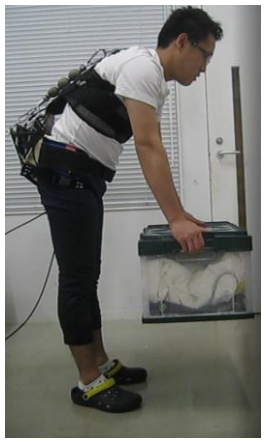


Inose et al. 2017

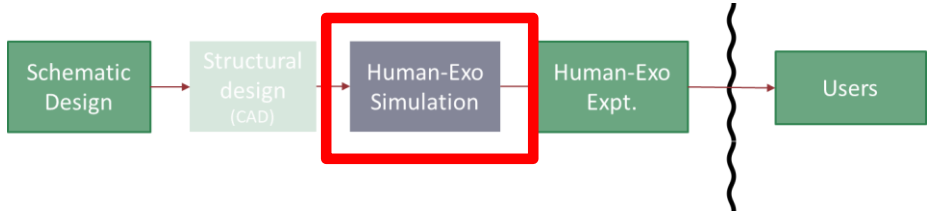


Courtesy Dr. Taro Nakamura, Chuo University

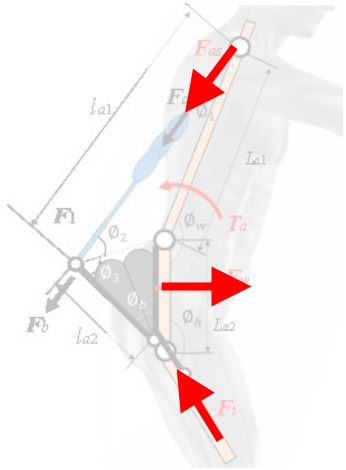
Same Motion
Different Conditions
1: No Exo



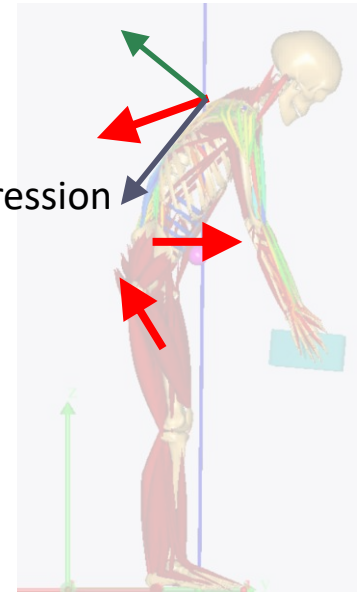
Stoop lifting



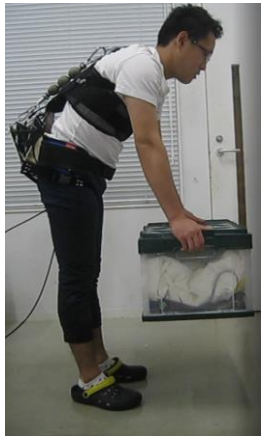
Case 2: Soft Waist Exoskeleton



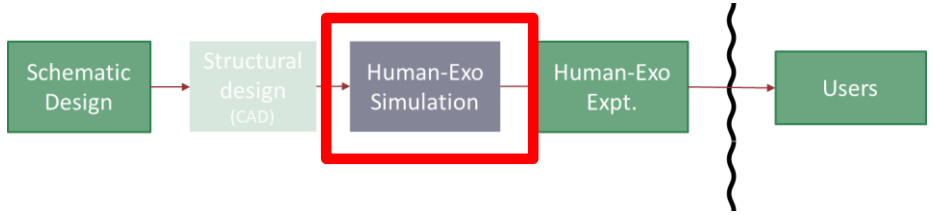
Inose et al. 2017



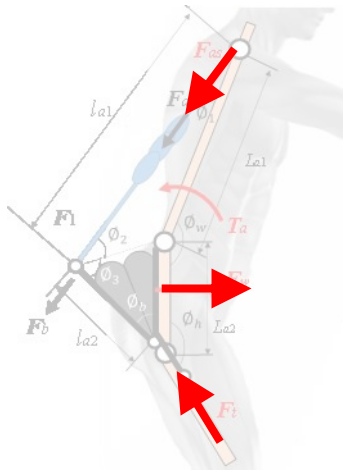
Same Motion
Different Conditions
1: No Exo
2: Old design



Stoop lifting



Case 2: Soft Waist Exoskeleton

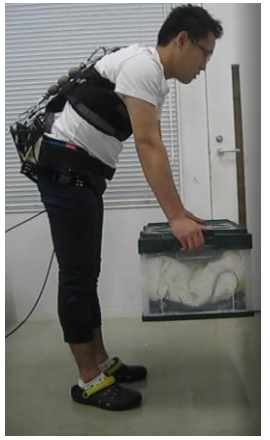


Inose et al. 2017

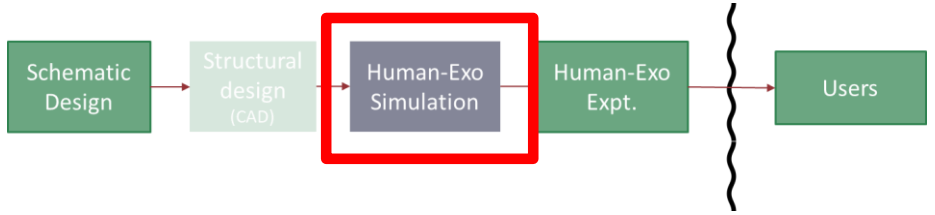
No Compression

Same Motion
Different Conditions

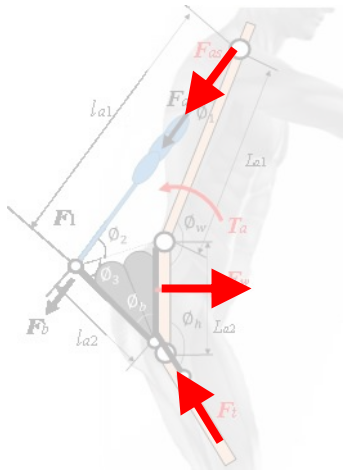
1: No Exo
2: Old design
3: New design



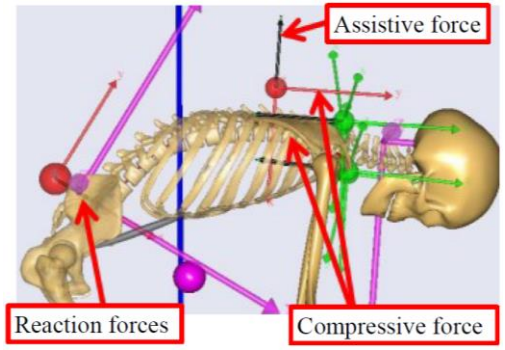
Stoop lifting



Case 2: Soft Waist Exoskeleton



Inose et al. 2017



Inose et al. 2017

Three conditions

1: No device

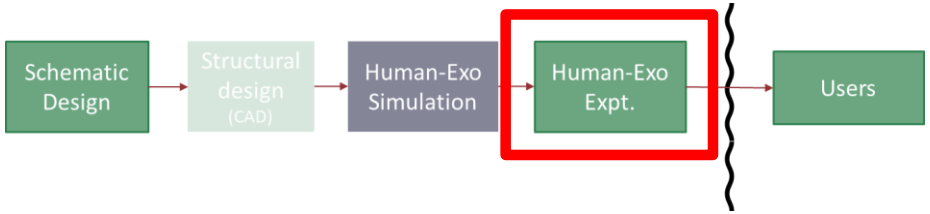
2: Old device

3: New device

Inose et al. 2017

EMG measured

Stoop lifting

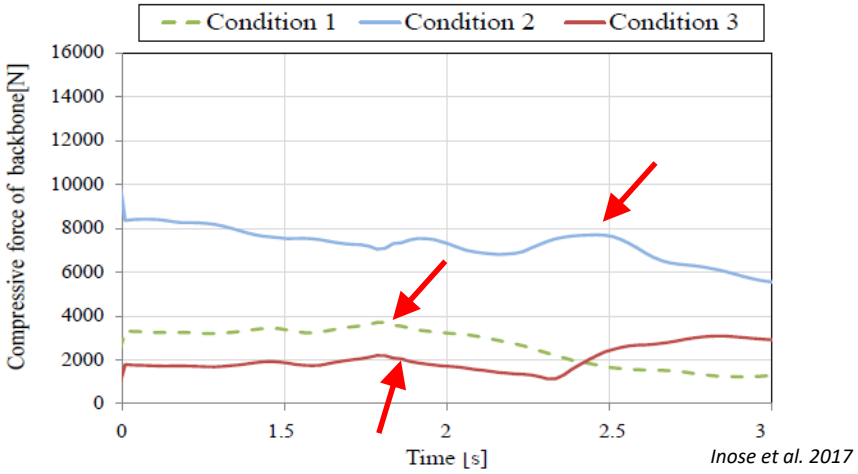


Case 2: Soft Waist Exoskeleton

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?



Inose et al. 2017

ANYBODY
Outputs

Human
- Muscle forces/activites
- 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?

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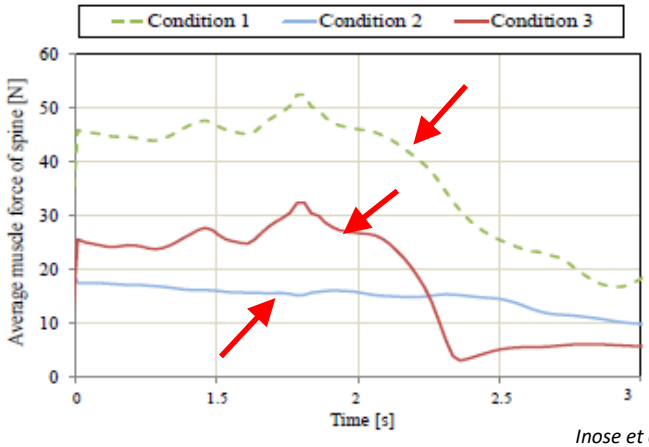
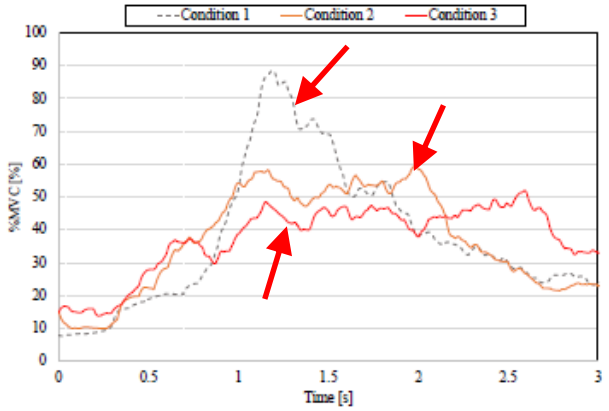
Average spinal muscle force



Inose et al. 2017

Erector Spinae EMG



Inose et al. 2017

Case 2: Soft Waist Exoskeleton

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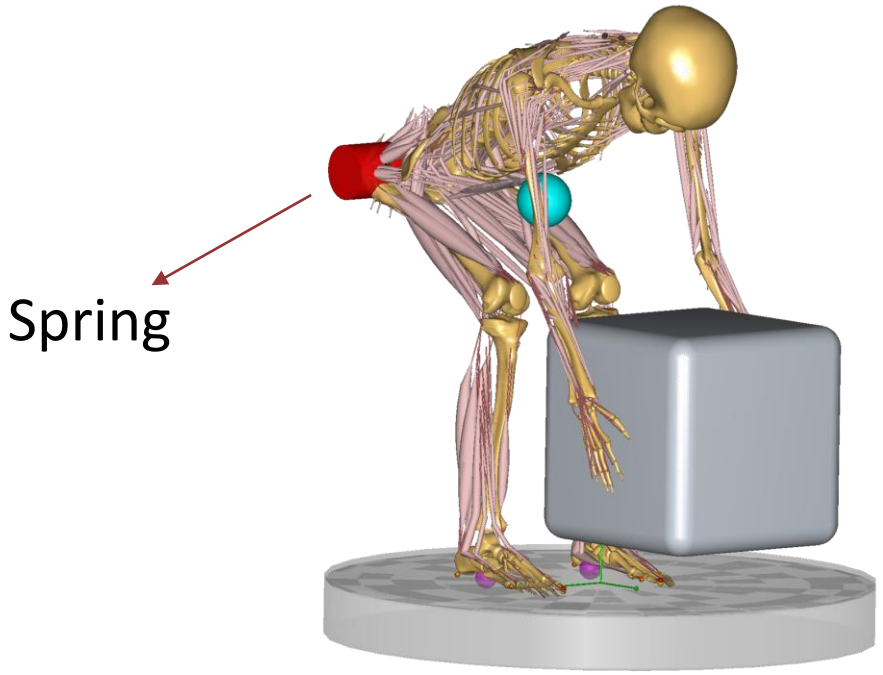
Case 3: Waist Assist Exoskeleton

Internal study done at AnyBody Technology

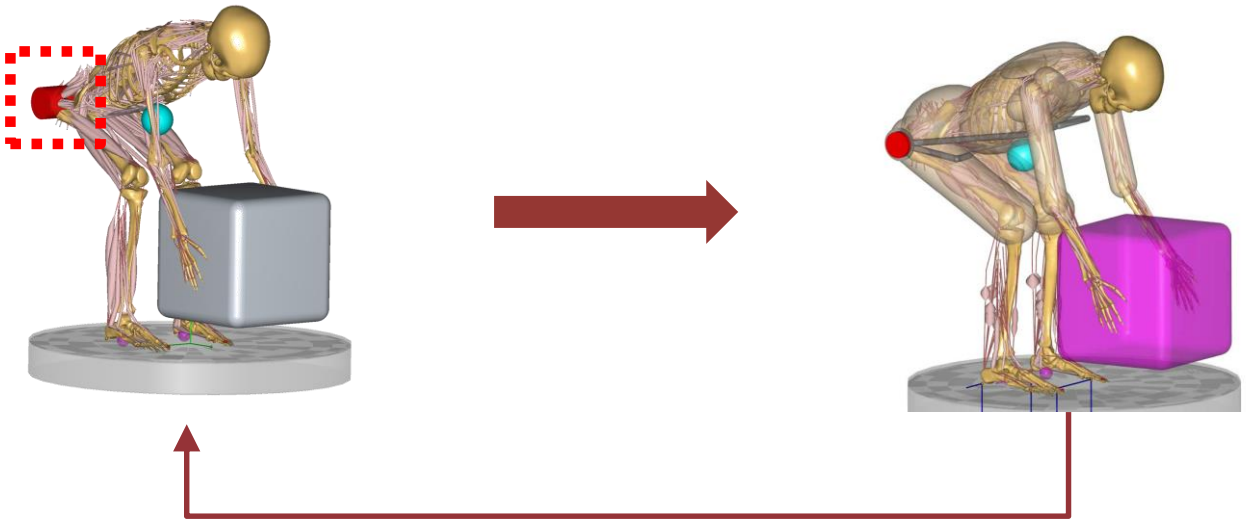
Case 3: Waist Assist Exoskeleton



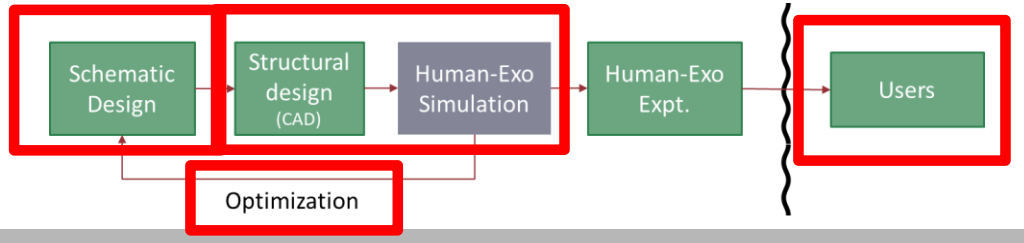
Case 3: Waist Assist Exoskeleton

What spring stiffness value minimizes Metabolic cost?

Case 3: Waist Assist Exo



Parameter Study (in AnyBody): Hip spring stiffness



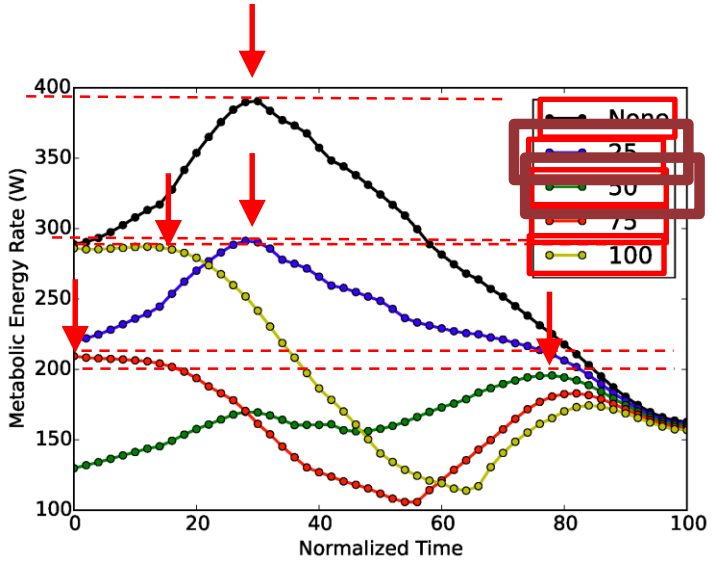
Case 3: Waist Assist Exo

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefts & 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

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Case 3: Waist Assist Exo

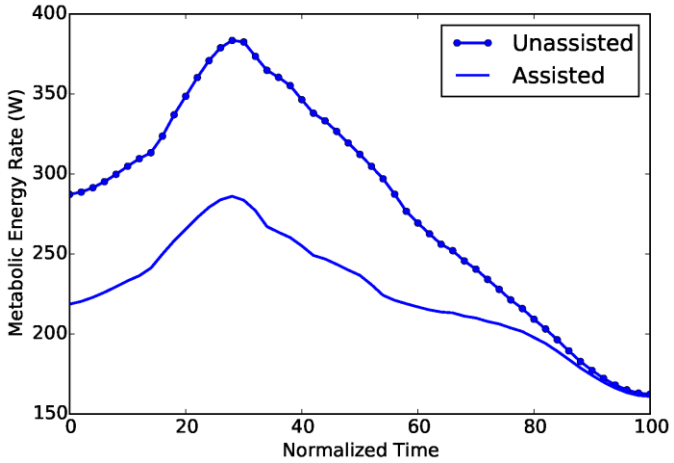
Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefts & safety to users

- Exo reduces metabolic energy cost? By How much?

$K = 25\ Nm/rad$

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



ANYBODY
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Case 3: Waist Assist Exo

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefts & safety to users

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

ANYBODY
Outputs

Human
- Muscle forces/activites
- Joint forces
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- Kinematics

Human-Exo Interaction
- Forces (straps, pads etc)

Exo
- Actuator forces & power
- Kinematics

Take Home Messages

Pain Point 1
Reducing time and costs of R&D

Pain Point 2
Proving benefts & safety to users

Pain Points facing Exo designers can be addressed by musculoskeletal simulation

Value of simulation outputs

Human
- Muscle forces & activity
- Metabolic Power
- Joint forces
- Kinematics with Exo

Human-Exo Interaction
- Forces (straps, pads etc)

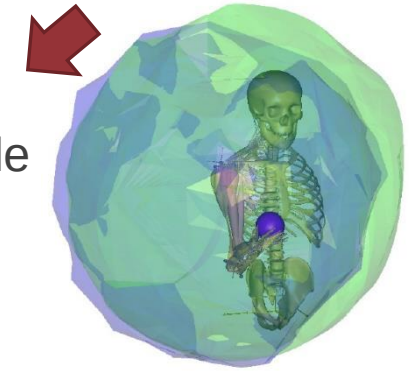
Exo
- Actuator forces & power

Acknowledgements

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

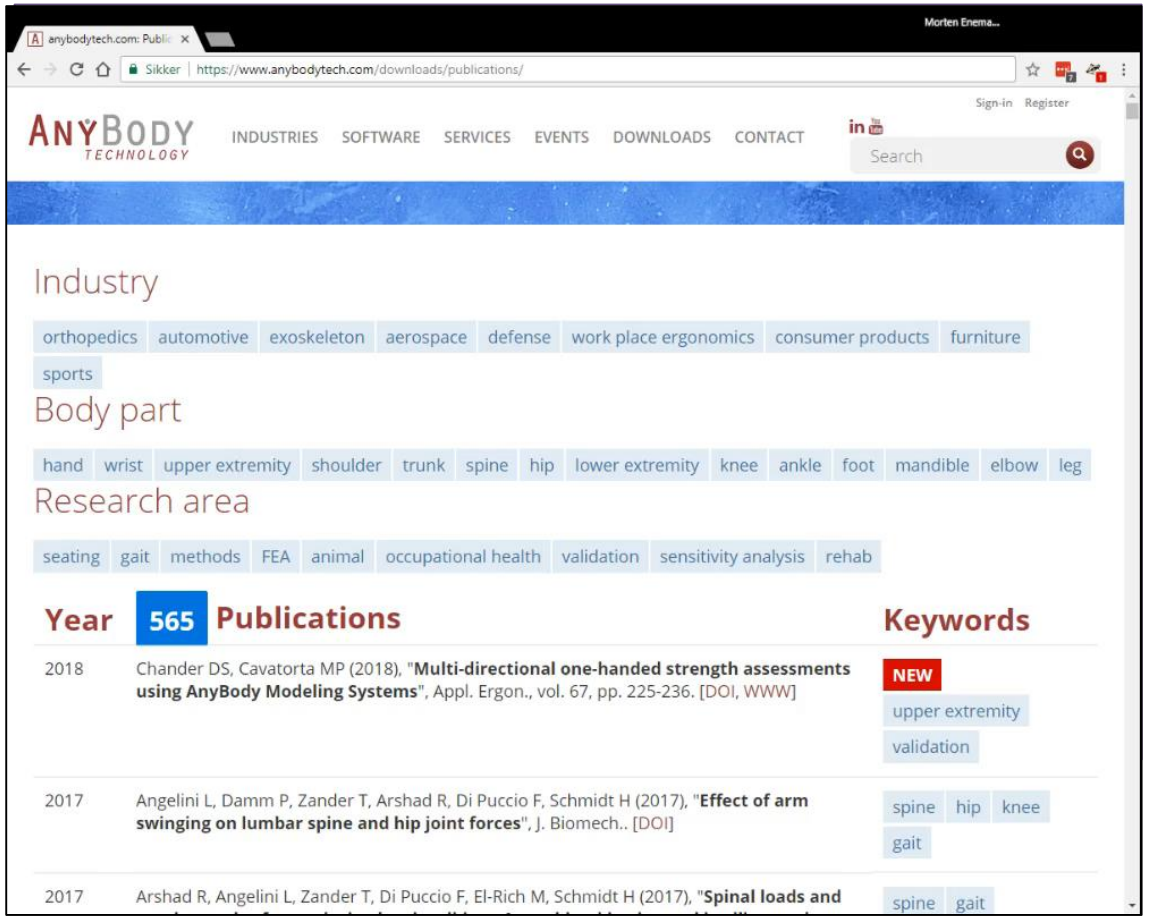
Upcoming webcasts

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.

Meet us? Send email to sales@anybodytech.com

Upcoming webcasts

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

www.anybodytech.com

- Events, dates, publication list, ...

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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: