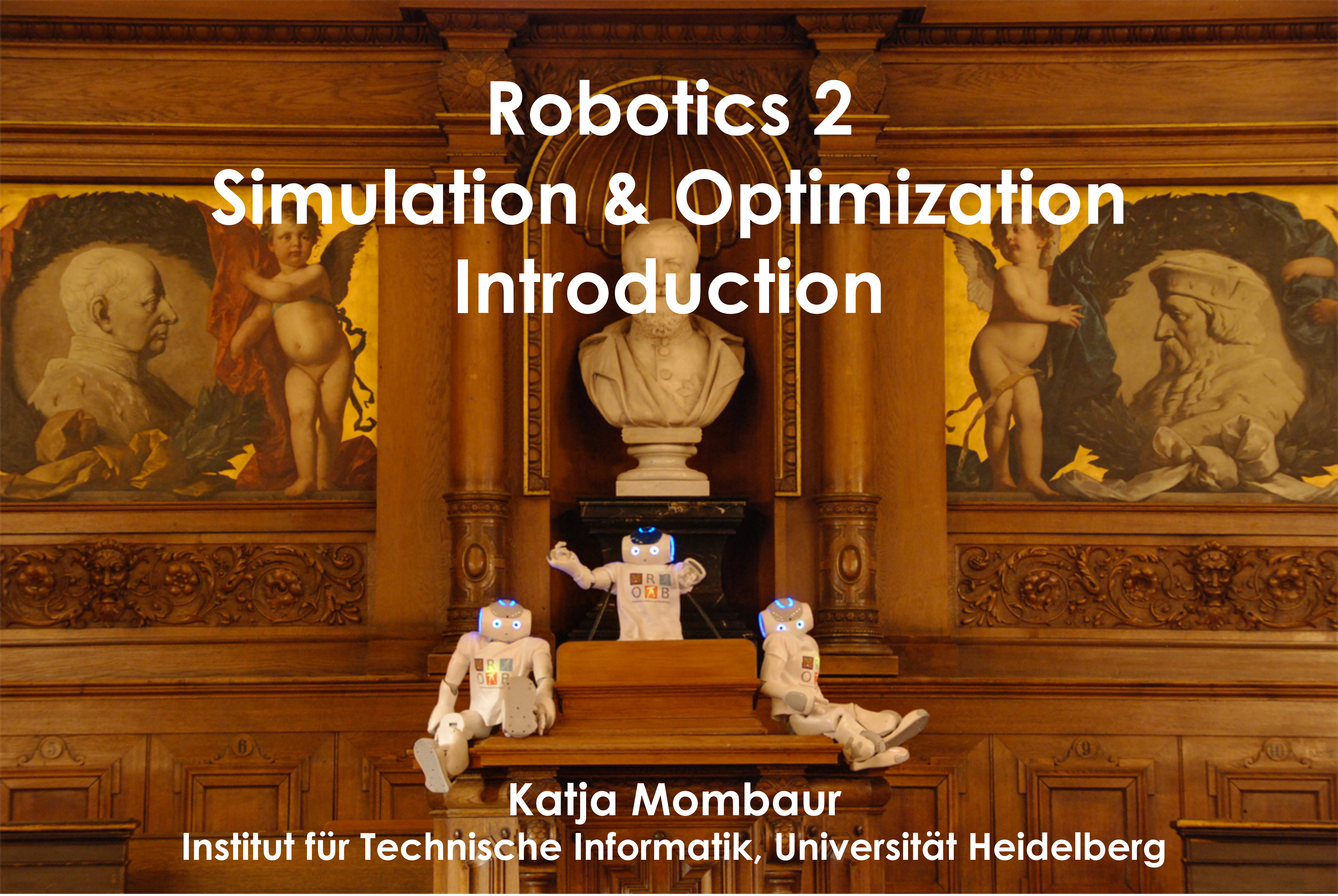


Robotics 2
Simulation & Optimization
Introduction

Katja Mombaur
Institut für Technische Informatik, Universität Heidelberg

Robotics 2 - 29 April 2019

Contents & organization of the lecture

Introduction of the team

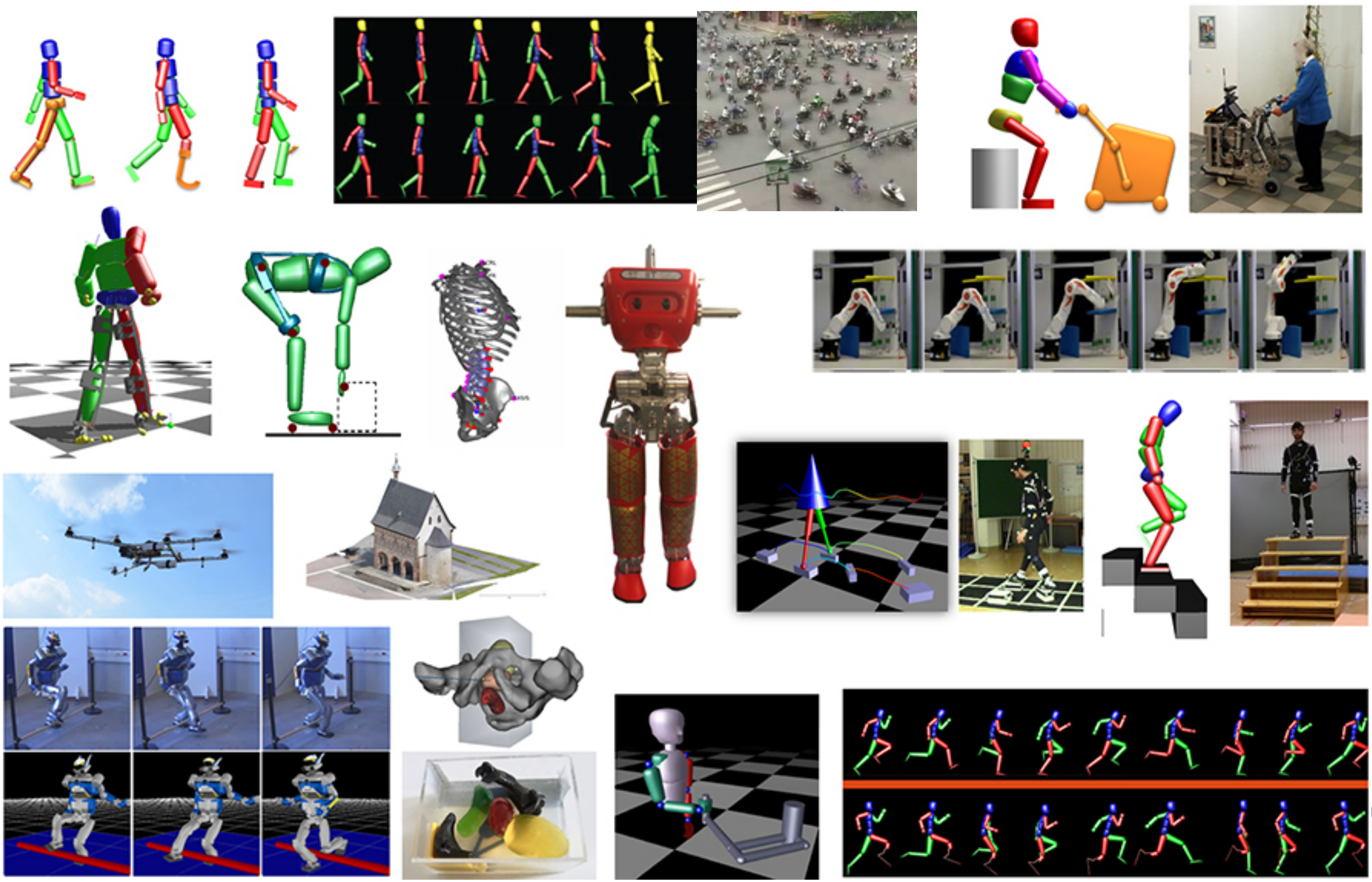
Lecturer

Programming Exercises & Organization

ZITI Chair

Optimierung, Robotik & Biomechanik ORB

ORB Research Topics



Target group of the course

- Offered as part of the Master Computer Engineering (Technische Informatik), specialization “Robotics, Biomechanics & Biomedical Engineering”
- Master students of Computer Science, Scientific Computing Mathematics, Physics
- Advanced bachelor students of these fields
- Students of other fields are welcome to join

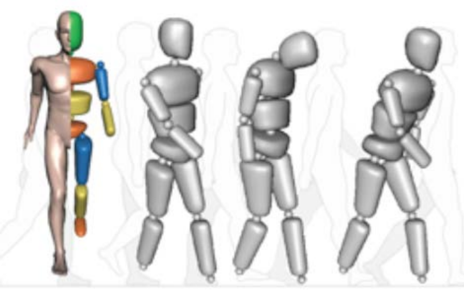
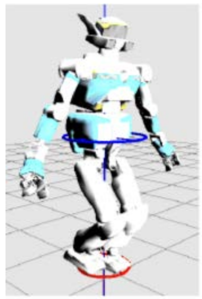
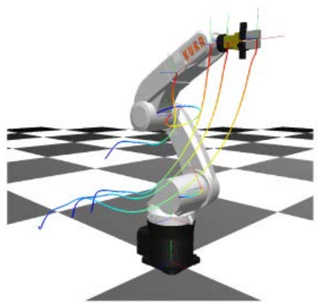
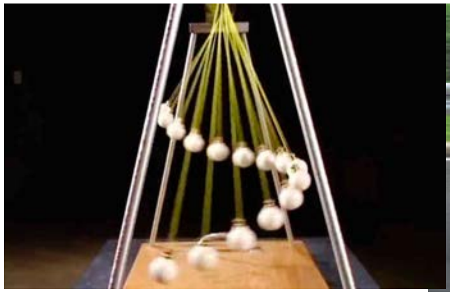
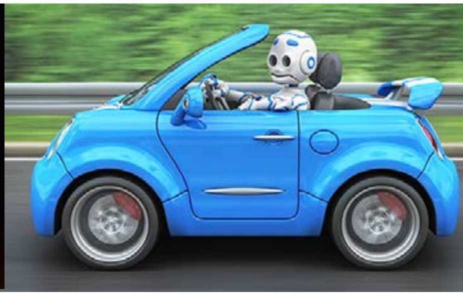
Goals of the course

- Learn how to
  - Generate motions and control / determine motor inputs for complex robotic systems
  - Let all degrees of freedom act in a coordinated way

using simulation & optimization methods

Goals of the course

- Give an application oriented introduction to the use of **Simulation and Optimization Methods in Robotics**

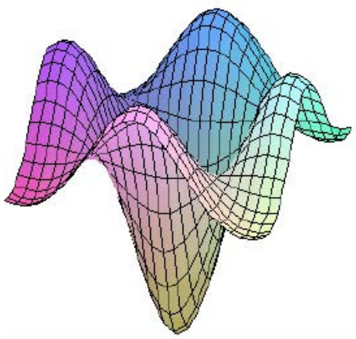






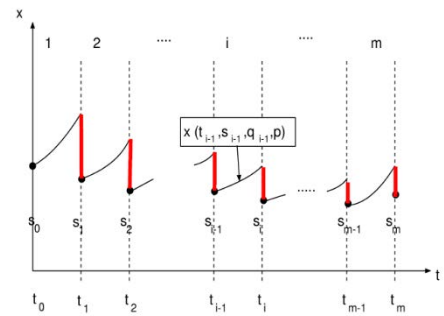
- **Lecture:**
  theoretical and mathematical foundations of simulation, optimization & optimal control

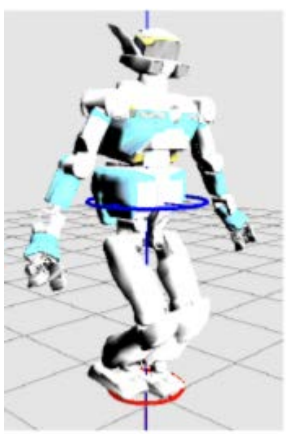
- **Programming exercises**
  Learn how to use state of the art software tools for modeling, visualization, simulation and optimal control with simple examples

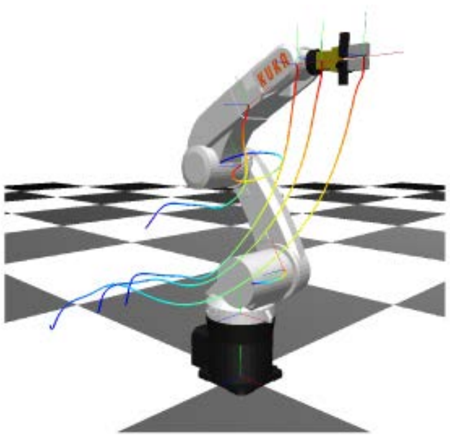
Contents of the course:
Robotics 2 - Simulation and optimization of robot motions

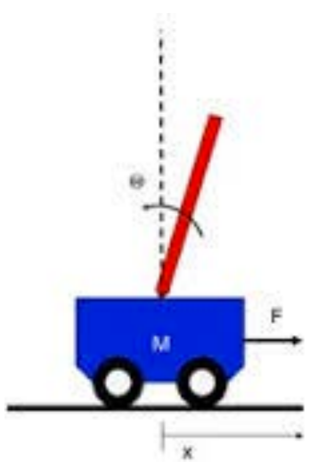
- dynamic process modeling
- optimization methods
- simulation: integrators / sol. initial value problems
- boundary value problems
- optimal control methods
- multi-phase optimal control
- different optimality criteria for robotics / biomechanics
- robot modeling
- programming exercises: get to know tools for robot modeling, simulation, optimization and visualization

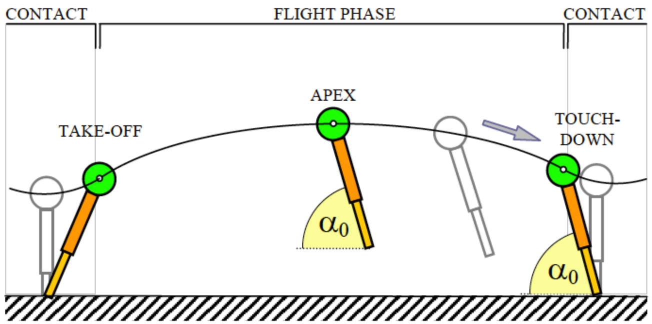






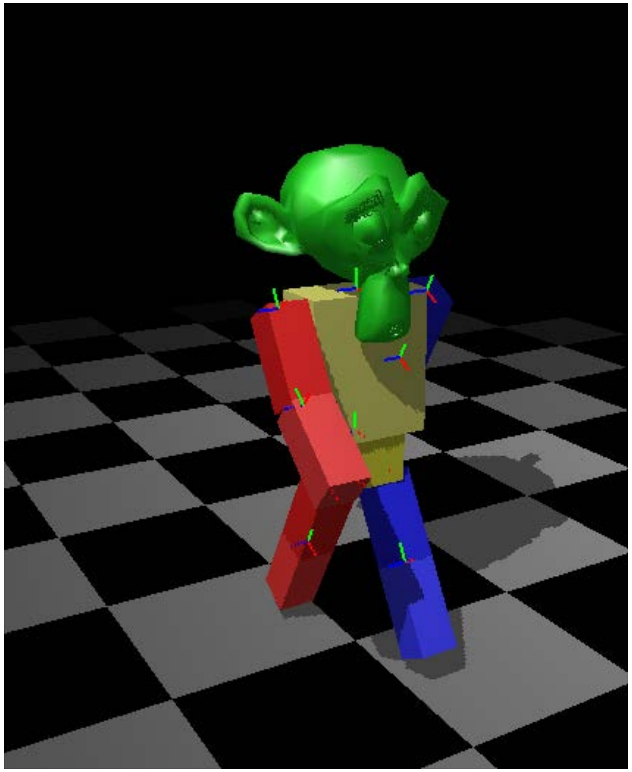






Computer exercises

- Tutor: Kevin Stein
- Topics:
  - Simulation und Visualization of mechanical systems **(MeshUp)**
  - Generating dynamical models of multibody systems with **RBDL (Rigid Body Dynamics Library)**
  - Formulation and solution of optimal control problems with **MUSCOD-II**

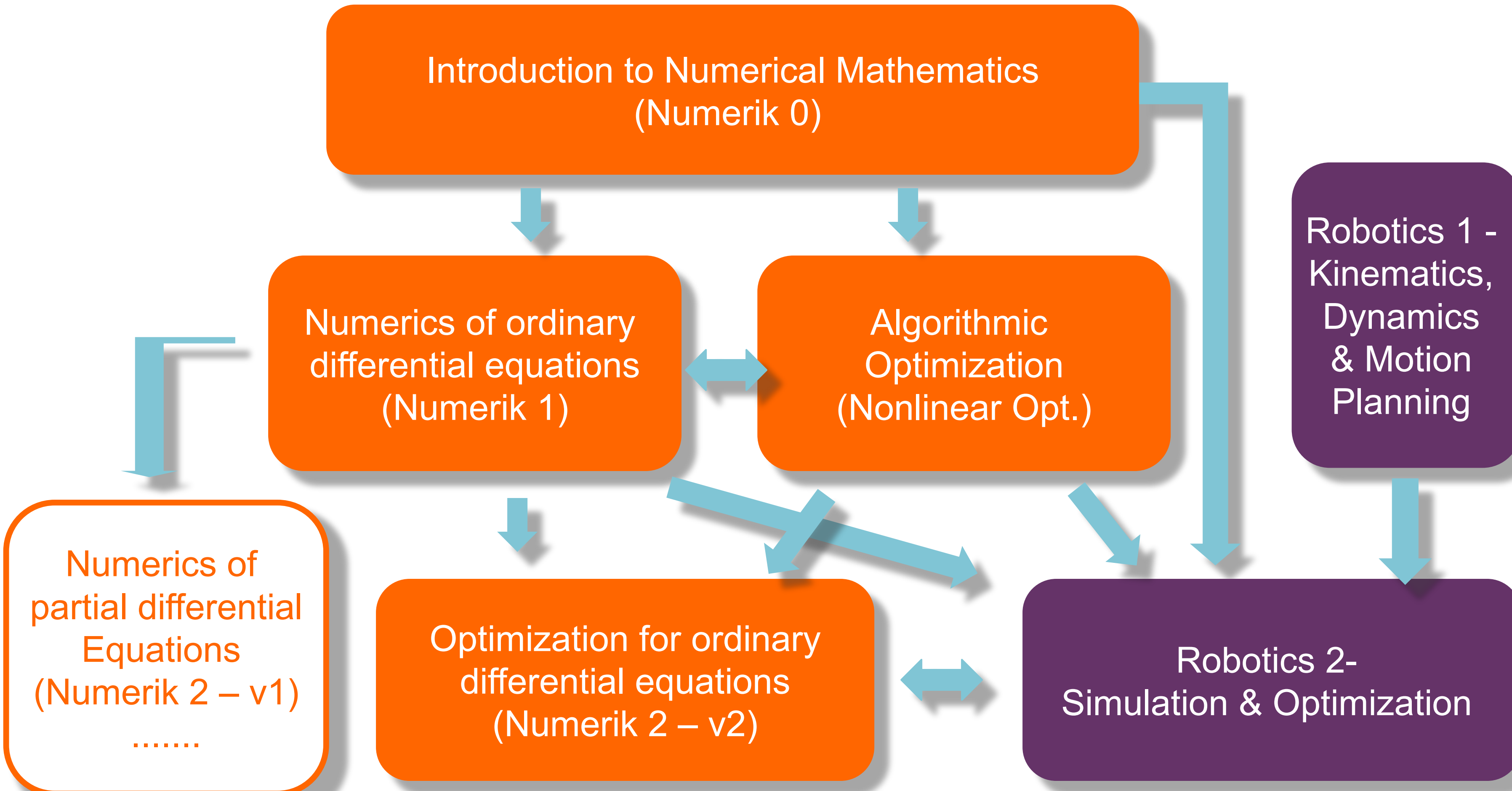


Required / useful knowledge to attend this lecture & exercises

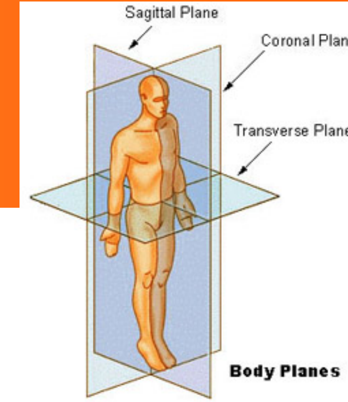
- **Prerequisites:**
  - programing skills in C/C++
  - Contents of course “Robotics 1 (Kinematics, Dynamics & Motion Planning)“
  - basic knowledge in numerical analysis

- **Useful knowledge:**
  - Lecture "Introduction to numerical mathematics";
  - Lectures "Algorithmic optimization", "Numerical mathematics 1";
  - Knowledge of Matlab, Octave

Classes in Numerical Methods & Optimization



Relation to parallel course Biomechanics 1(P)

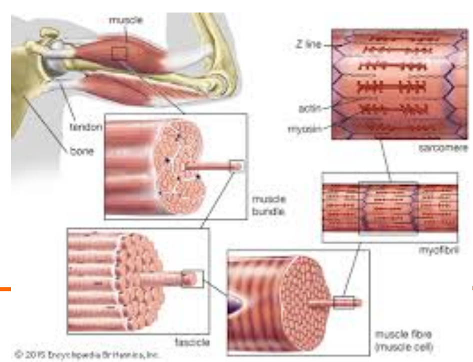


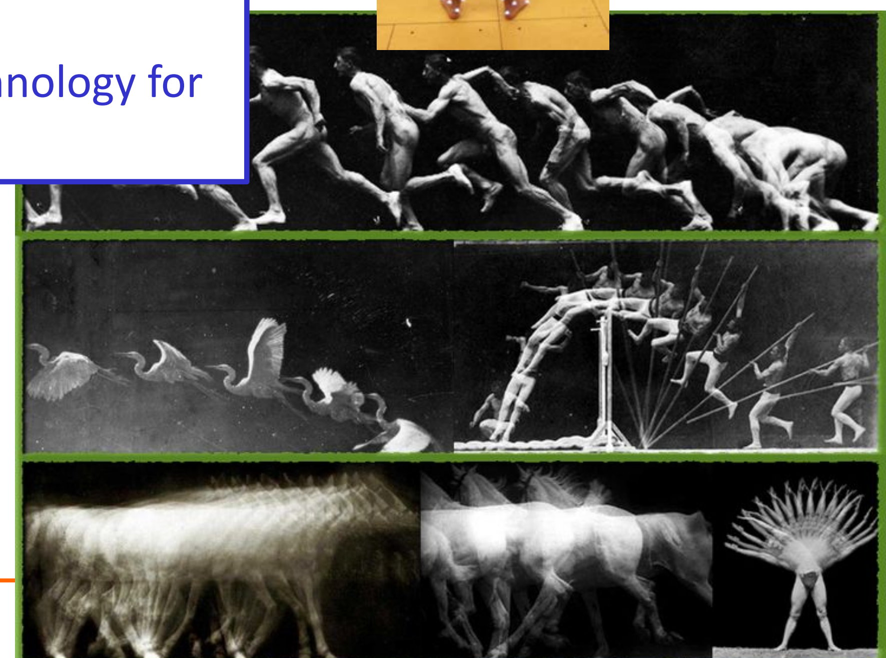
- Human body / anatomical & physiological basics of humans and animals
- body proportions / anthropometric data

Robotics 2 focuses on
simulation & optimization methods
that can be used in both robotics & biomechanics

Biomechanics 1 focuses on
general principles of biological movement
modeling in biomechanics
biomechanical measurements and assistive technology for human movement

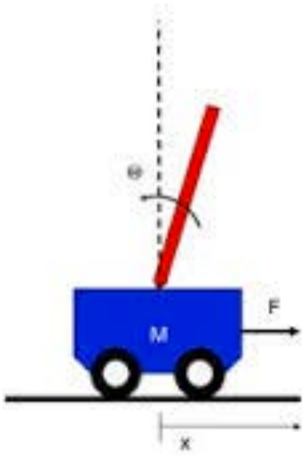
- Lecture for theory + Lab course
  Project work instead of exam

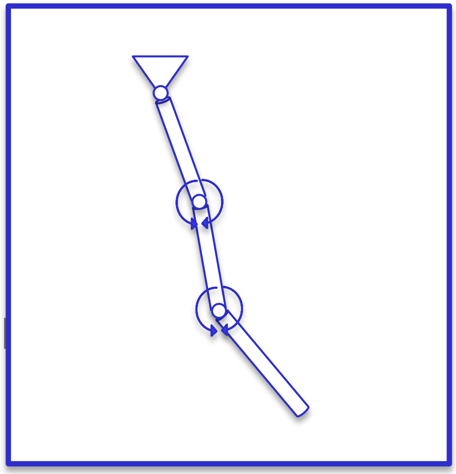


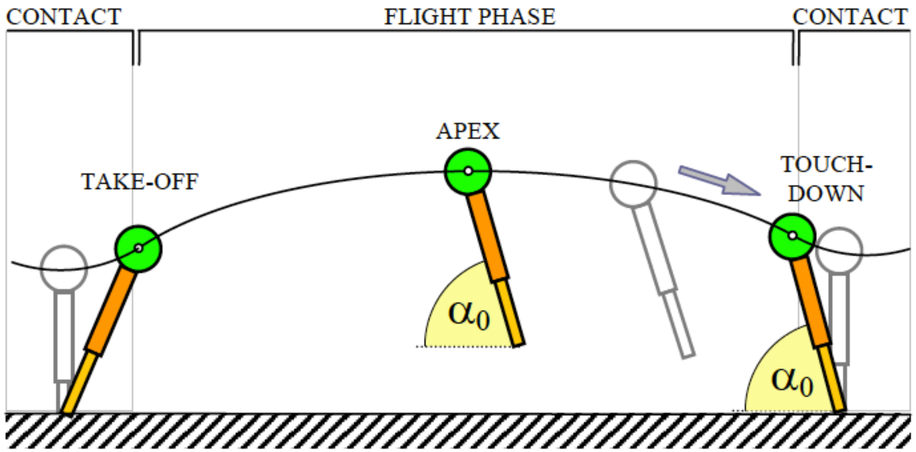


What you will have learned at the end of this semester

- You will have optimized and controlled such simple systems

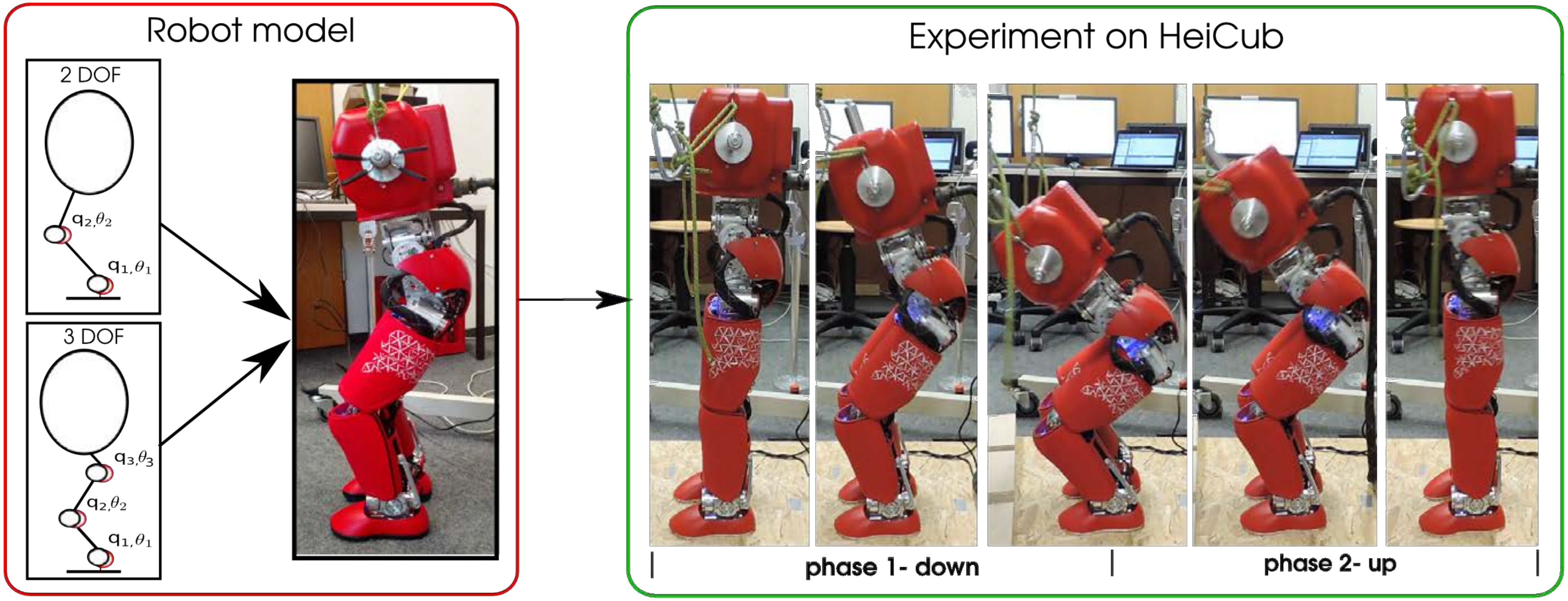






What you will have learned at the end of this semester

- You will also have analyzed, simulated and optimized more complex robot models



You will understand all necessary ingredients leading to such optimized robot motions

Exam modalities

- **The grade for the class is determined by the grade of a 2 hour exam** at the end of the semester
  - First exam (erster Prüfungsversuch)
    Date: TBD (most probably on / around July 29,2019 i.e. first week of vacation)
    Registration via MÜSLI until July 20, 2019
  - Second exam (zweiter Prüfungsversuch) - in case of failure or sickness during the first exam
    Date will be announced in time (most probably in last week of vacation period)

- **Admission to the exam** will be decided based on a successful participation in the computing exercises, i.e.
  - Regular participation (decision is left to the tutor's discretion)
  - Independent solution of at least 80 % of the programming exercises & presentation to the tutor at CIP pool

Organizational stuff

- Please register for the class in MÜSLI (until the end of this week)
- Class is also integrated in MOODLE:
  - Lecture slides will be uploaded after each lecture
  - Programming exercise sheets will be available the night before at latest
  - PW ROB2-2019

Organizational stuff

- Programming exercises will take place at CIP Pool, Mathematikon A
  - Tuesday 2 – 4 pm, starting on May 7, 2019*
  - Required tools are installed at CIP Pool, but can also partly be installed at your own laptops

- ** Tomorrow at 2pm the second lecture will take place (instead of exercises)
  - ** Exceptionally in Mathematikon B, 3rd floor, room 128

Organizational stuff

- **Effort for this course:**

      180 hours (for 6 ECTS)
  = 60 h studies at the University (lecture + exercises; “Präsenzstudium“)
  + 60 h independent studies (“Selbststudium“)
  + 60 h exam preparation

- **Independent studies**
  - Repeat what was done lecture and ask questions next time!
  - To facilitate these studies, we will additionally make available **“support sheets“** in regular intervals via Moodle containing
    - short questions to allow you to verify your understanding
    - Longer exercises in “exam style”

  NOTE THAT THESE ARE NO CLASSICAL EXERCISE SHEETS.
  YOU DO NOT HAVE TO HAND THEM IN, AND YOU ARE NOT FORCED TO USE THEM. IT IS JUST AN OFFER.

Introduction

Why do we need simulation & optimization in robotics?

- Evaluate motions in the computer before they are transferred to reality
- Generate feasible motions for highly complex systems
- Generate optimal motions for highly complex systems

Human-centered robots – Robots that work closely with the human and that need motion intelligence

HRP-2 AIST - Kawada

Baxter - Rethink Robotics

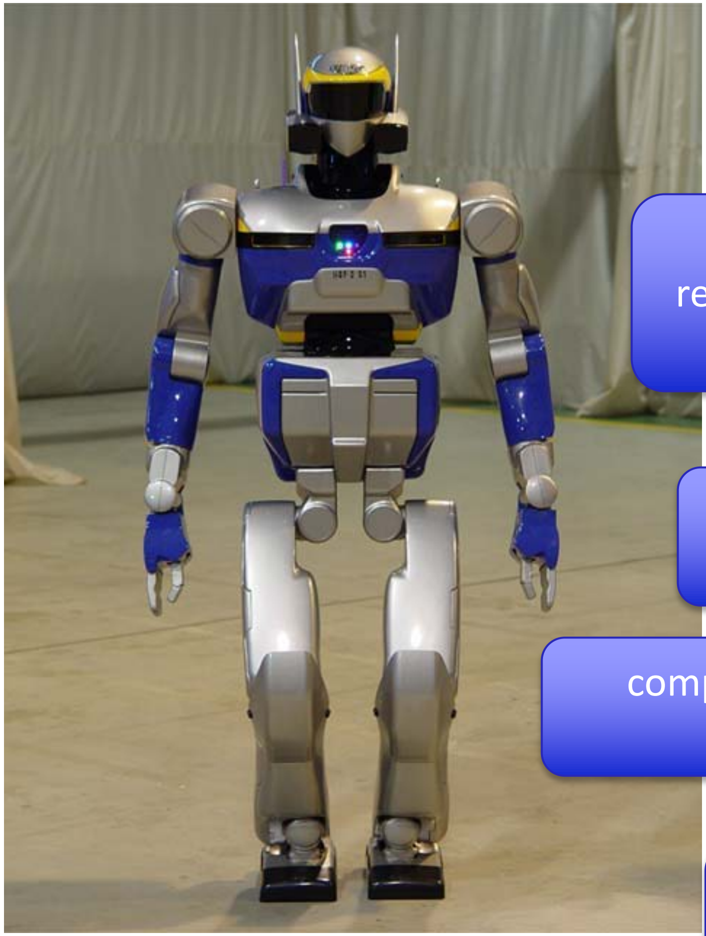
Da Vinci - Intuitive Surgical

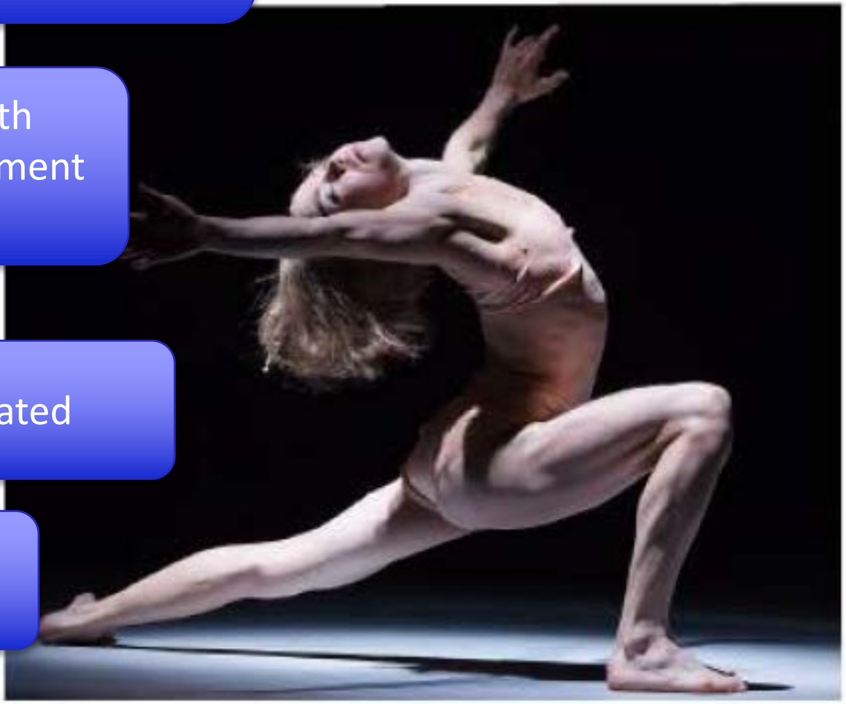
Össur

LIRMM

MOBOT

Difficulties in understanding and generating movement





highly complex systems with many degrees of freedom

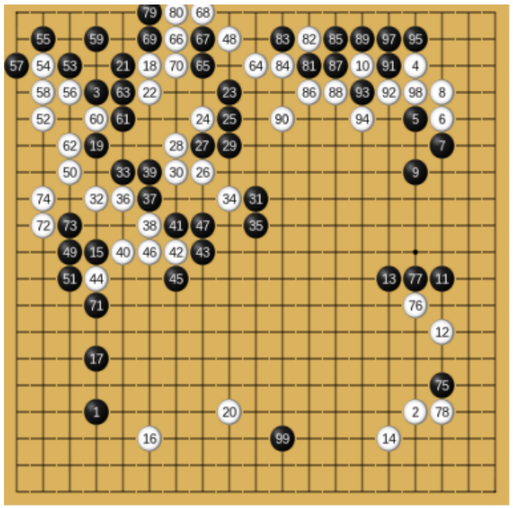
redundant with respect to movement tasks

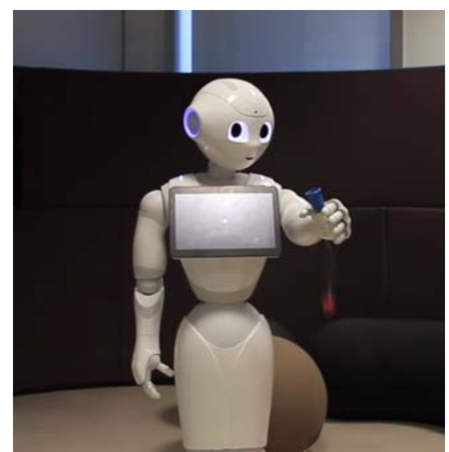
underactuated

complex stability control

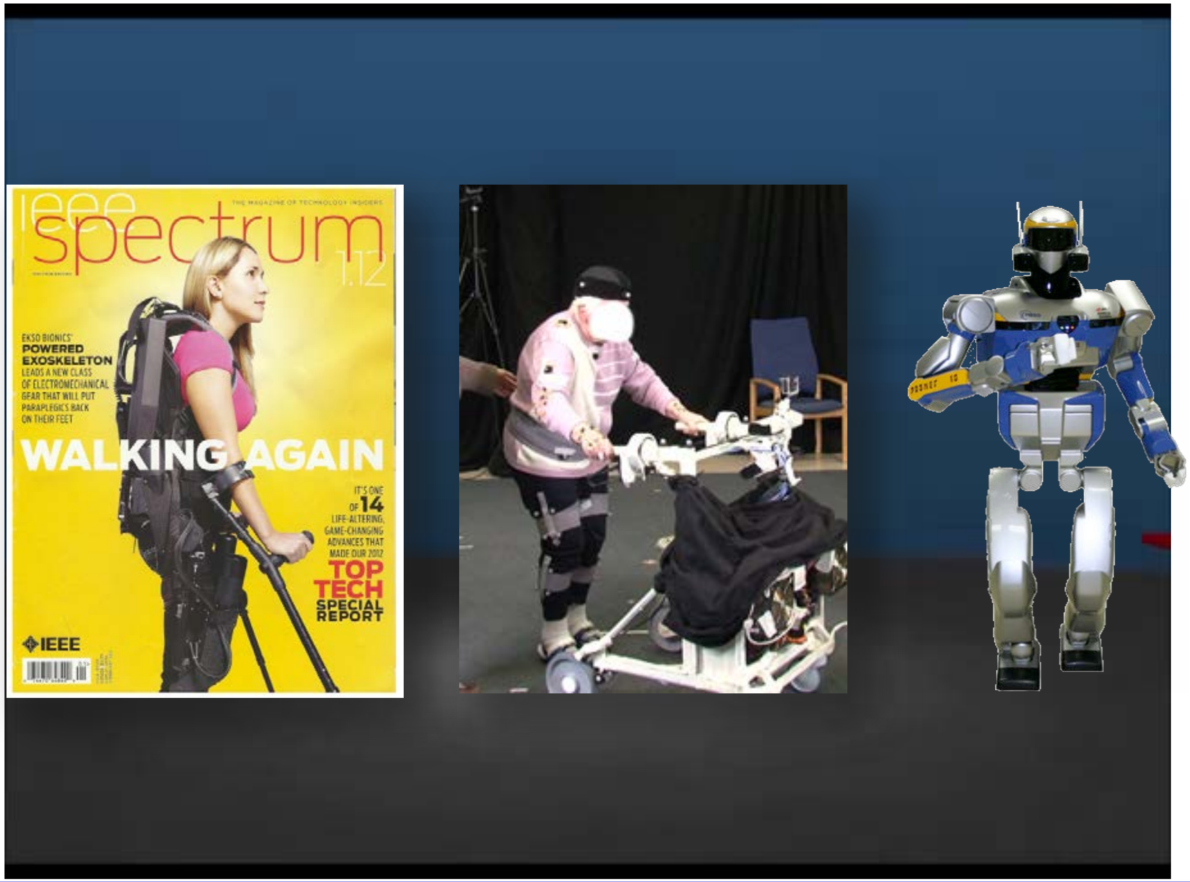
motions get easily infeasible

Which problems can be solved by machine learning?





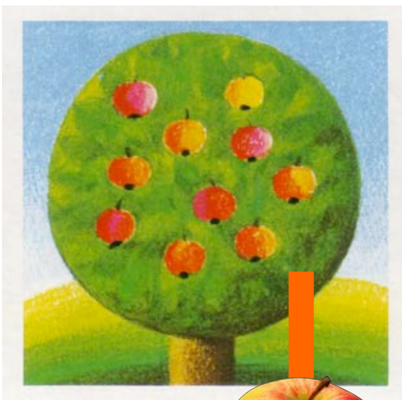
Motions of complex robots in general can not be learned from scratch ....

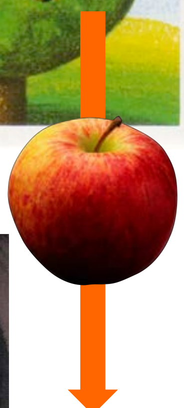


Google Deepmind

... in the interest of the users and the robots!

Simulation and optization based on physical models are a much better approach





$$\ddot r_{x,1} = \ddot r_{x,H} + c_T(\cos\phi_1\ddot\phi_1 - \sin\phi_1\dot\phi_1^2)$$
$$+ c_T(\sin\phi_1\ddot\phi_1 + \cos\phi_1\dot\phi_1^2)$$

$$+ l_T(\cos\phi_1\ddot\phi_1 - \sin\phi_1\dot\phi_1^2) + c_S(\cos\phi_2\ddot\phi_2 - \sin\phi_2\dot\phi_2^2) - w_S(\sin\phi_2\ddot\phi_2 - \cos\phi_2\dot\phi_2^2$$
$$+ l_T(\sin\phi_1\ddot\phi_1 + \cos\phi_1\dot\phi_1^2) + c_S(\sin\phi_2\ddot\phi_2 + \cos\phi_2\dot\phi_2^2) + w_S(\cos\phi_2\ddot\phi_2 - \sin\phi_2\dot\phi_2^2$$

$$+ c_T(+\cos\phi_3\ddot\phi_3 - \sin\phi_3\dot\phi_3^2)$$
$$+ c_T(+\sin\phi_3\ddot\phi_3 + \cos\phi_3\dot\phi_3^2)$$

$$+ l_T(\cos\phi_3\ddot\phi_3 - \sin\phi_3\dot\phi_3^2) + \quad \cos\phi_4\dot\phi_4^2$$
$$+ l_T(\sin\phi_3\ddot\phi_3 + \cos\phi_3\dot\phi_3^2) + \quad \sin\phi_4\dot\phi_4^2$$

c_{kn}

$$\phi_4 \equiv \phi_3$$
$$\ddot\phi_4 \equiv \ddot\phi_3$$

$$(\ddot\phi_2 \equiv \ddot\phi_1 \quad \text{during second phase})$$

- conservation of ang

$$H_{swing,H} - M_{Hip} = \sum_{i=1}^{2}\left(r_{H,i} \times m\dot r_i + \Theta_{i,z}\dot\phi_i\right) = const.$$

- conservation of angular momentum of robot about stance point

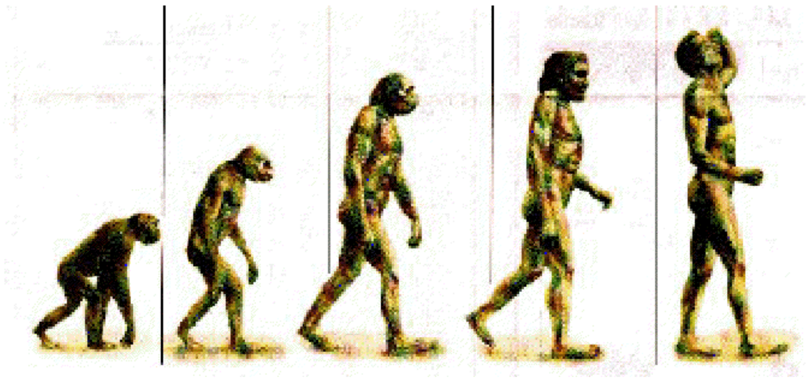
$$H_{robot,S} = \sum_{i=1}^{4}\left(r_{S,i} \times m\dot r_i + \Theta_{i,z}\dot\phi_i\right) = const.$$

- equal angular velocities of thigh and shank of swing leg after imp

$$\dot\phi_1 = \dot\phi_2$$

Optimization computations in th computer result in natural motions

- Motions of humans and animals have been optimized in the course of evolution and by individual learning



4-6 Mio. years

15 – 20 **years**

- Use mathematical optimization as a key tool for motion studies in robotics, biomechanics and biomedical engineering
    - solves redundancy and feasibility issues
    - can handle complex underactuated systems

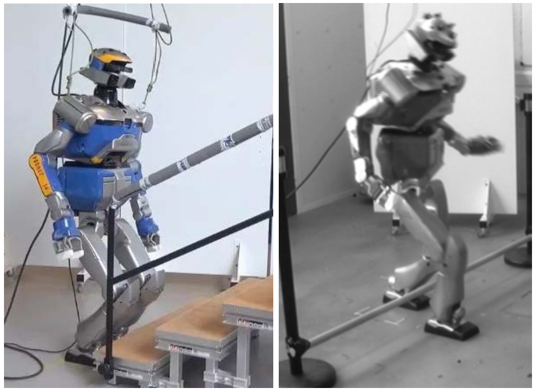
In the rest of this course unit I will give you a perspective …

- what can be included in robot models and human models
- how simulation and optimization can be used to …

better understand human movement

better analyze and design wearable robots

improve and predict motions of humanoid robots



Models of humans and robots

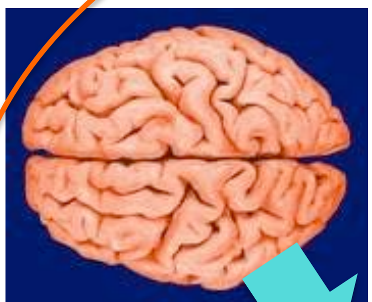
What is in the mathematical model of a human?

Biomechanics 1

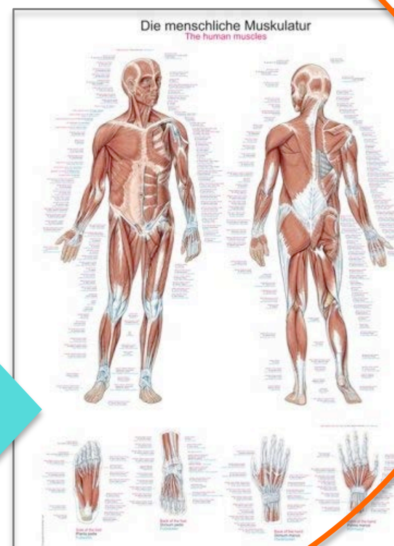
Rob 1 & 2

- Human neuro-musculo-skeletal system

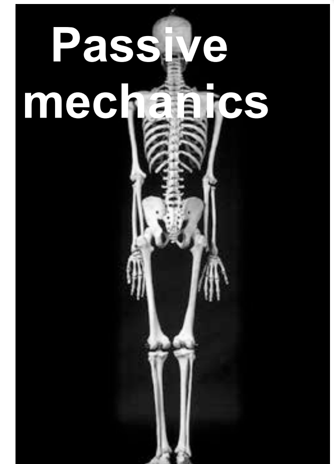
Brain & nervous system



Actuators



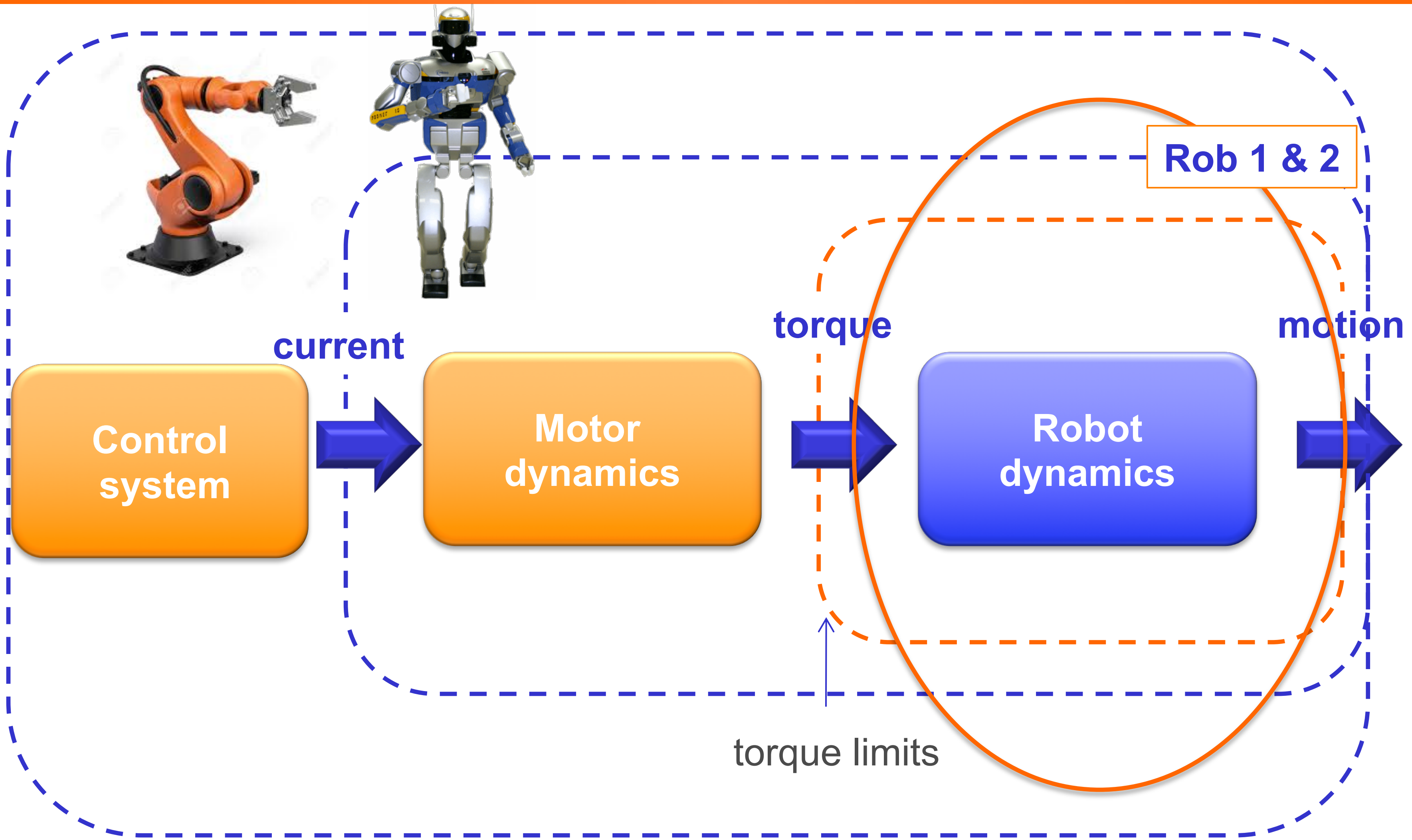
Passive mechanics



NEUROSCIENCE → **BIOMECHANICS**

A full human model convering all aspects does not exist yet!

What is in the mathematical model of a robot?



What is in the mathematical model?

Whole-body dynamics of human / robot

$$\dot{q} = v$$
$$\dot{v} = a$$
$$\begin{pmatrix} M(q,p) & G(q,p)^T \\ G(q,p) & 0 \end{pmatrix} \begin{pmatrix} a \\ \lambda \end{pmatrix} = \begin{pmatrix} -N(q,v) + F(q,v,p,\mathcal{M}) \\ \gamma(q,v,p) \end{pmatrix}$$

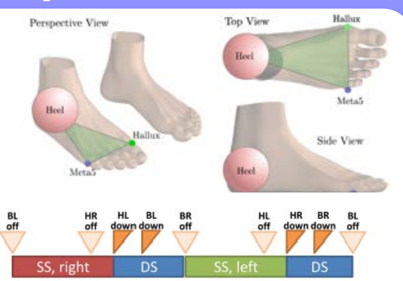
RBDL

Dynamod

Phase switching and contact dynamics

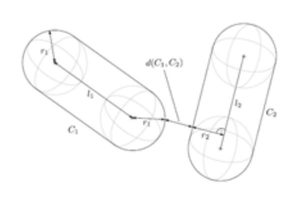
$$s(q(\tau_s), v(\tau_s), p) = 0$$

$$\begin{pmatrix} M(q,p) & G(q,p)^T \\ G(q,p) & 0 \end{pmatrix} \begin{pmatrix} v^+ \\ \Lambda \end{pmatrix} = \begin{pmatrix} M(q)v^- \\ 0- \end{pmatrix}$$

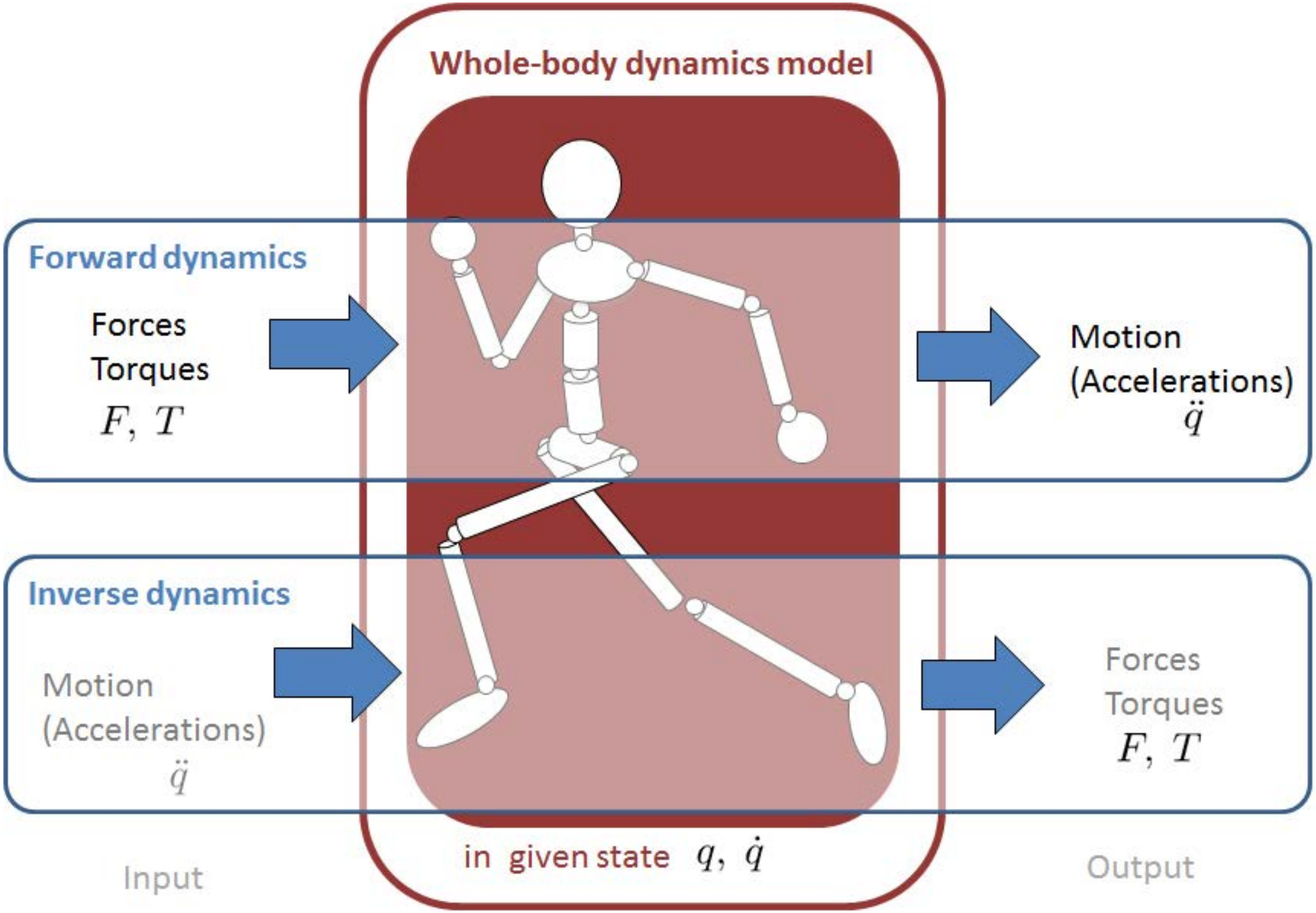


Feasibility constr

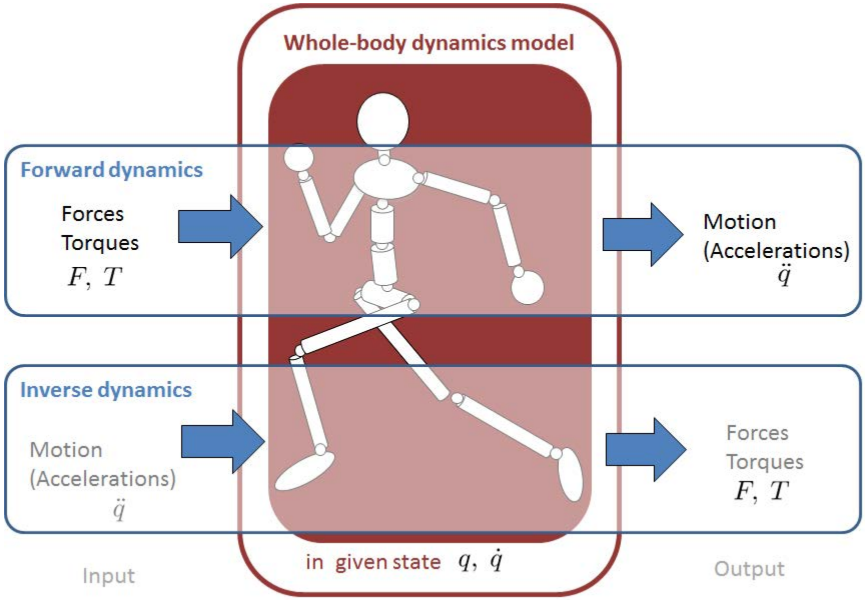
limitations on all variables
collision avoidance ....



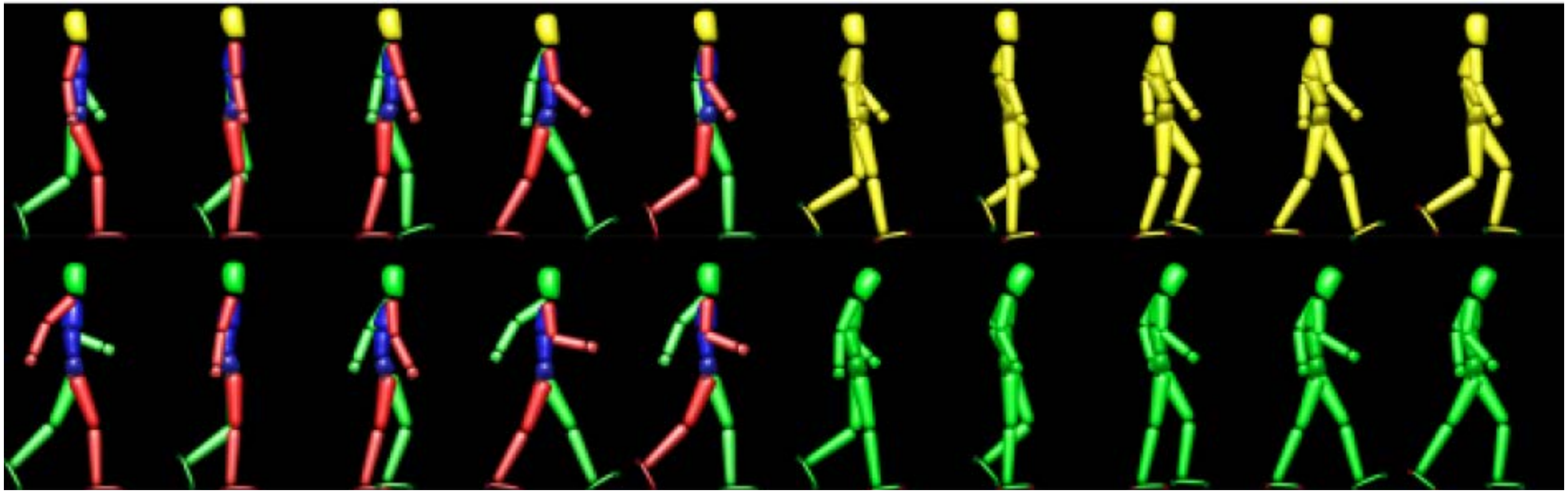
Forward and inverse dynamics models can be used

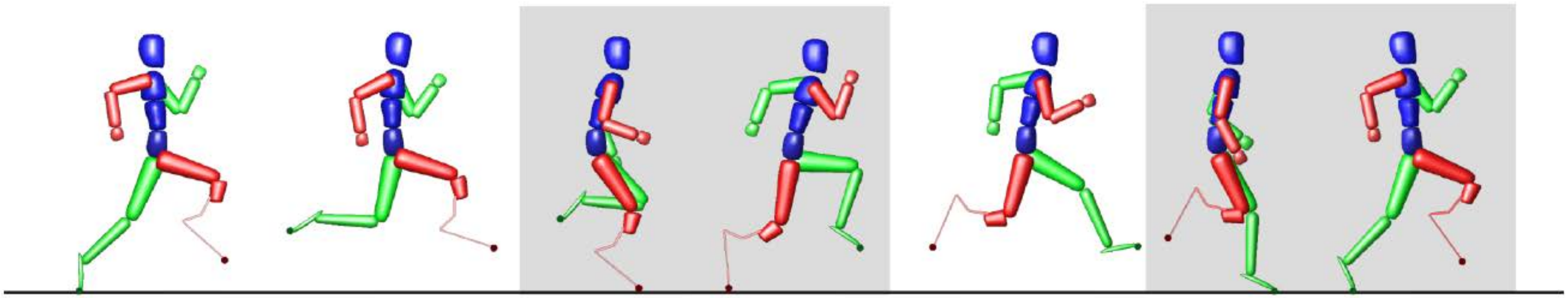


Model-based Simulation vs Model-based Optimization



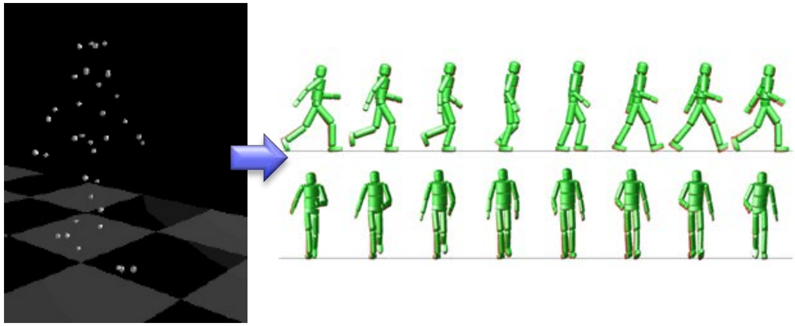
- In simulation, the input side must always be known, and then the output side is determined
- In optimization – or optimal control to be more precise (which is optimization including a simulation of an underlying model) unknown inputs and outputs optimizing a cost function are determined at the same time



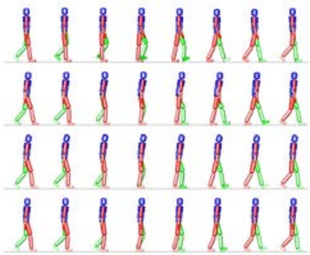


Model-based optimization for human movement understanding

Different roles of optimization in human movement analysis and improvement



- Detailed gait analysis of a given / recorded human motion by means of the model

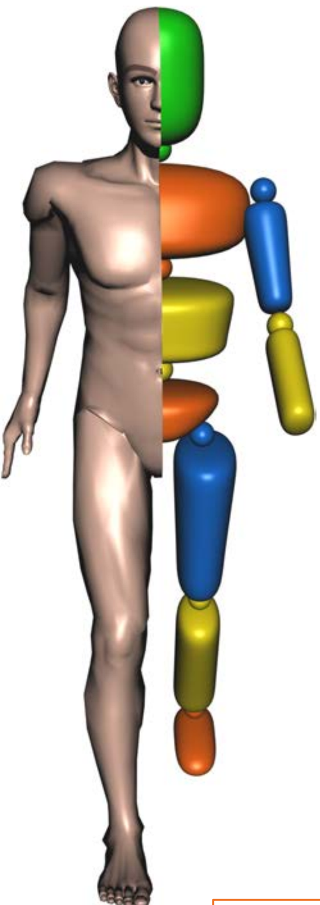


- Predictive motion generation using a good optimality criterion
  - what will a movement look like under different conditions?

- Understanding optimality in human movement: what is optimized in which situation?
  - inverse optimal control

    (not discussed here)

Fitting a dynamic model to experimental data



Mathematical model + least squares fitting objective function

$$
\begin{aligned}
m_T \ddot{r}_{x,1} &= F_{2x} - F_{1x} \\
m_T \ddot{r}_{y,1} &= F_{2y} - F_{1y} - m_T g \\
\theta_T \ddot{\phi}_1 &= (F_{1x} c_T + F_{2x}(l_T - c_T)) \cos\phi_1 + (F_{1y} c_T + \\
\\
m_S \ddot{r}_{x,2} &= -F_{2x} \\
m_S \ddot{r}_{y,2} &= -F_{2y} - m_S g \\
\theta_S \ddot{\phi}_2 &= F_{2x}(c_S \cos\phi_2 - w_S \sin\phi_2) + F_{2y}(c_S \sin\phi_2 \\
\\
m_T \ddot{r}_{x,3} &= F_{3x} + F_{1x} \\
m_T \ddot{r}_{y,3} &= F_{3y} + F_{1y} - m_T g \\
\theta_T \ddot{\phi}_3 &= (-F_{1x} c_T + F_{3x}(l_T - c_T)) \cos\phi_3 (-F_{1y} c_T + F_{3y}(l_T - c_T)) \sin\phi_3 + u_0 \\
\\
m_S \ddot{r}_{x,4} &= -F_{3x} + B_x \\
m_S \ddot{r}_{y,4} &= -F_{3y} + B_y - m_S g \\
\theta_S \ddot{\phi}_4 &= F_{3x}(c_S \cos\phi_4 - w_S \sin\phi_4) + F_{3y}(c_S \sin\phi_4 + w_S \cos\phi_4) \\
&\quad + B_x((l_S - c_S)\cos\phi_3 + w_S \sin\phi_3) + B_y(-(l_S - c_S)\sin\phi_3 - w_S \cos\phi_3) - u_2
\end{aligned}
$$

$$
\begin{aligned}
\text{with} \quad u_2 &\equiv 0 \\
u_1 &\equiv 0 \quad \text{during second phase} \\
F_{jx}, F_{jy} & \quad \text{constraint forces} \\
B_x, B_y & \quad \text{ground reaction forces}
\end{aligned}
$$

$$
\min_{\boldsymbol{x}(\cdot), \boldsymbol{u}(\cdot)} \sum_{j=0}^{m} \frac{1}{2} \left(|| \boldsymbol{q}_j^D - \boldsymbol{q}(t_j) ||_2^2 + \gamma_u || \boldsymbol{W} \boldsymbol{u}(t_j) ||_2^2 \right)
$$

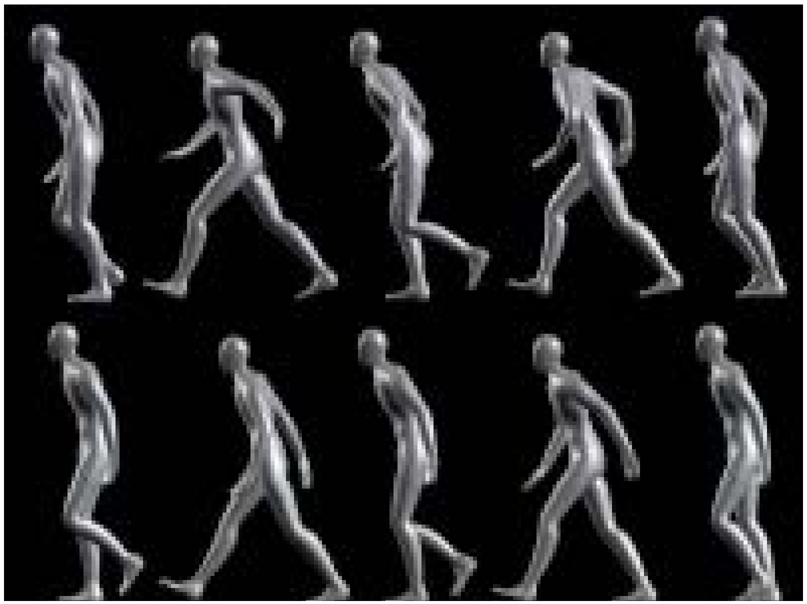
Physically correct description of the dynamics of the system

Reconstructed motion

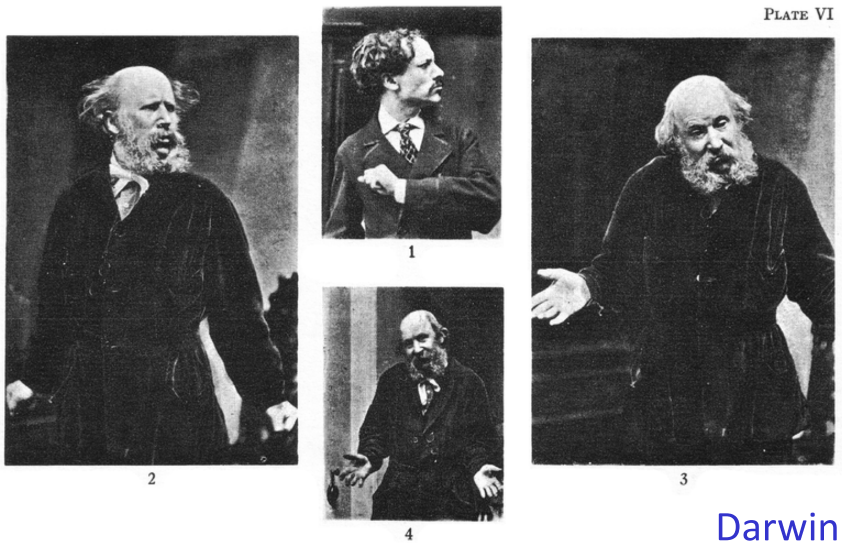
Reconstruction of dynamic information from pure kinematic measurements possible, no force plates etc. required.

Example for motion analysis: Study of emotional body language

with Martin Felis, Alain Berthoz



Motion Capture data of motions under different emotions



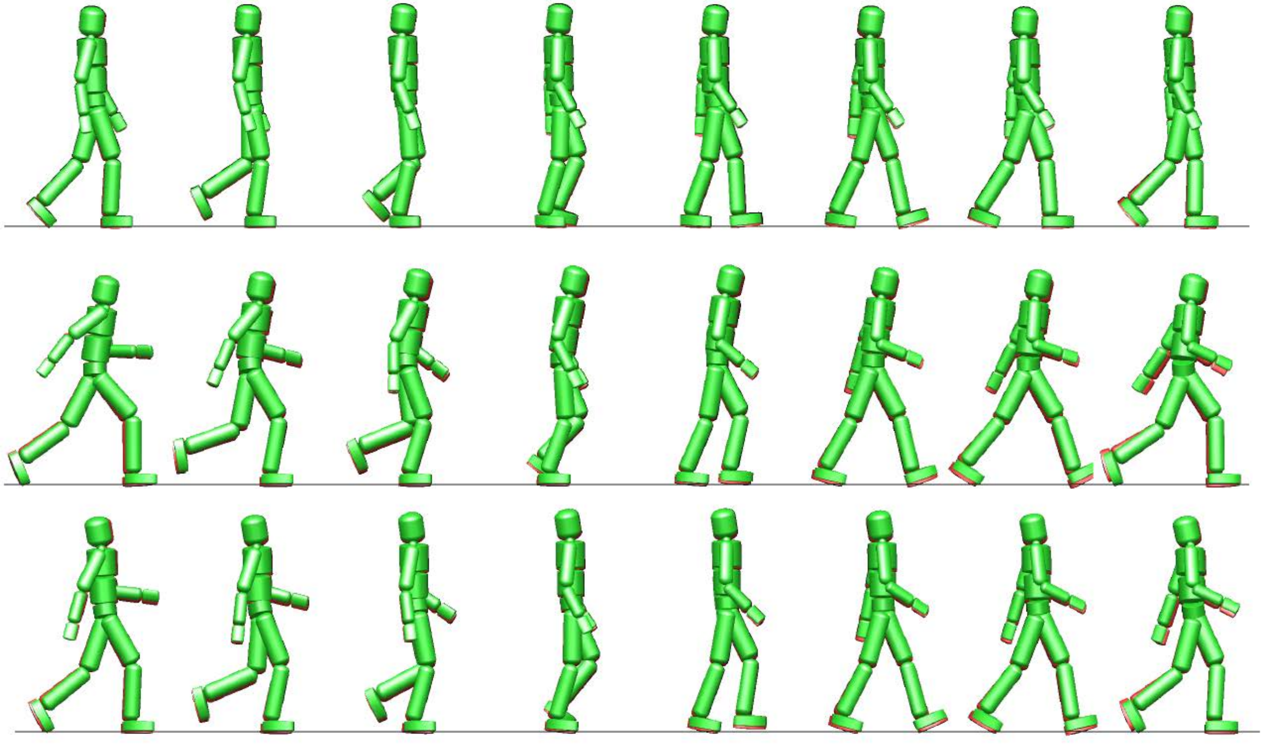
Darwin

Fitting dynamic models to data of emotionally modified walking motions

neutral walking

angry walking

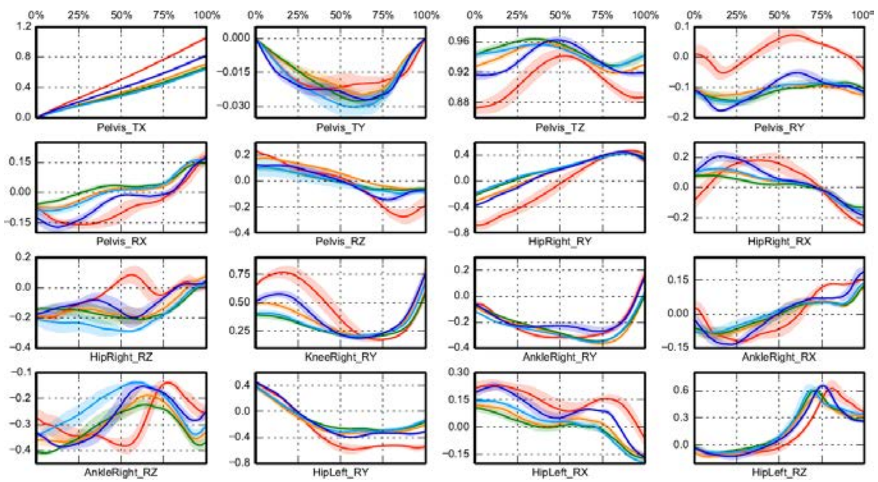
joyful walking



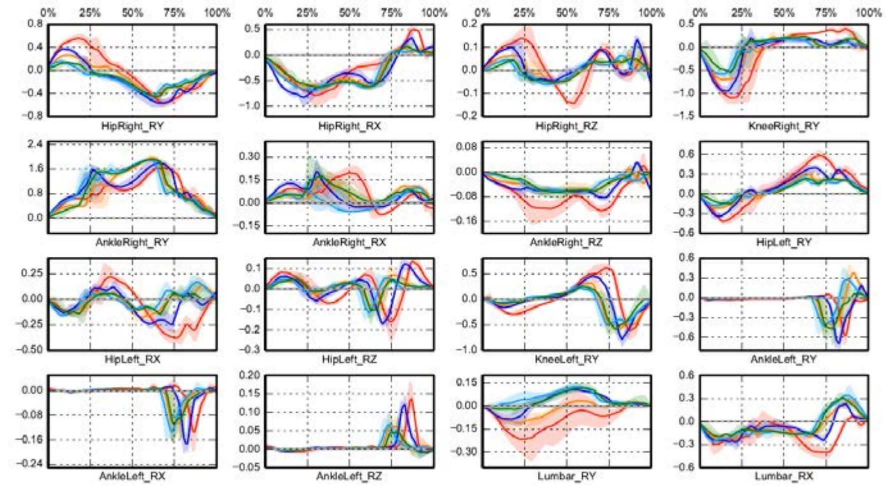
green: kinematic data from motion capture
red: fit of dynamic model

Optimization-based analysis reveals full information about the model

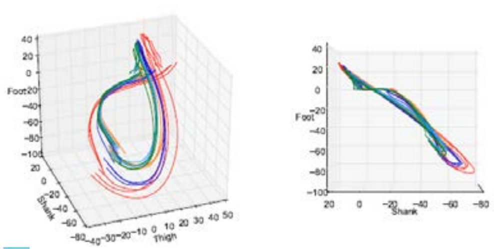
- All state variable trajectories (positions, velocities)



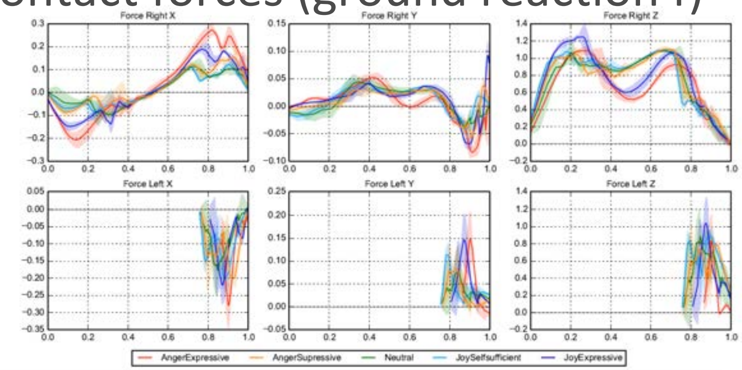
- All control variable histories (joint torques)



- Intersegmental coordination



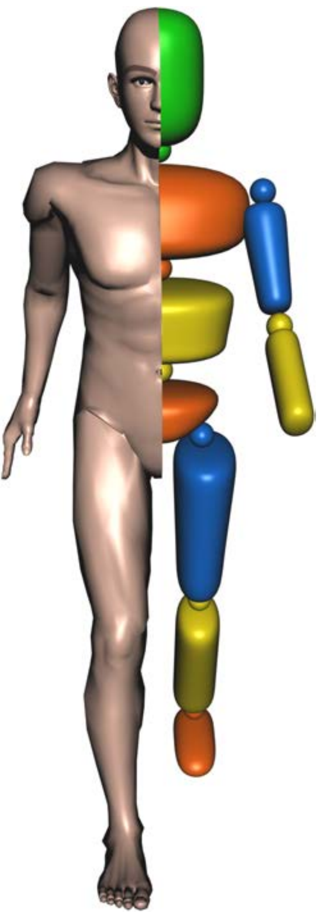
- Contact forces (ground reaction f)



Katja Mombaur

ZUKUNFT SEIT 1386

Generation of realistic motions by means of optimization



Mathematical model + suitable objective function

$$
\begin{aligned}
m_T \ddot{r}_{x,1} &= F_{2x} - F_{1x} \\
m_T \ddot{r}_{y,1} &= F_{2y} - F_{1y} - m_T g \\
\theta_T \ddot{\phi}_1 &= (F_{1x} c_T + F_{2x}(l_T - c_T)) \cos\phi_1 + (F_{1y} c_T + F_{2y}(l_T - \\
\\
m_S \ddot{r}_{x,2} &= -F_{2x} \\
m_S \ddot{r}_{y,2} &= -F_{2y} - m_S g \\
\theta_S \ddot{\phi}_2 &= F_{2x}(c_S \cos\phi_2 - w_S \sin\phi_2) + F_{2y}(c_S \sin\phi_2 + w_S \cos \\
\\
m_T \ddot{r}_{x,3} &= F_{3x} + F_{1x} \\
m_T \ddot{r}_{y,3} &= F_{3y} + F_{1y} - m_T g \\
\theta_T \ddot{\phi}_3 &= (-F_{1x} c_T + F_{3x}(l_T - c_T)) \cos\phi_3 (-F_{1y} c_T + F_{3y}(l_T - c_T)) \sin\phi_3 + u_0 \\
\\
m_S \ddot{r}_{x,4} &= -F_{3x} + B_x \\
m_S \ddot{r}_{y,4} &= -F_{3y} + B_y - m_S g \\
\theta_S \ddot{\phi}_4 &= F_{3x}(c_S \cos\phi_4 - w_S \sin\phi_4) + F_{3y}(c_S \sin\phi_4 + w_S \cos\phi_4) \\
&\quad + B_x((l_S - c_S)\cos\phi_3 + w_S \sin\phi_3) + B_y(-(l_S - c_S)\sin\phi_3 - w_S \cos\phi_3) - u_2
\end{aligned}
$$

with $u_2 \equiv 0$

$u_1 \equiv 0$ during second phase

F_{jx}, F_{jy} constraint forces

B_x, B_y ground reaction forces

Physically correct description of the dynamics of the system

$$\min_{x,u,T} \int_0^T \phi(x(t), u(t), p)\, dt$$

Realistic motion

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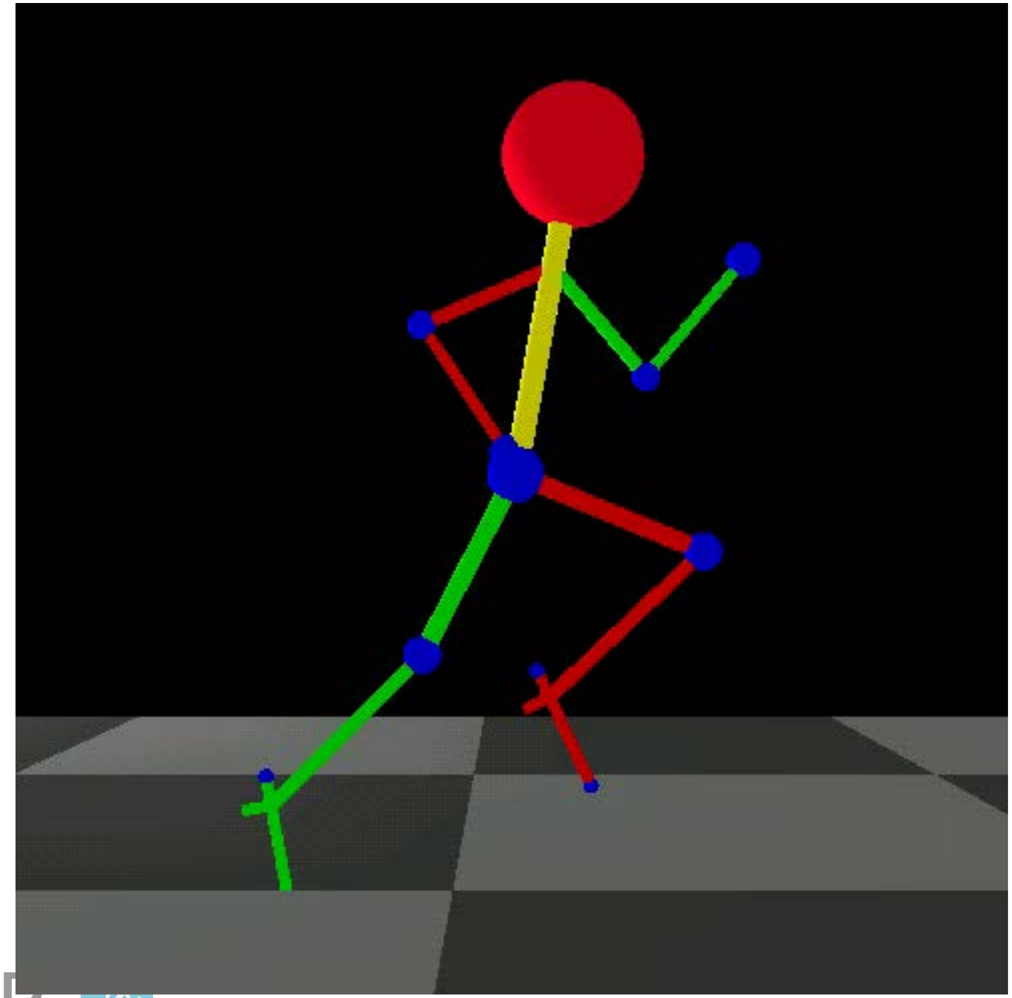
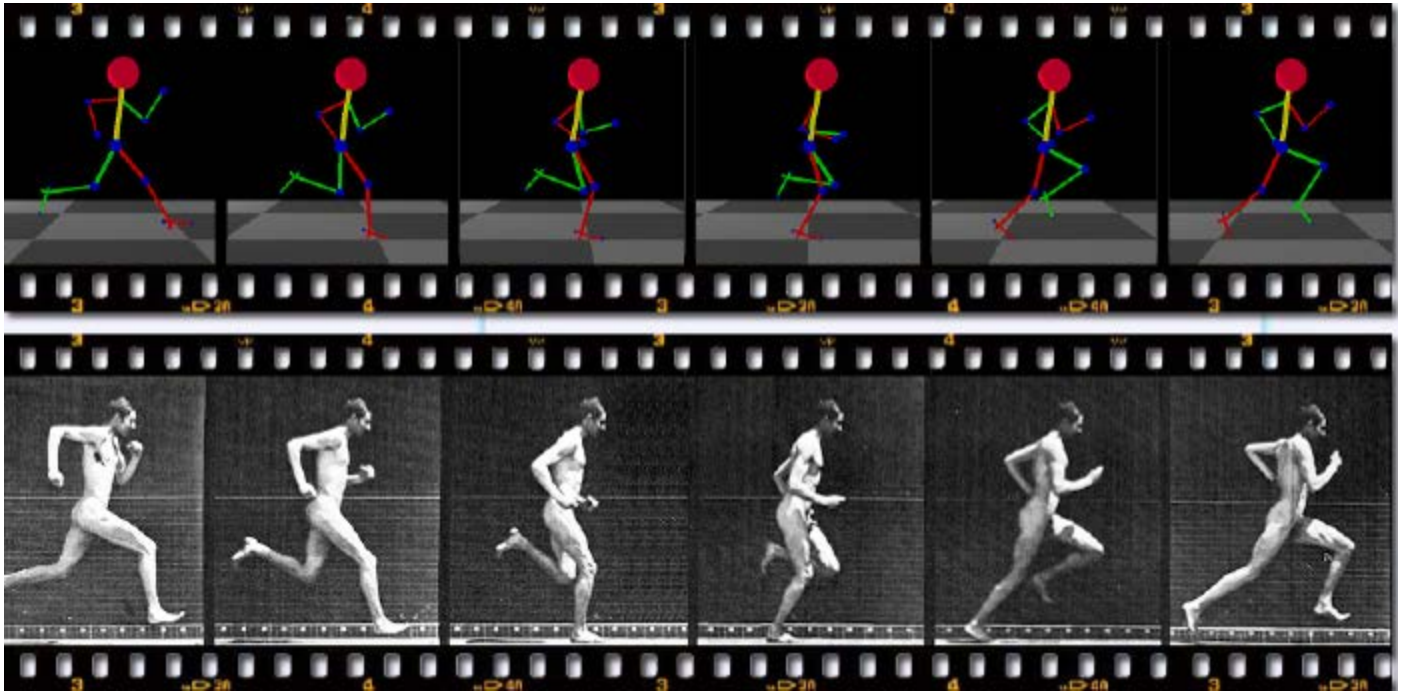
Optimal control of human-like running

with G. Schultz



- 2D,
  9 bodies
  11 DOF
- Human-like masses and geometry; powered by torques and spring-damper elements
- Optimization of energy-related criteria (torques squared and torque changes squared)
- Optimal running at
  10 m/s =36 km/h average speed

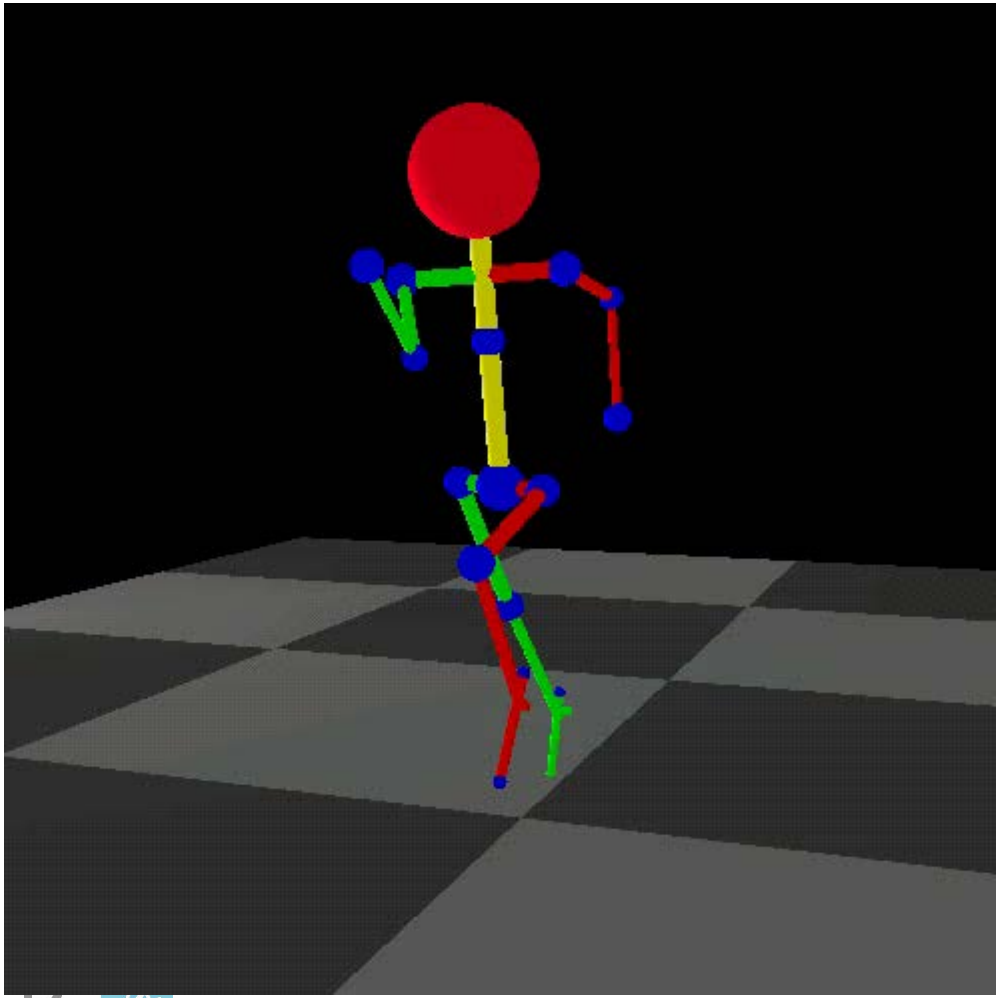
Comparison with biological running



Muybridge

- Optimization results show good correlation with human running
- Computations give useful biological insights (e.g. required torques, ground reaction forces etc.)

Optimal control of human-like running in 3D

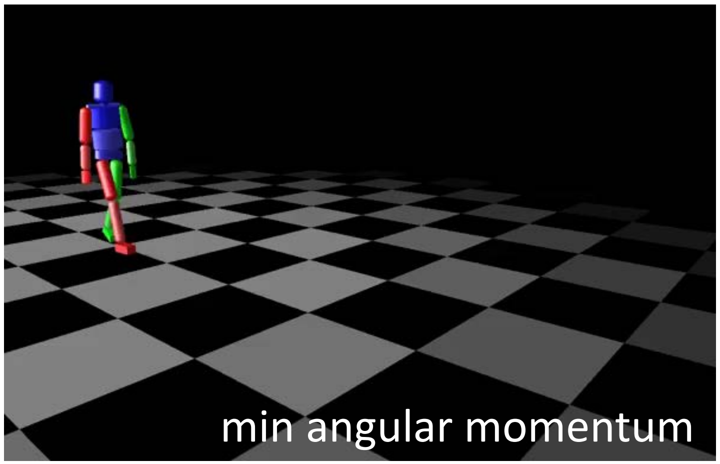


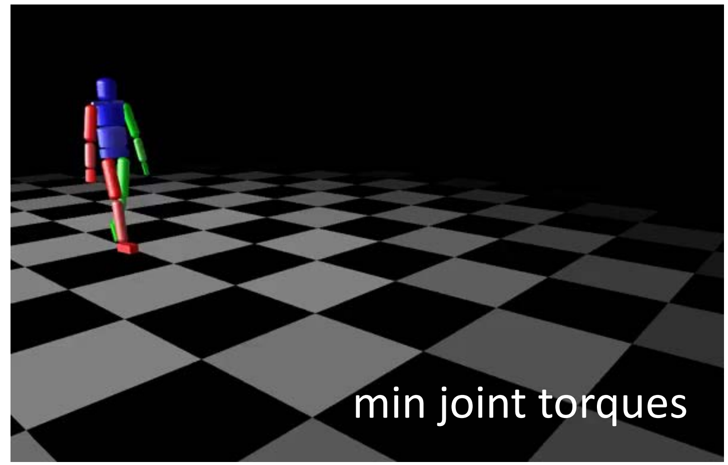
- 3D, 12 bodies, 25 DOF
- Optimal running at 10 m/s average speed; minimizing energy (as above)
- Investigation of 3D effects

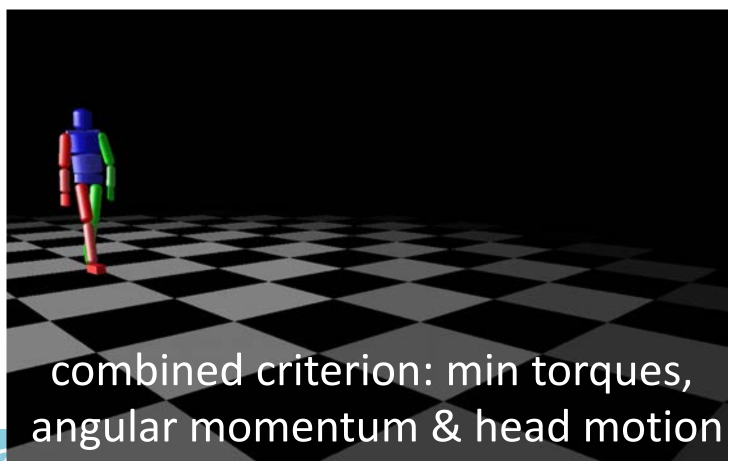
Walking generation for humans with different objective functions

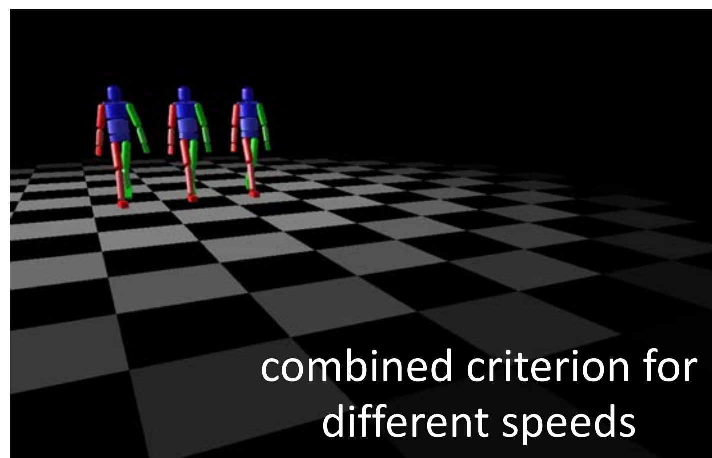
using a 3D human model with 34 DOF (Heiman)

with Martin Felis

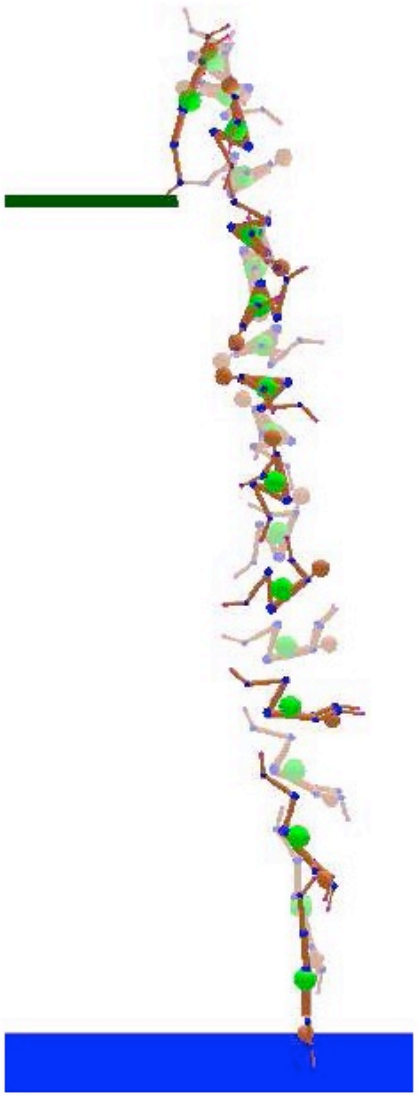


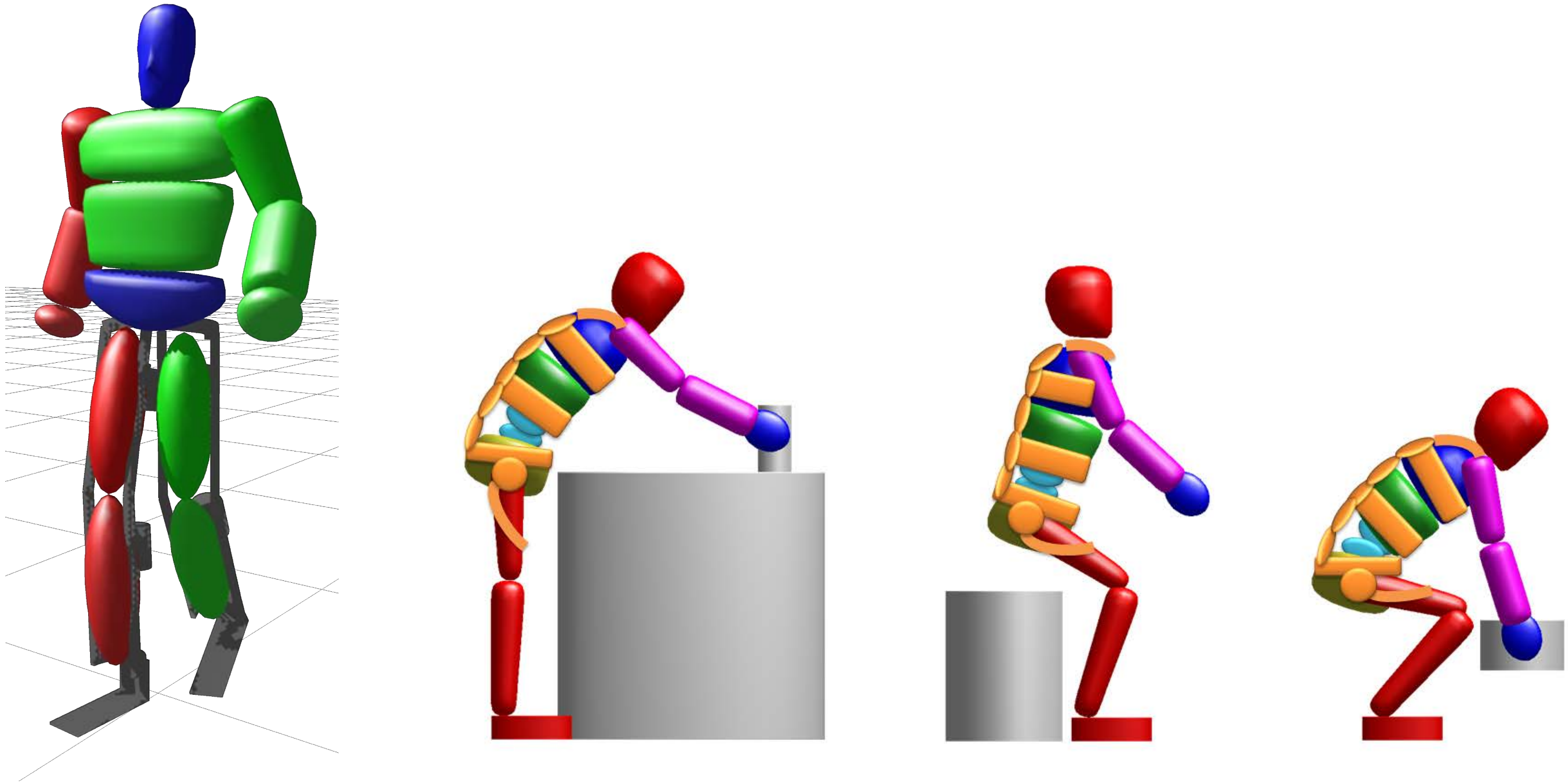






Optimization also can generate other types of motions: example platform diving





Model-based optimization for wearable robots and assistive devices

Rehabilitation and biomedical engineering - where robotics & biomechanics meet

Prostheses, orthoses, exoskeletons, external devices...

Key question:

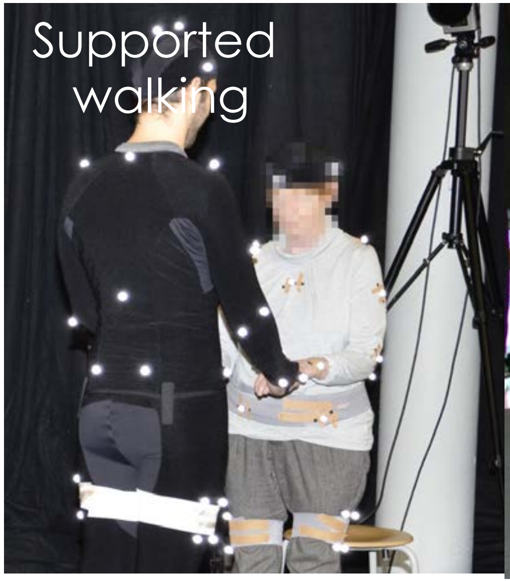
- How should assistive devices be designed and controlled in order to best support the respective human movement?

Development of 2 types of mobility assistance robots for elderly people

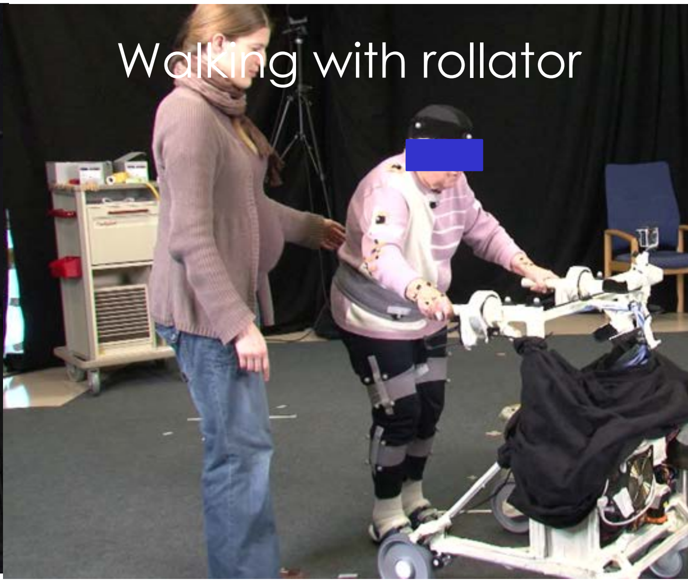
- Support walking motions and sit to stand transfers

Clinical experiments in Bethanien hospital

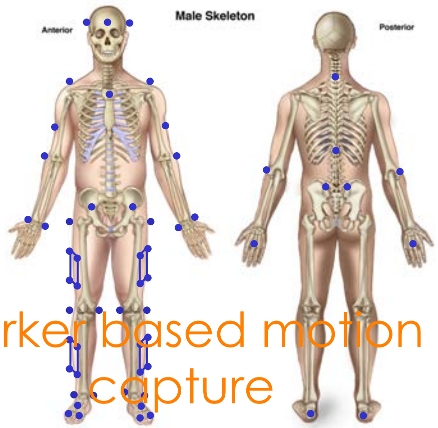
Free walking



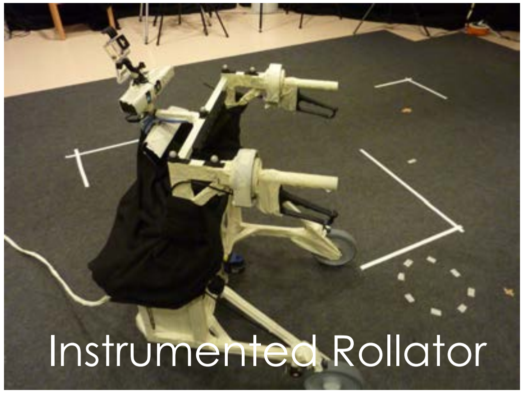
Supported walking



Walking with rollator



Marker based motion capture



Instrumented Rollator

Sit to stand transfers are most challenging and are used to define the design of the device

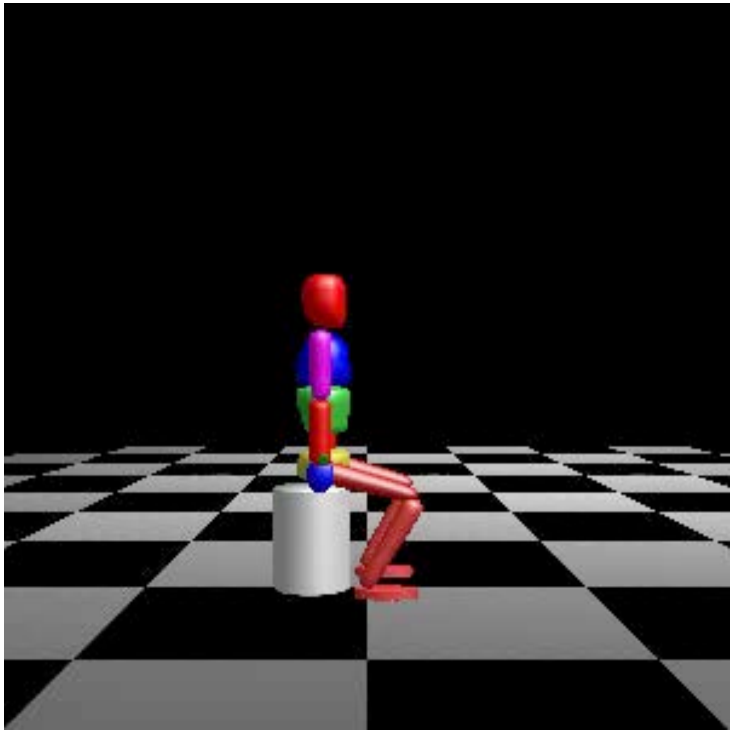
- different types of sit to stand support

rollator type support

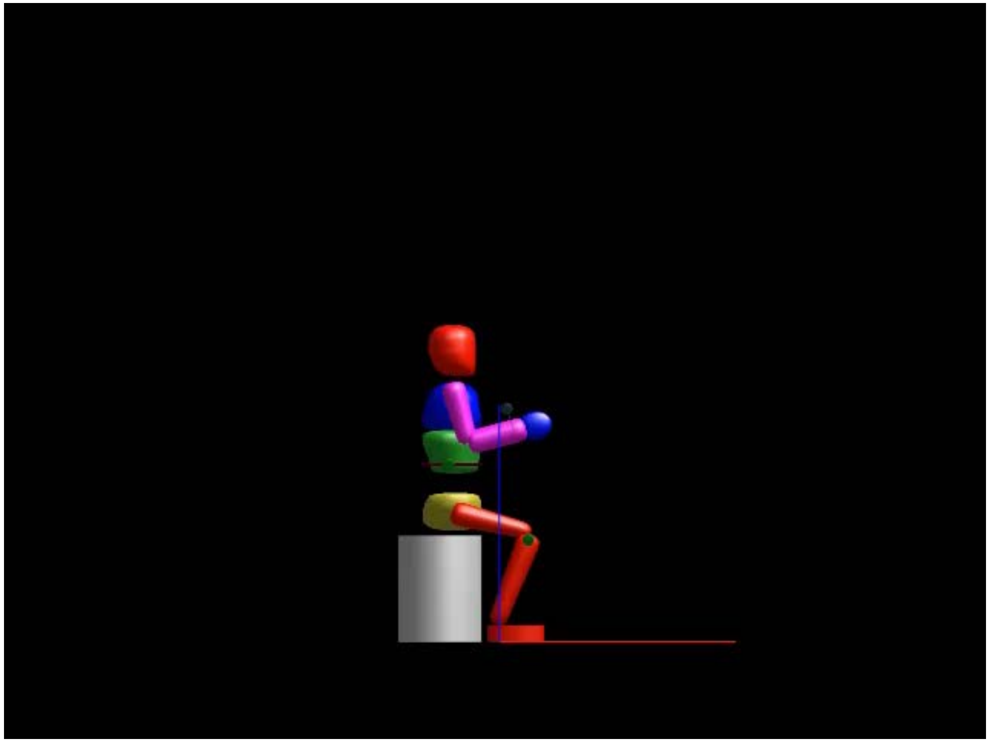
„nurse“ type support

Optimization of external support for sit to stand transfers

Rollator type
Support at the hands
up to 25 % of the weight

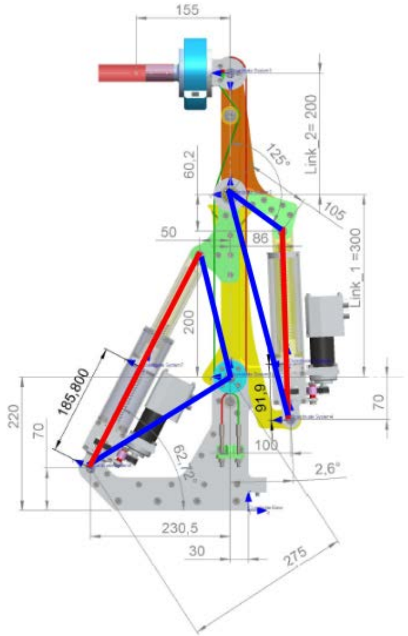


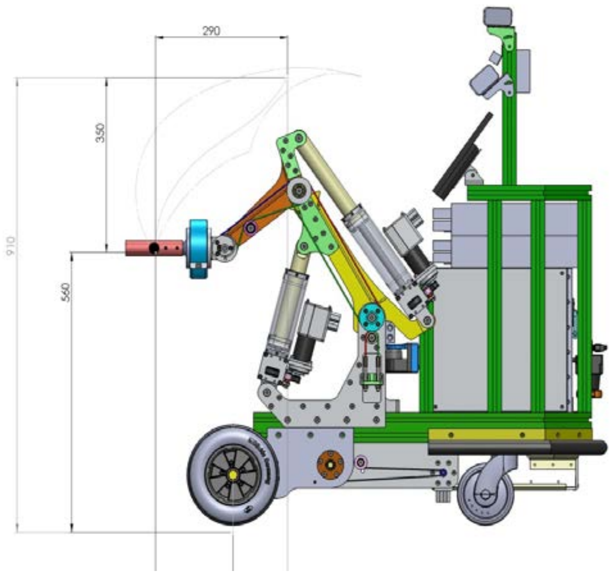
Nurse type
Support at the trunk
up to 50 % of the weight

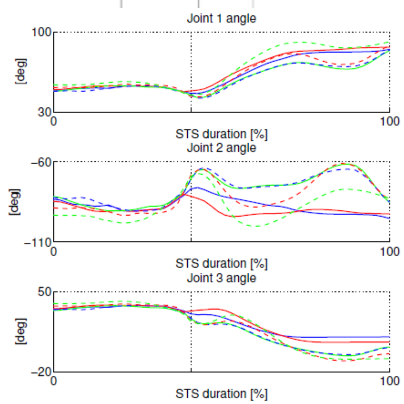


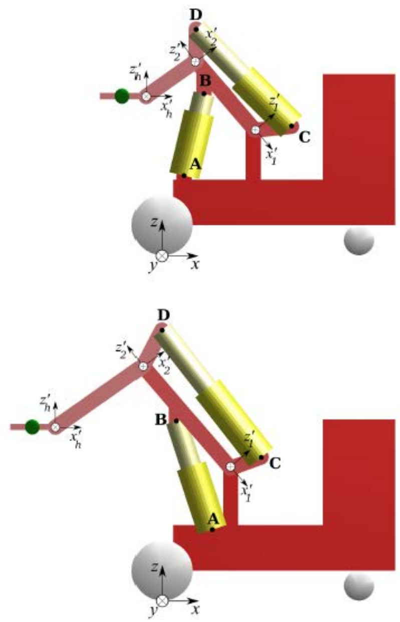
combined criterion minimizing joint torques, mechanical work and stabilizing head

Optimality studies of the rollator type assistance device





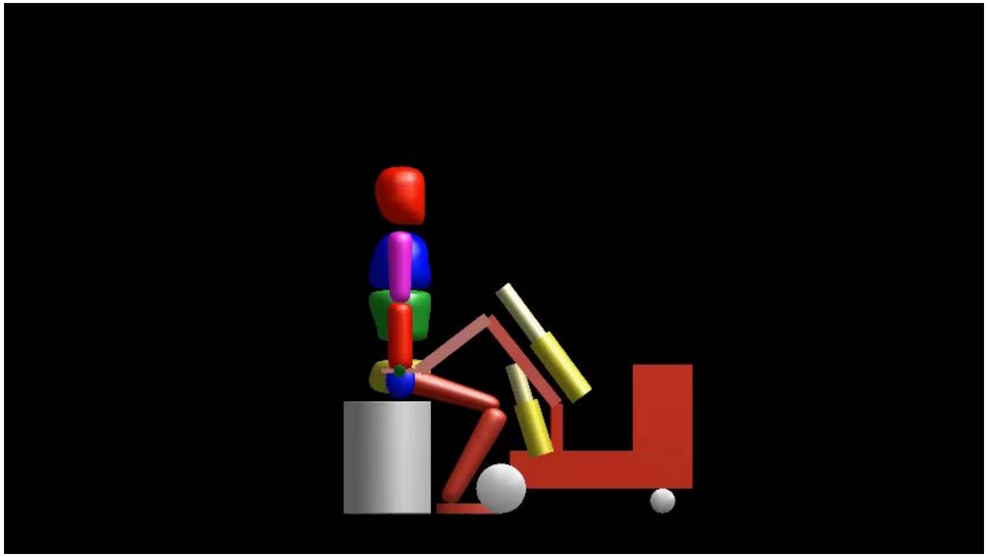


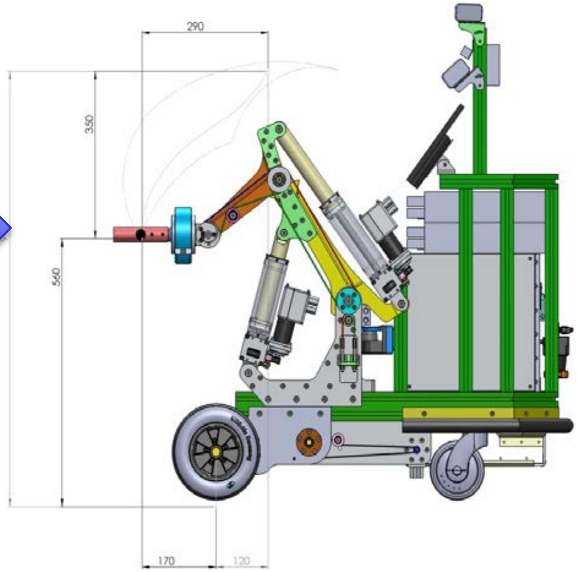


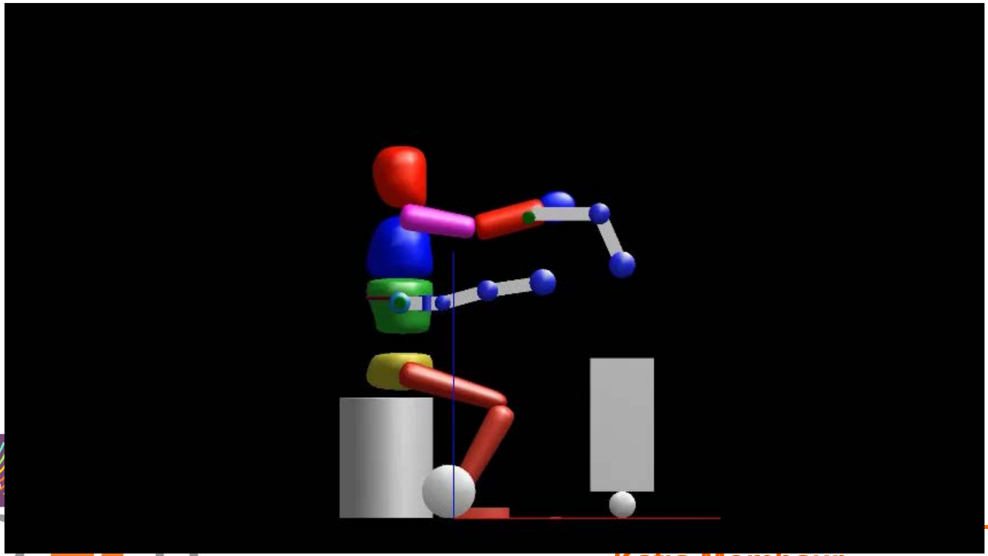
Avoid falling (Analysis / improvement)

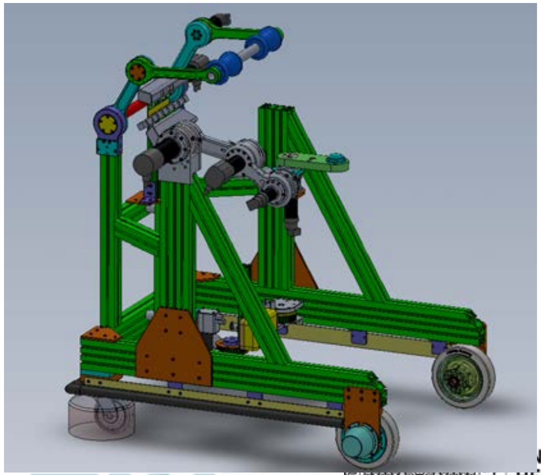
Variation of segment lengths, lever arms of actuators, etc.

Optimization of the prototype design in the computer

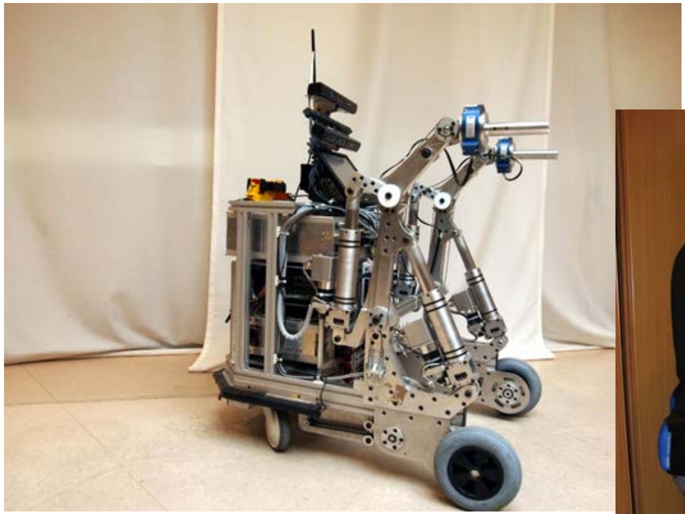


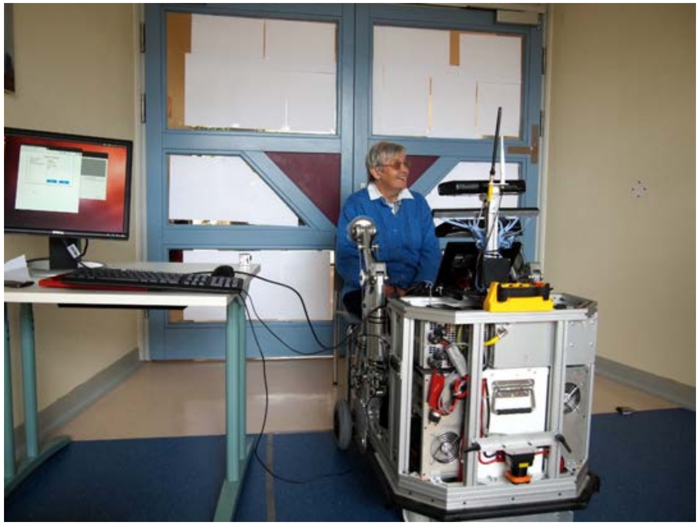






Prototypes & Validation studies in Bethanien





Follow-up research

- involving researchers from Computer Engineerig, Computer Science, Physics, Gerontology, Geriatrics, Psychology, Network for Aging, Law

Frailty Levels*

3- managing well	4- vulnerable	5- mildly frail	6- moderately frail

im Projekt entwickelte Technologien adressieren folgende Levels

B3 - Exosuit Light | B2- Exoskelett | B1 Mobilitätsassistenzroboter

B5 Exergame Stabilität & B6 Spiel Mobilitätsentscheidungen (versch. Levels)

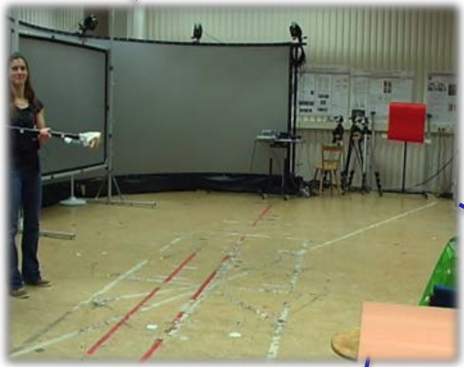
kann im Projekt evaluierte Technologie Frailty Levels realistisch simulieren?

B4 Alterssimulationsanzüge

* Frailty Skala nach Rockwood et al, 2005 und camapcanada.ca/Frailtyscale.pdf

How to best design a lower limb exoskeleton?

Must sustain nominal walking situations ....

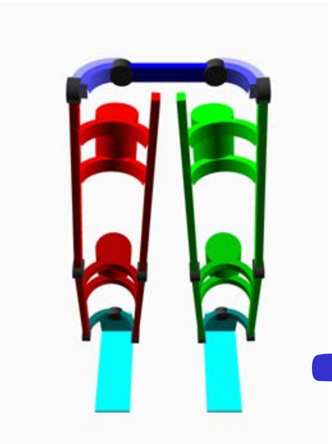


... but also large perturbations

Reference data from measurements

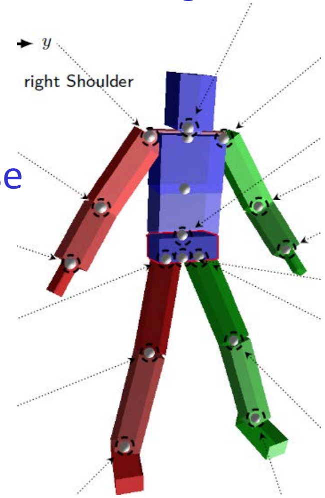
Modeling combined human-exoskeleton systems

1. Formulate parameterized exoskeleton model

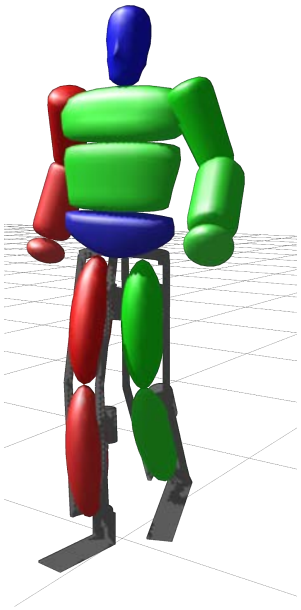


\+

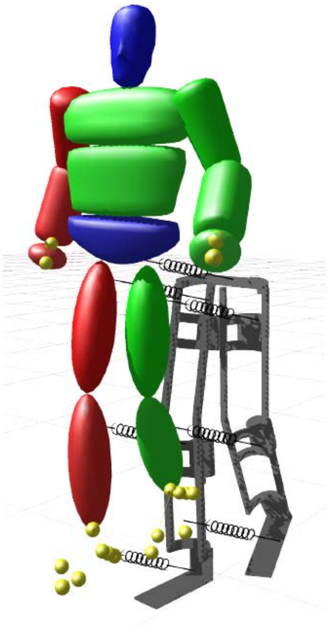
2. Formulate/choose parameterized human model



3. Choose strategy for combination of models



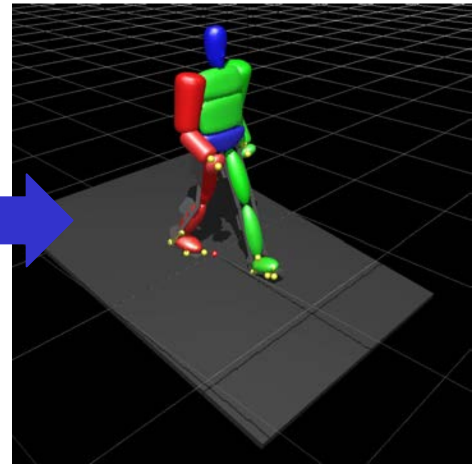
I. Rigid coupling:
a) lumped model
b) constraint-based formulation

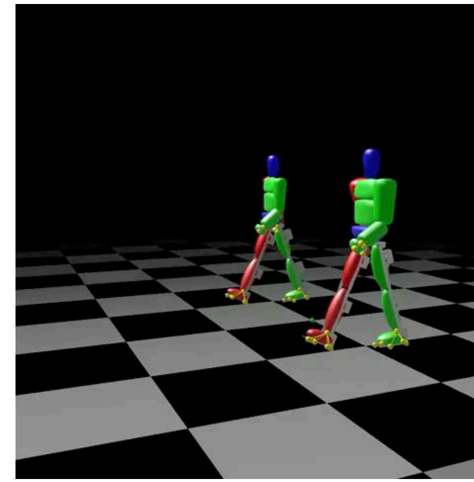


II. Compliant coupling:
a) springs
b) extended surfaces

Fitting a simulated exoskeleton walking motion to human motion capture data

with H. Koch, T. Asfour

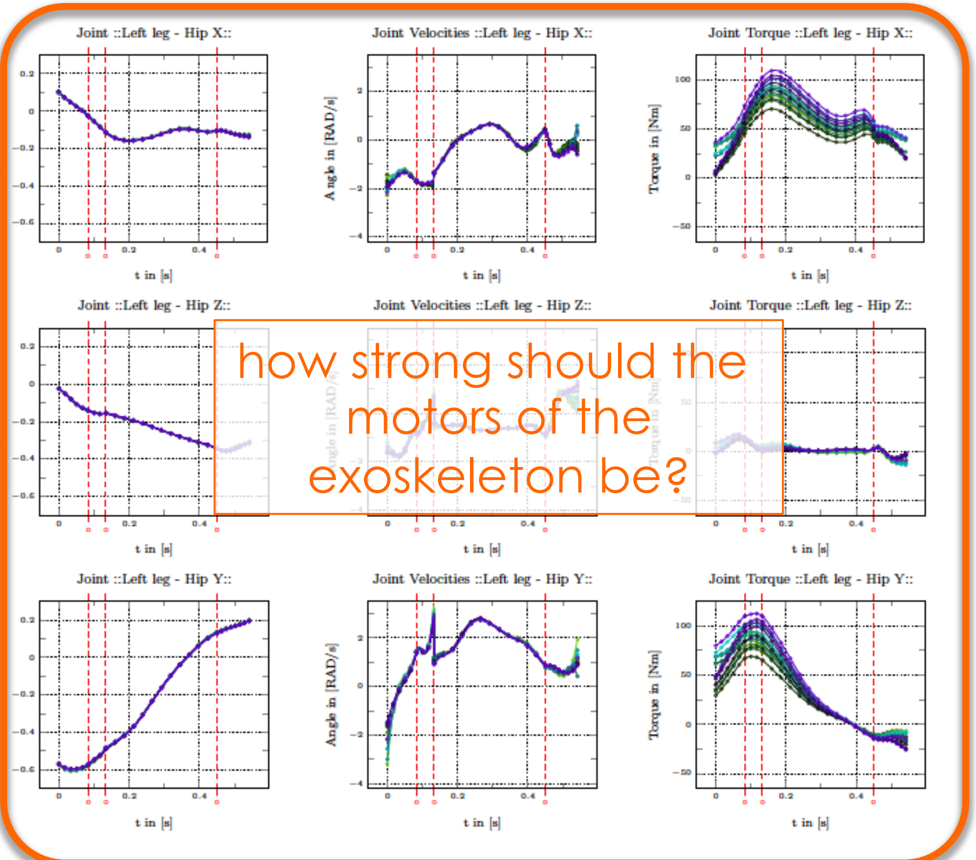


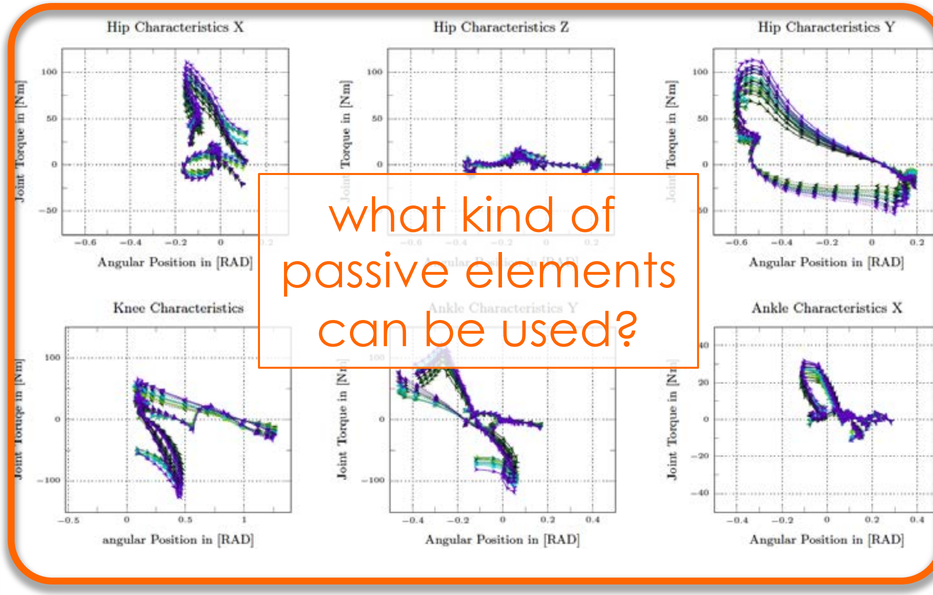


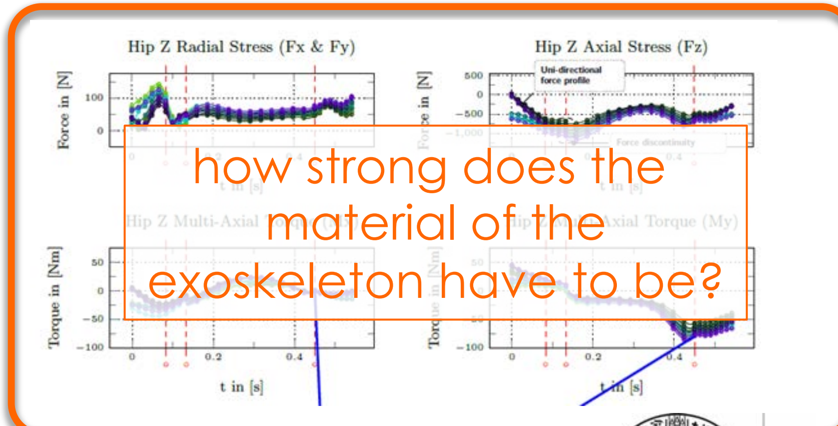
- Optimization task: fit combined model to measured data
- Level ground walking and three different slopes (up and down)
- Different masses of exoskeletons and humans are used

	Human Mass				
Exos Mass	60 [kg]	70 [kg]	76 [kg]	80 [kg]	90 [kg]
10 [kg]	■	■	■	■	■
20 [kg]	■	■	■	■	■
30 [kg]	■	■	■	■	■

Computations give many insights to support design process







Many working activities are damaging the lower back

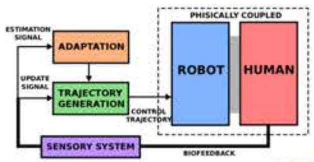


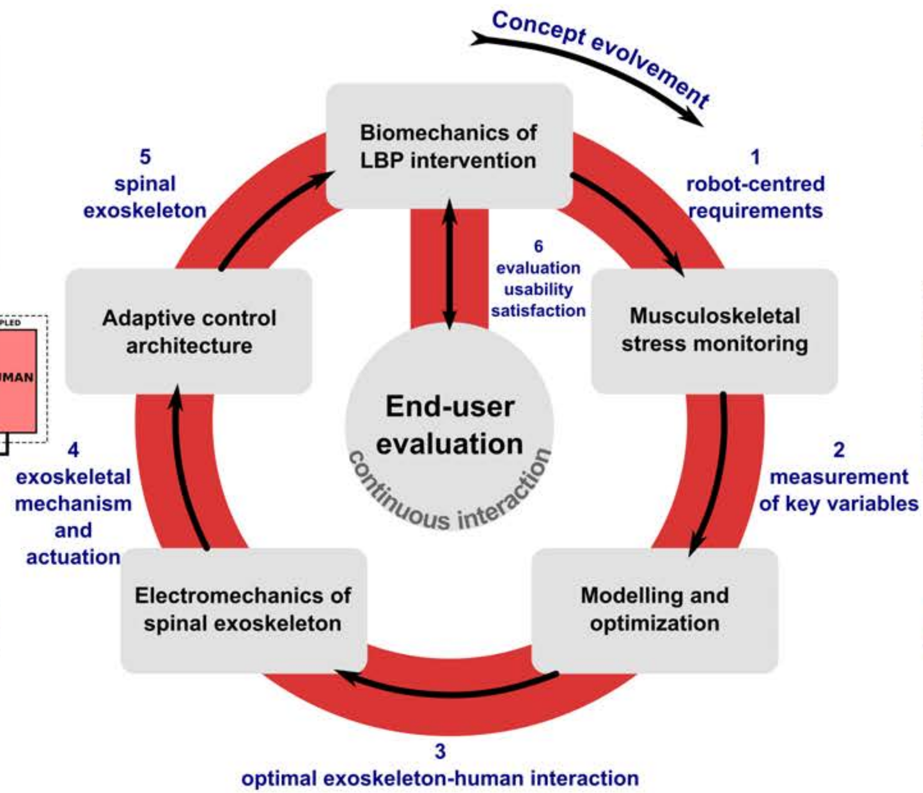


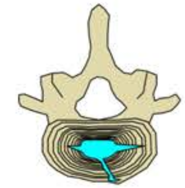

Pictures: SPEXOR project / S2P

Back pain is one of the leading causes for sick leaves worldwide

EU project SPEXOR: Development of spinal exoskeletons for prevention and reintegration







Institut "Jožef Stefan"

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Vrije Universiteit Brussel

VU VRIJE UNIVERSITEIT AMSTERDAM

ottobock.

S2P SCIENCE TO PRACTICE

heliomare

Coordination Jan Babic

Design and control of the exoskeleton

Sensors?

Control strategies?

Ergonomics/
comfort?

Best way to
support motions
?

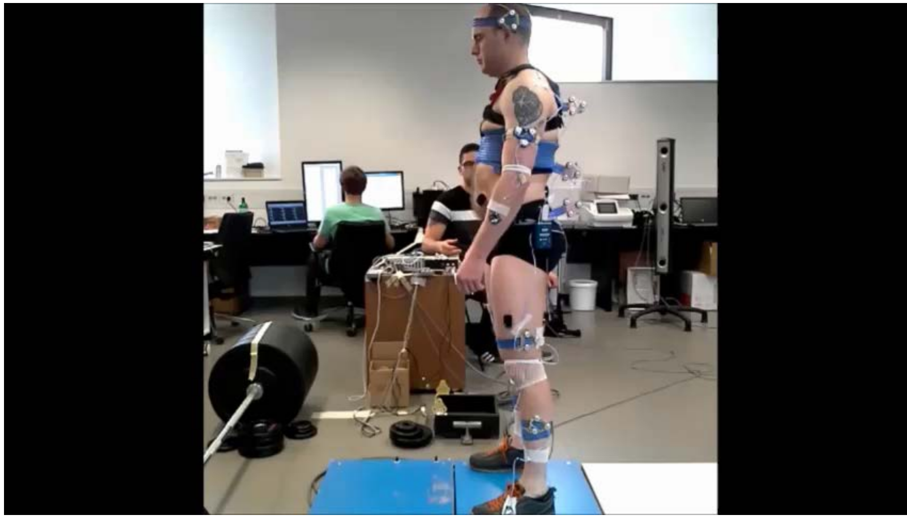
Contact points and
surfaces?

Choice of passive
elements?

Choice of actuators?

Use optimization to find some of the answers

Experiments for model calibration and validation



- ranges of motion
- maximum voluntary contraction

S2P SCIENCE TO PRACTICE

ziti

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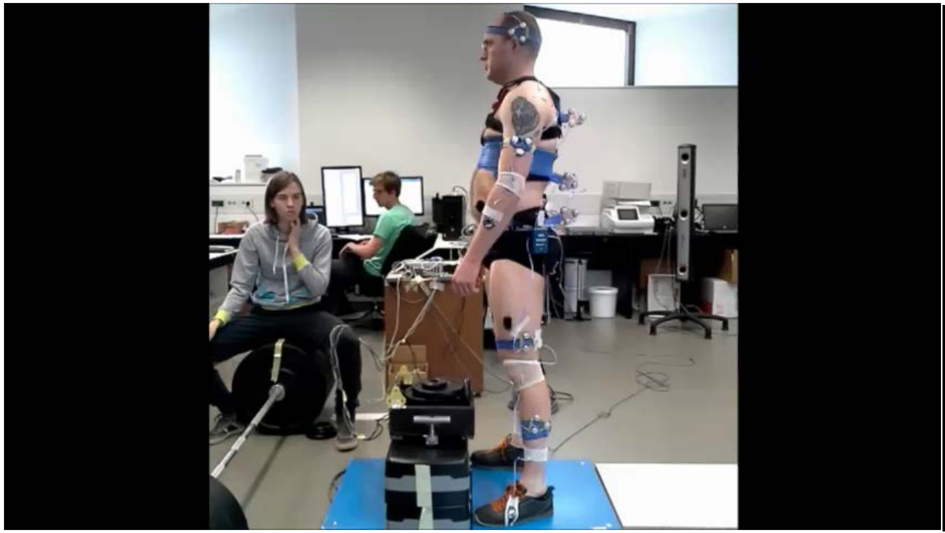
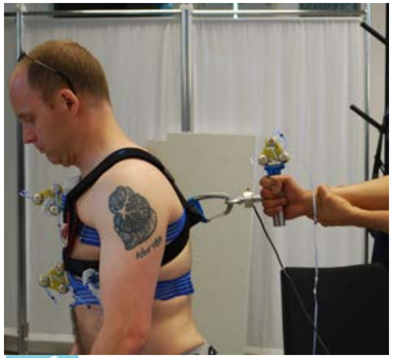
Experiments on reference motions and connections between human and exo

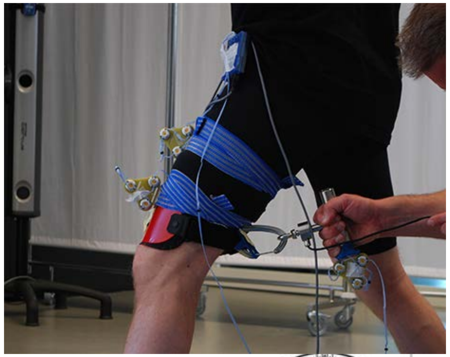
lifting box



lifting box & turning

Testing compliance of exo straps

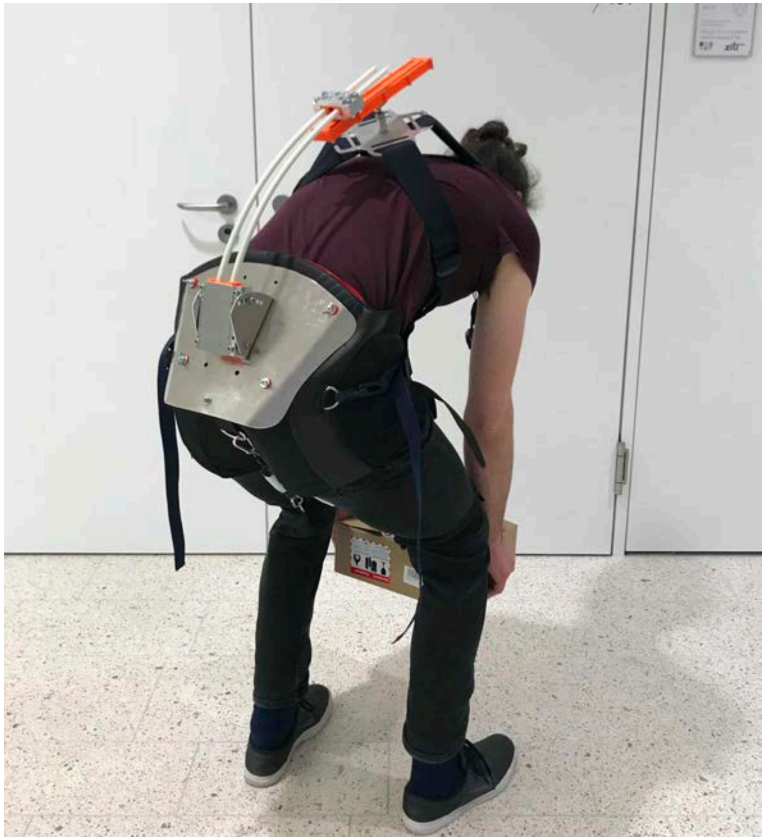




SPEXOR Exoskeletons

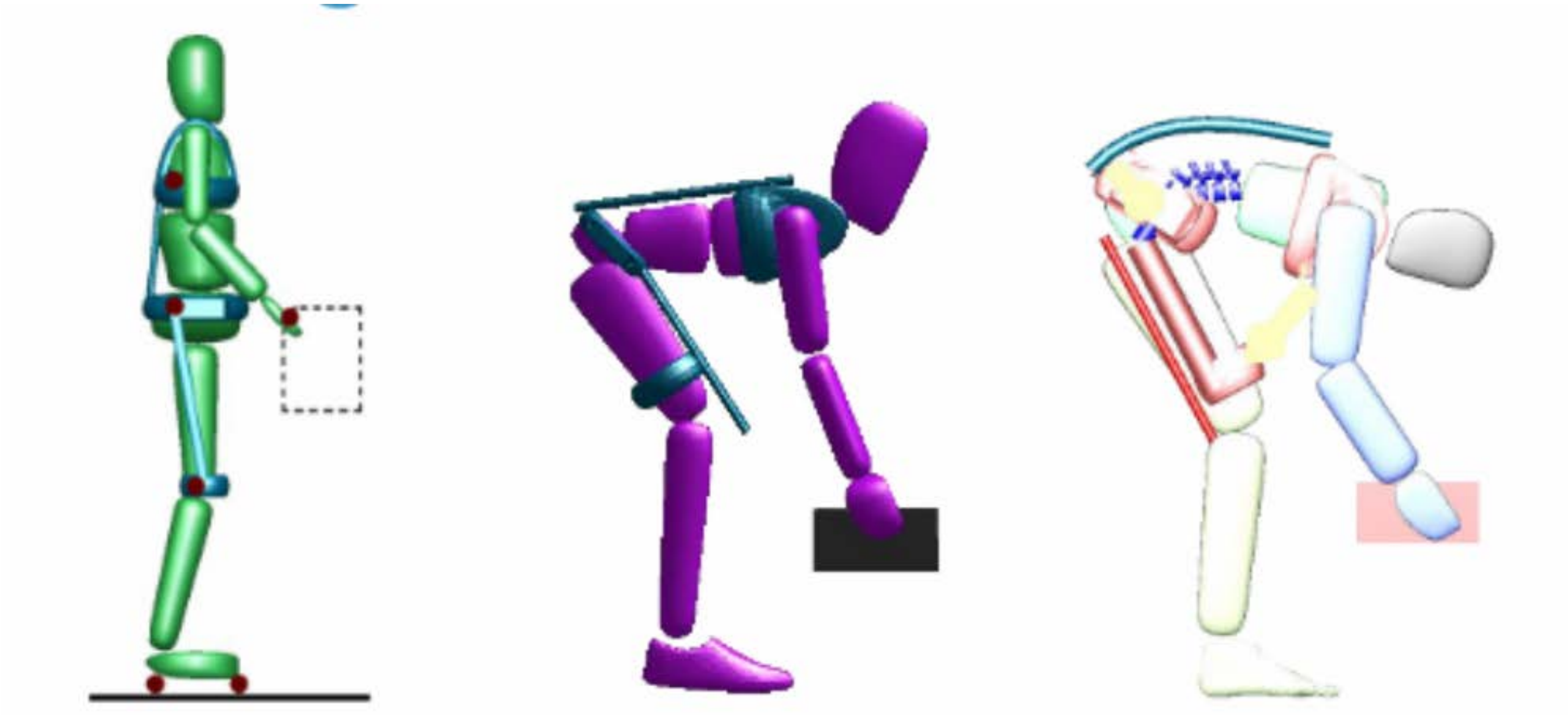
- VU Brussels

- Heidelberg University



Different SPEXOR prototypes are investigated

- Passive prototypes (springs, dampers, clutches etc.) &
  Active prototypes (actuators)
- Rigid and compliant elements considered, according to planning status in project



Different stragegies of motion selection for exoskeleton design

Track recorded trajectories without exoskeleton

or

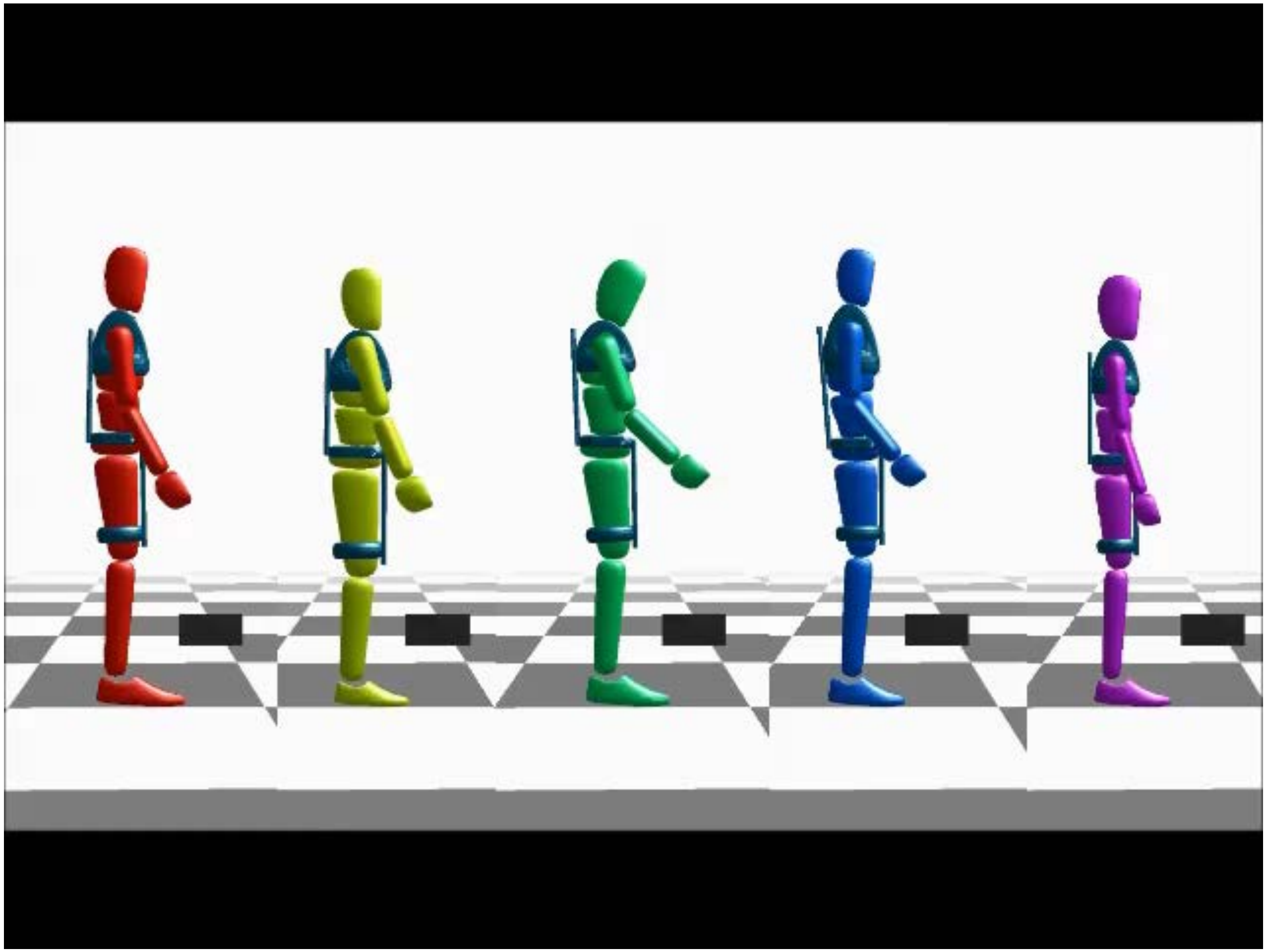
?

Aim for a different behavior (optimal w.r.t some criterion)

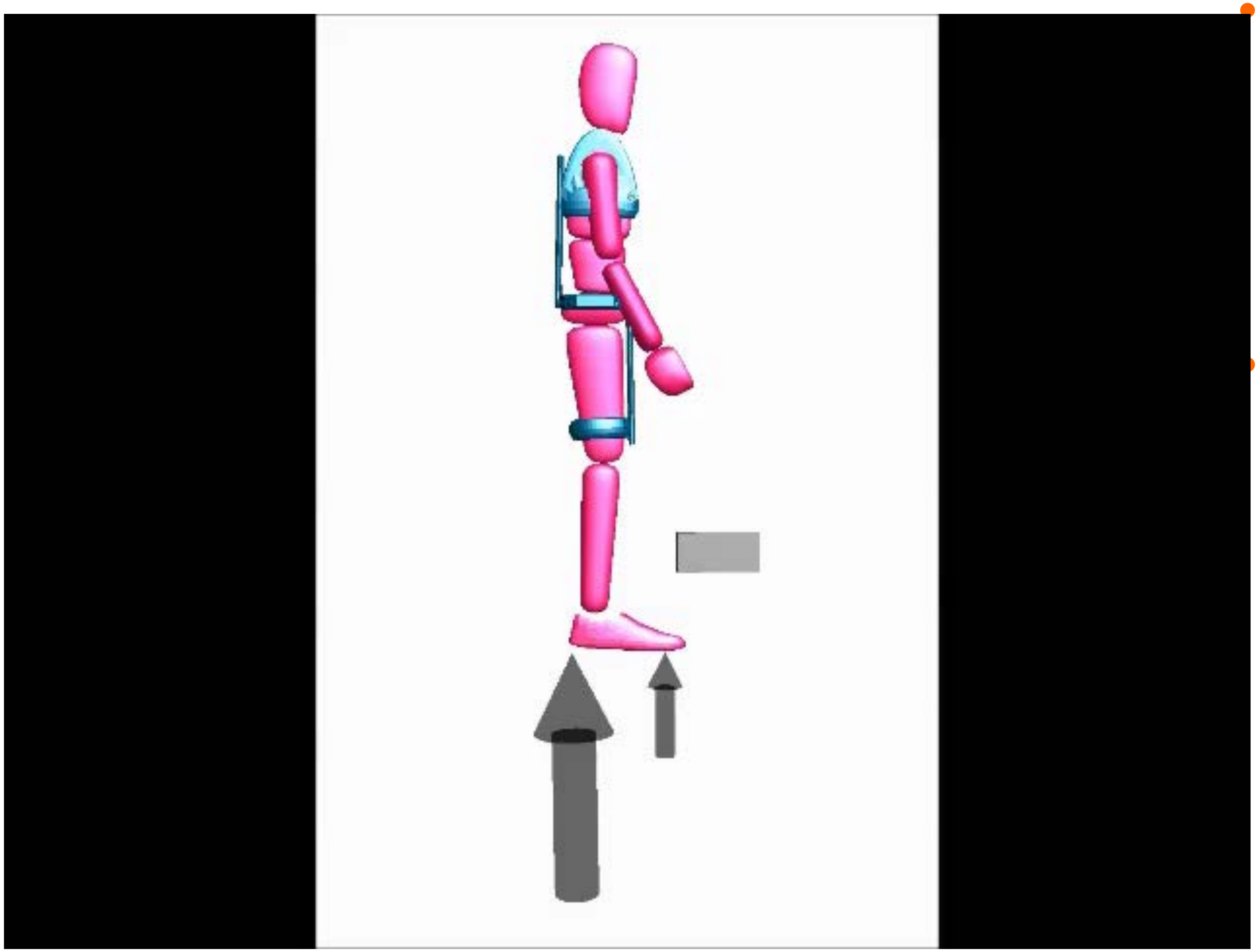
or combine?

Fitting models with exoskeletons to data

with Monika Harant, M. Sreenivasa, M. Millard., N. Sarabon



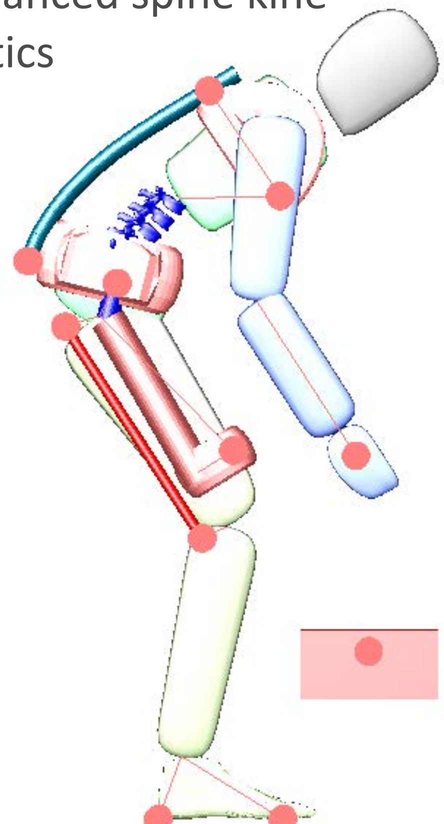
Contact and ground reaction forces can also be analyzed



- Acceptable limits can be considered in the design process
- Interaction forces can also be reduced

Latest exoskeleton models evaluated include compliant elements

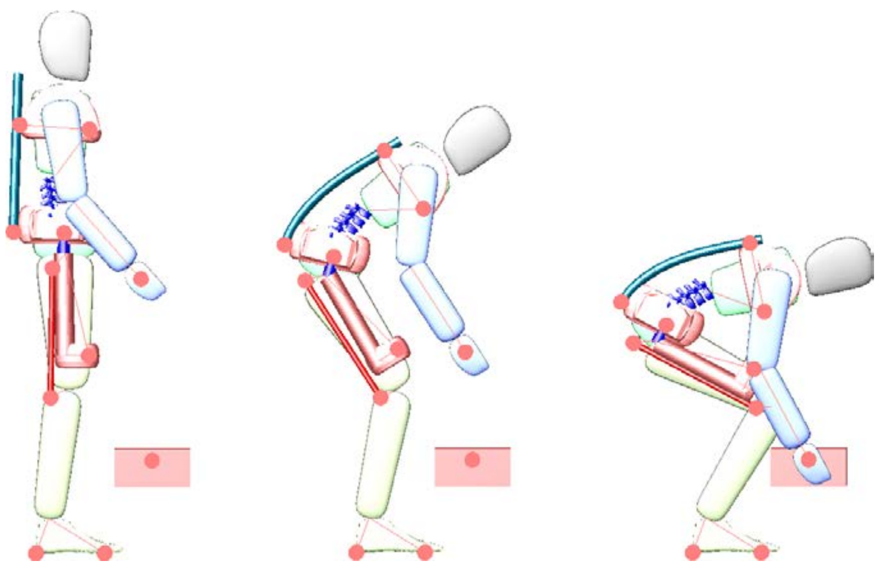
- bendable carbon fiber beam in lumbar joint
- enhanced spine kine-matics

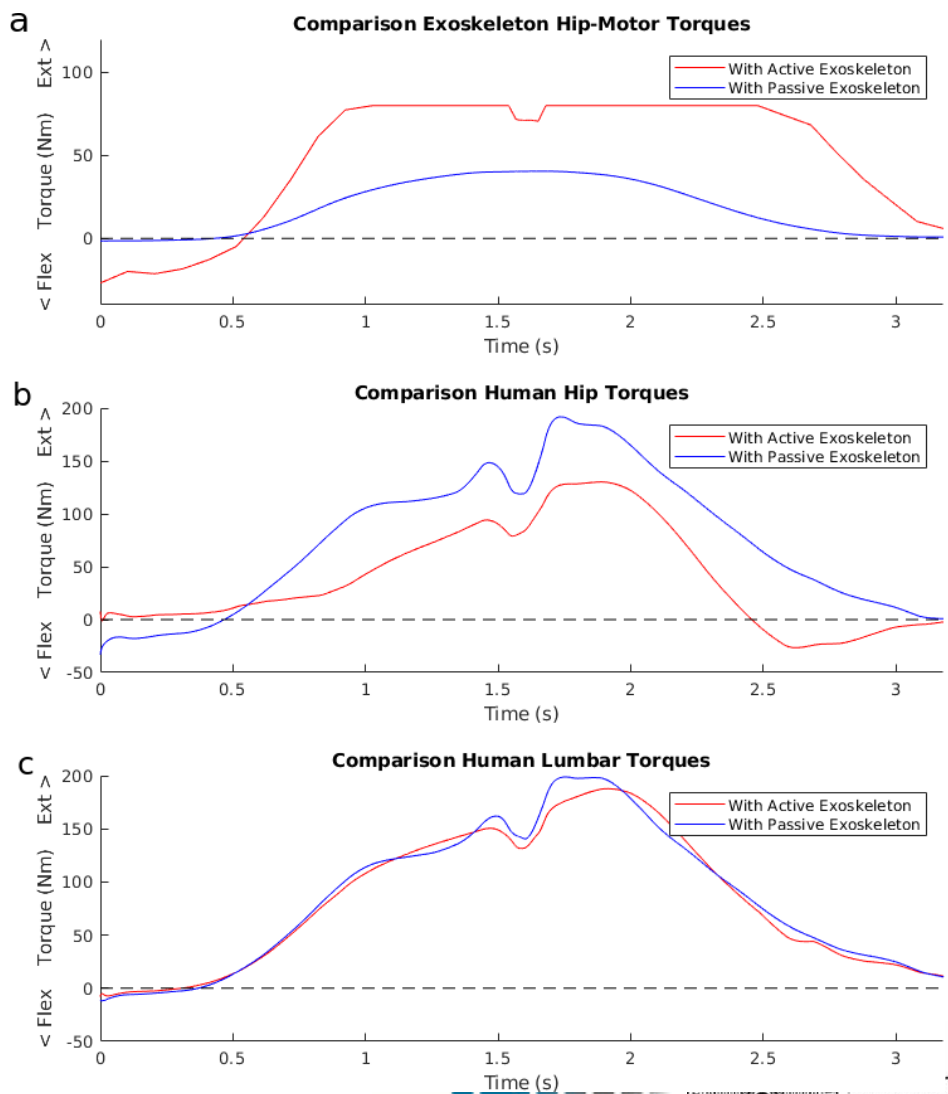


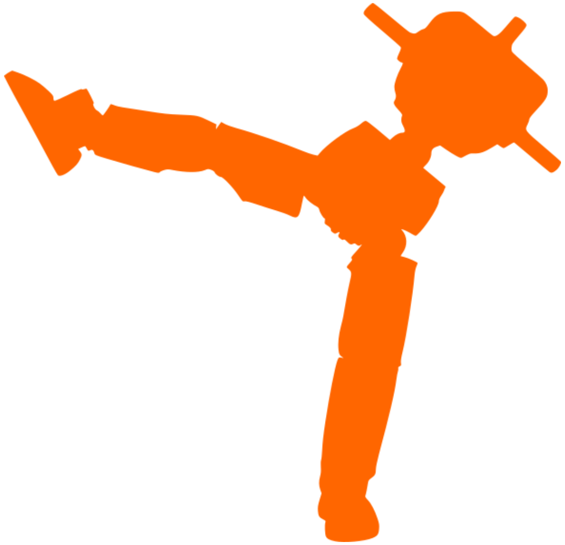
with M. Sreenivasa, M. Millard, J. v Dieen, I. Kingma

current SPEXOR passive prototype
M. Näf et al, Front. Robot. AI, 2018

Effects of passive and active compliant exoskeletons on torques







Model-based optimal control for humanoid robot motions

Humanoid robots will be used in situations which ...

- ... are too dangerous, too far away or too boring for humans
- .. in which however a human-like figure is requires

Pictures Wikimedia Commons

... ...and most of these situations require advanced motion capabilities

Humans are capable to perform a variety of walking tasks with ease

... but humanoids are not.

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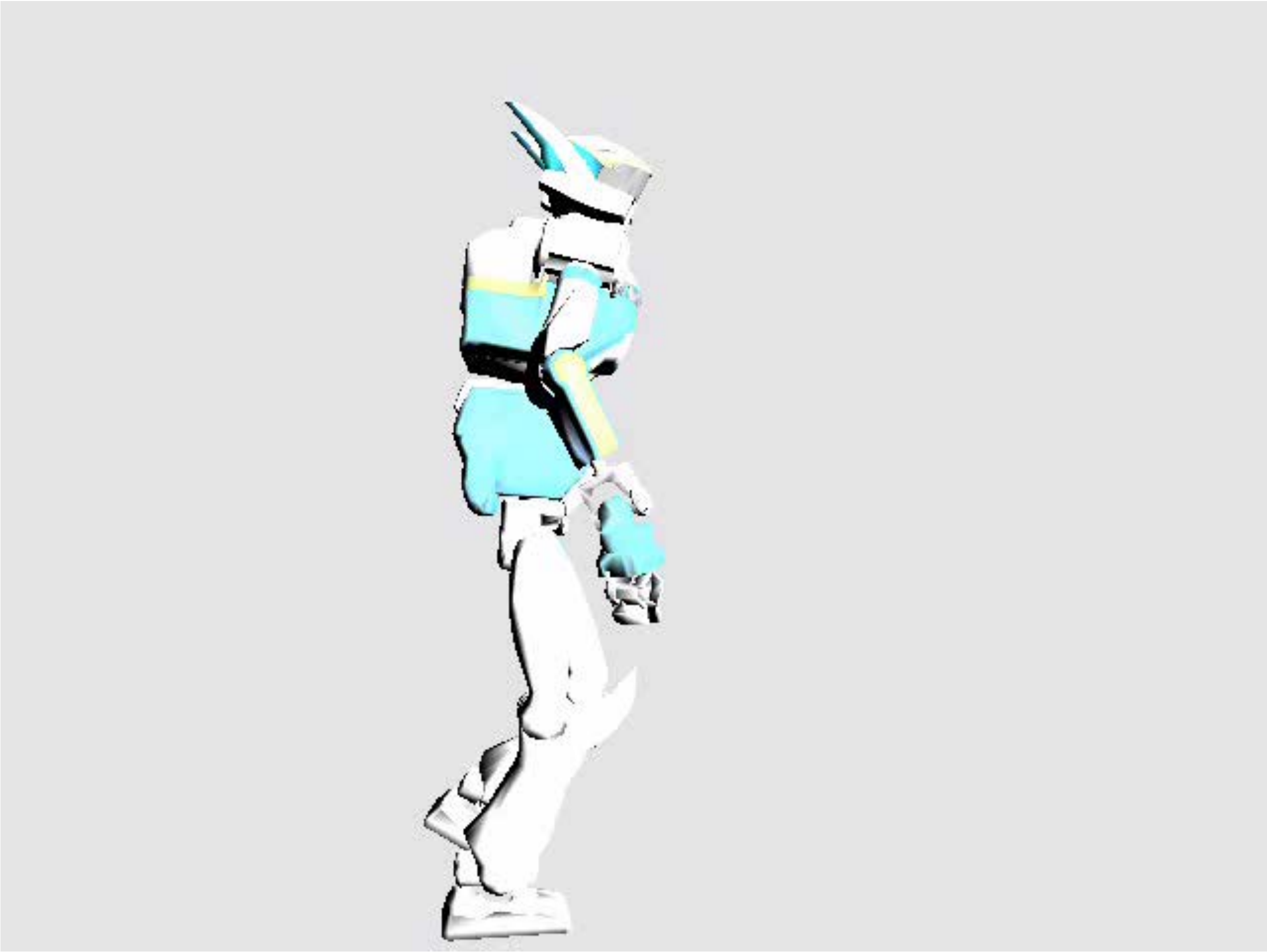
It would be nice if one could just map a human motion on the humanoid



It would be nice if one could just map a human motion on the humanoid

BUT.... this is only an animation and is not feasible in reality

The velocities are too high.....

The torques are too high.....

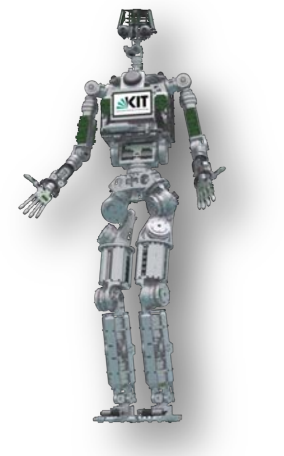
Strict stability criteria of robot are violated....

The accelerations are too high.....

The impacts are too big.....

KoroiBot's main goal was to develop new software, not hardware

Several state of the art robot platforms were available in Koroibot to which methods were be applied (very different size and degrees of freedom)



ARMAR IV

HRP-2

HRP-4

iCub

HeiCub

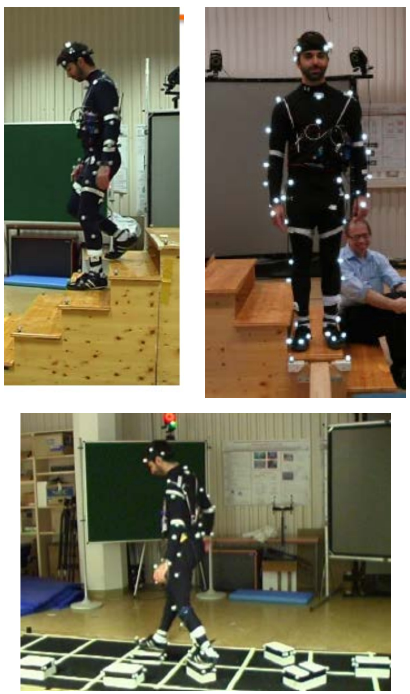
LEO

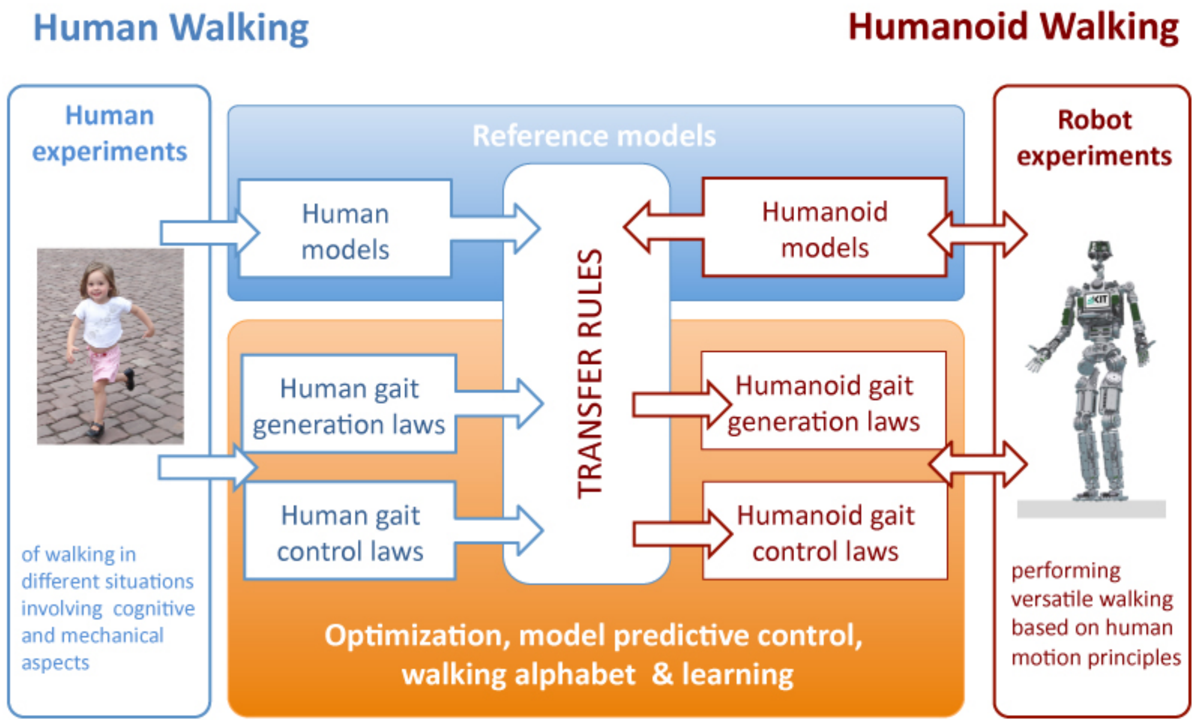
TUlip

Romeo

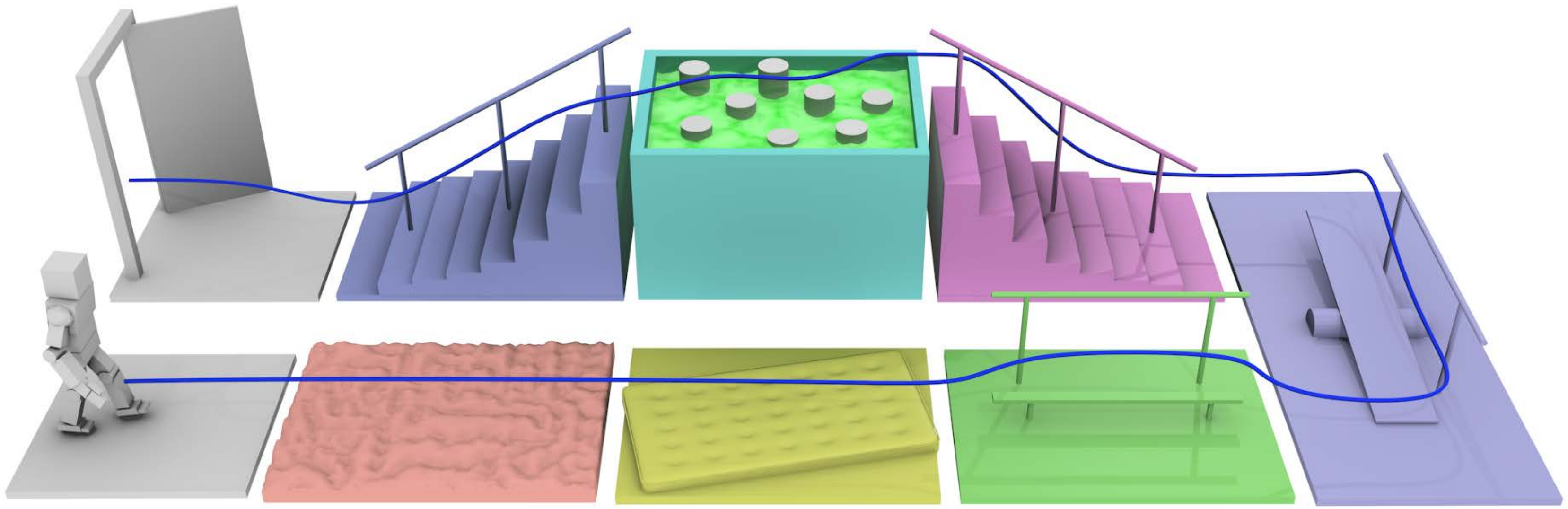
KoroiBot Methodology

Transfer motions from humans to robots by means of optimization, learning and motion primitives





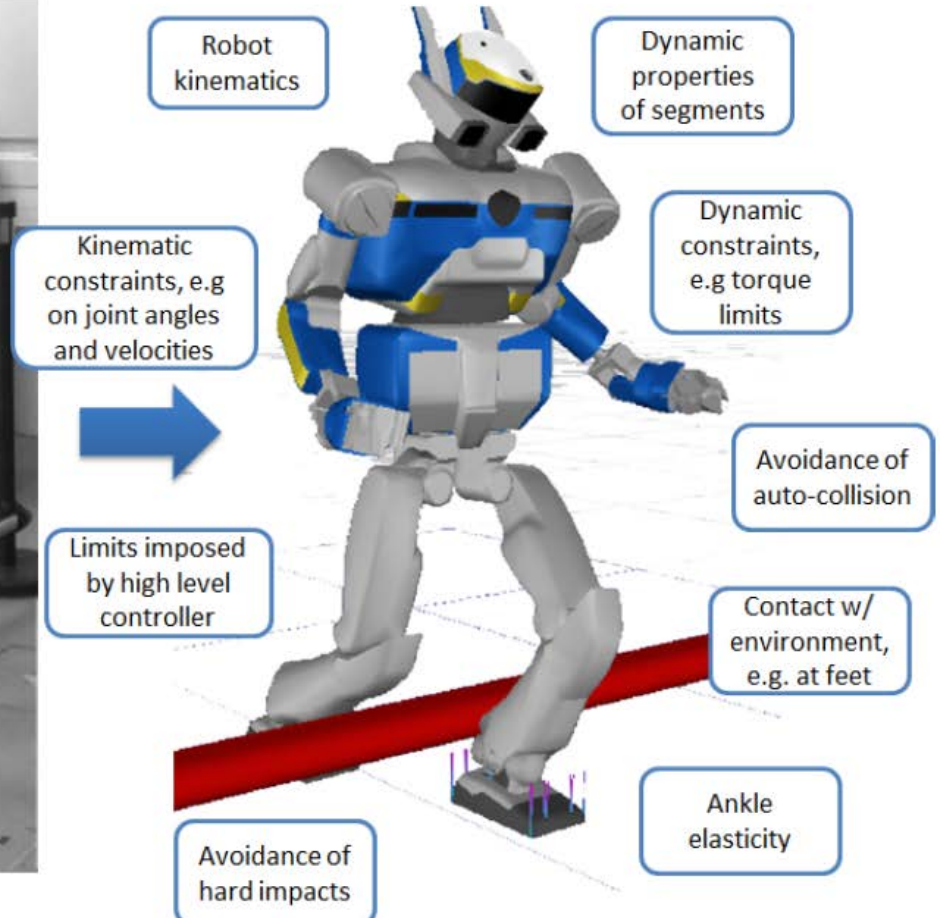
KoroiBot Scenario



Whole-body models of humanoid robots for optimization (example HRP-2)

Real robot

Whole-body dynamic model



Optimal control of a step over a large obstacle

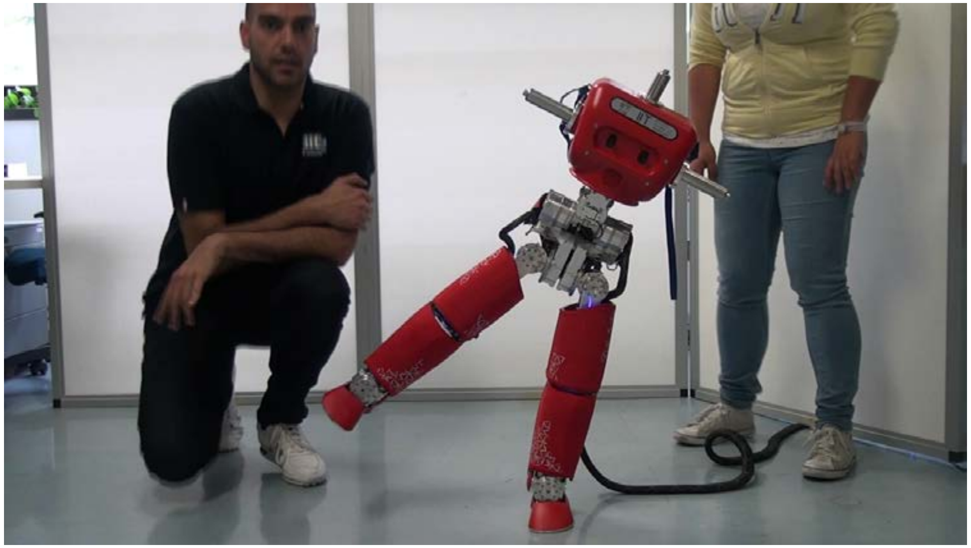
with H. Koch, P. Soueres

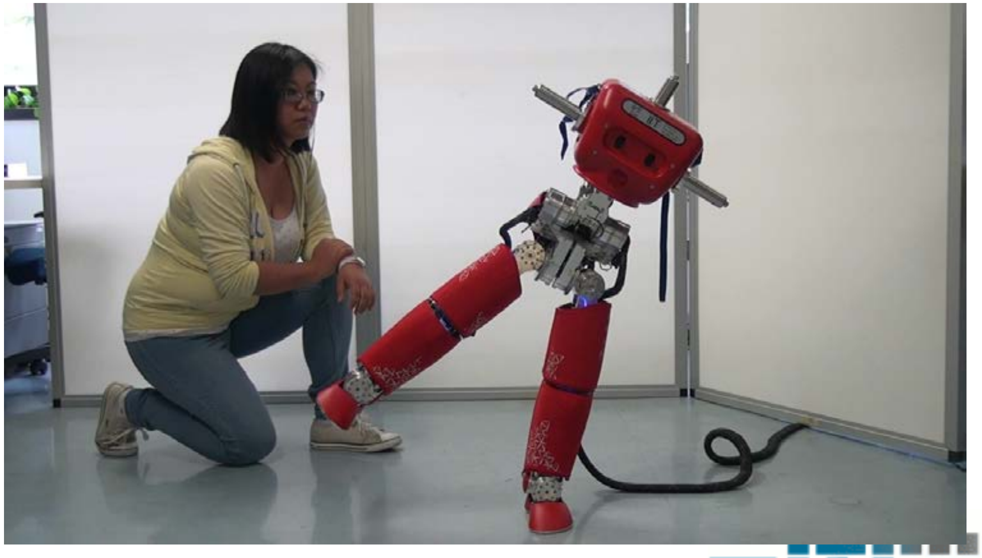
HRP-2 climbing stairs exploiting support by a handrail

Balancing on one foot - iCub (IIT)

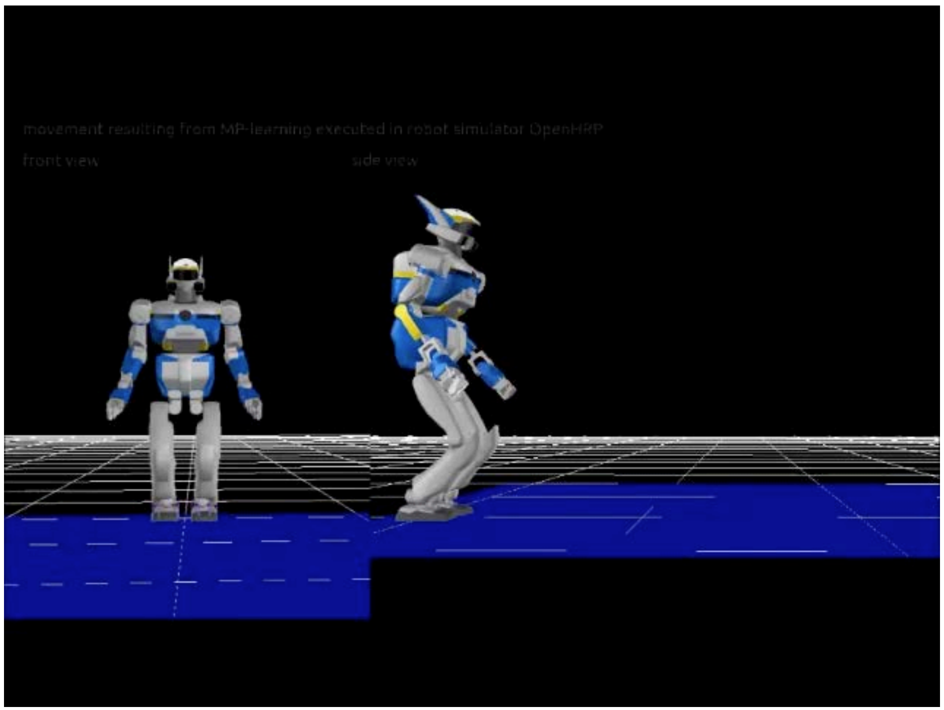
Balancing on one foot without arms - HeiCub

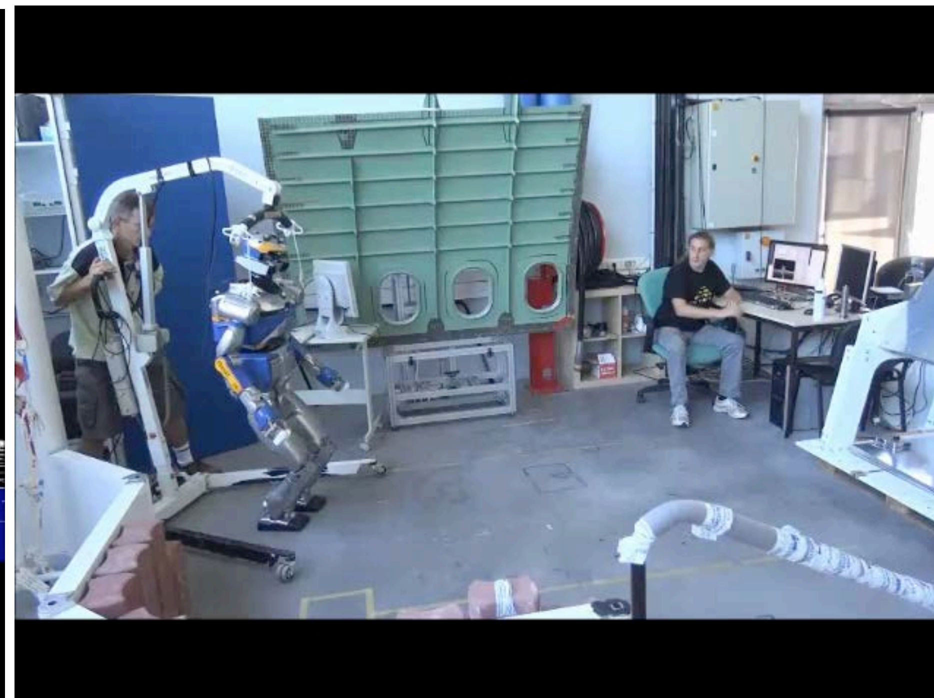
Y. Hu, D. Pucci, F. Nori



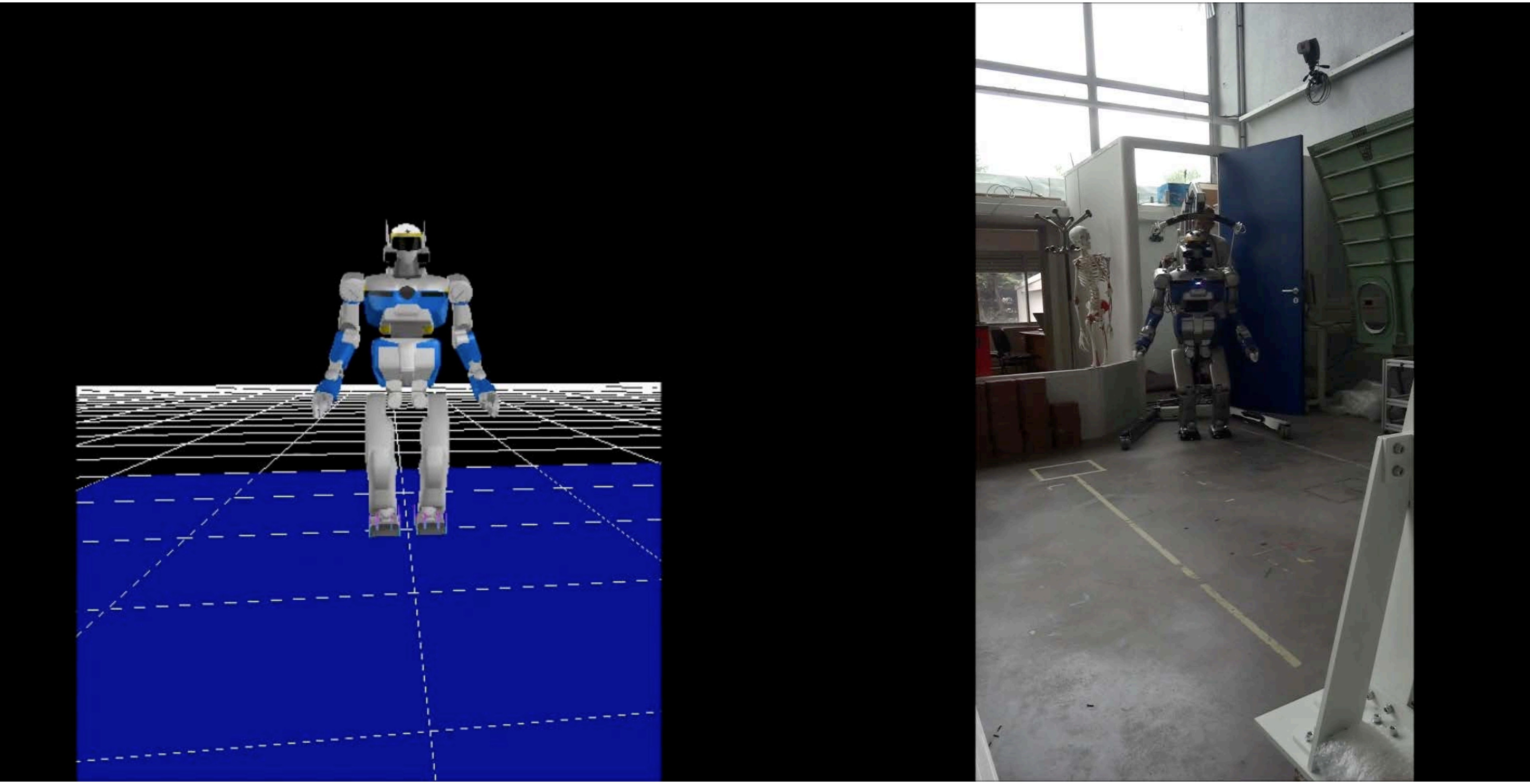


Generation of variable step length walking motions for the humanoid robot HRP-2



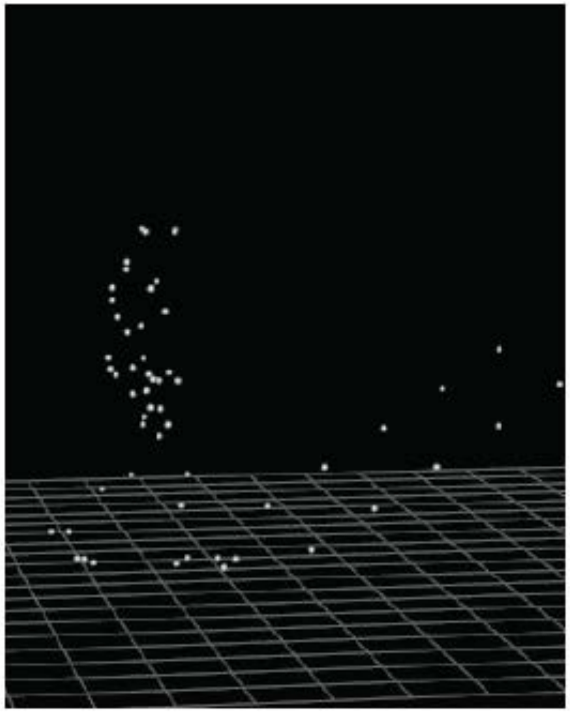


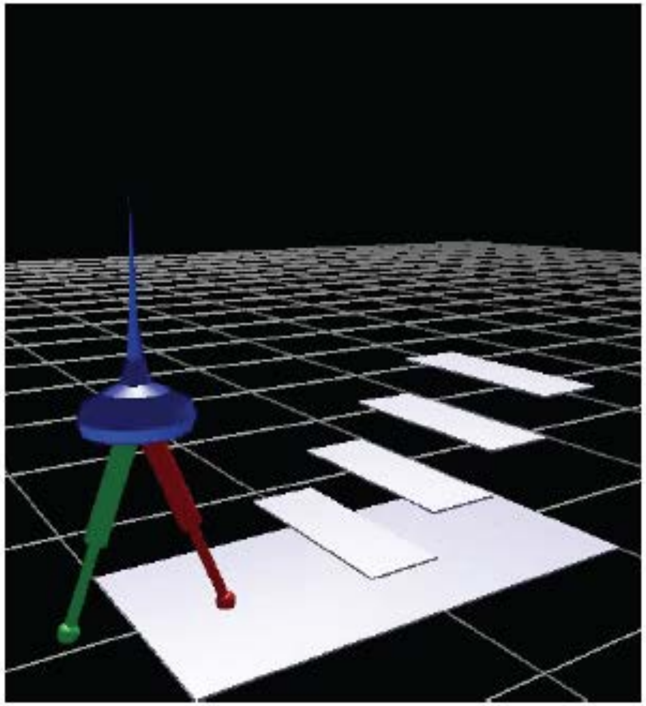
Generation of variable step length walking motions for the humanoid robot HRP-2



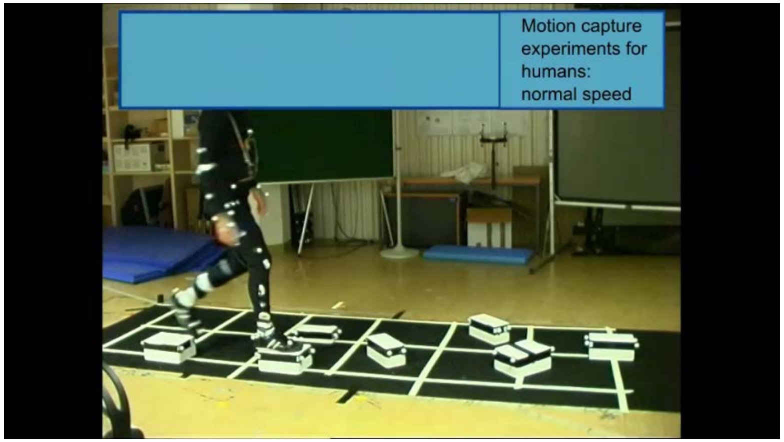
From measurements to computer models of human walking

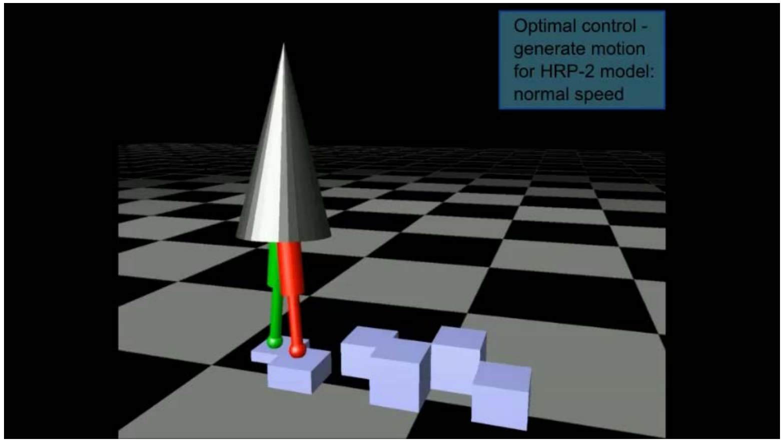
- Motion → Marker positions → dynamic model

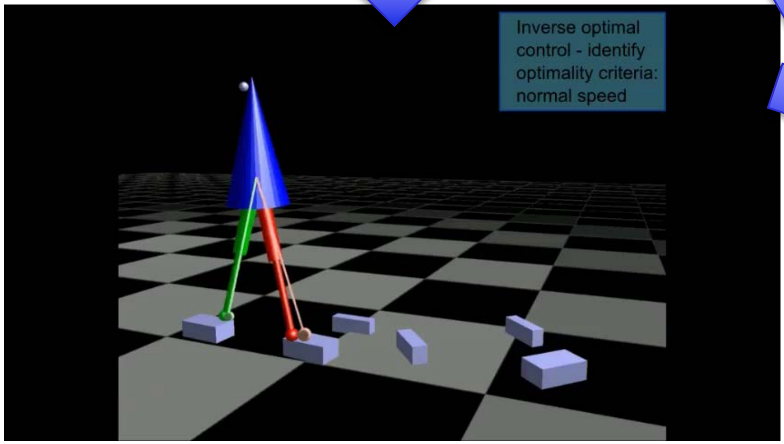


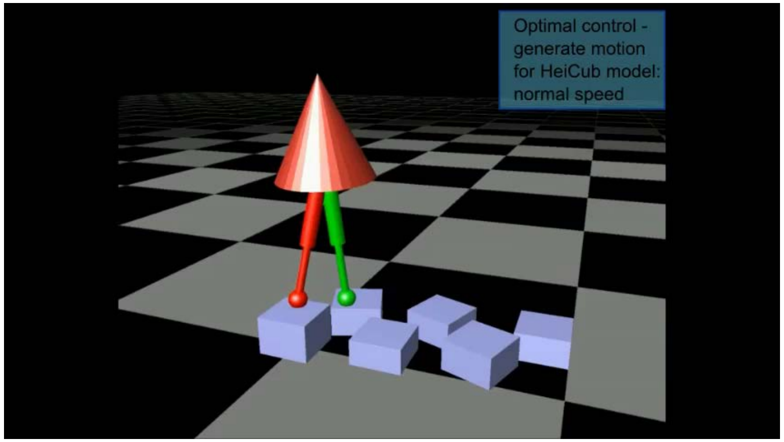


From human to humanoid step stone walking



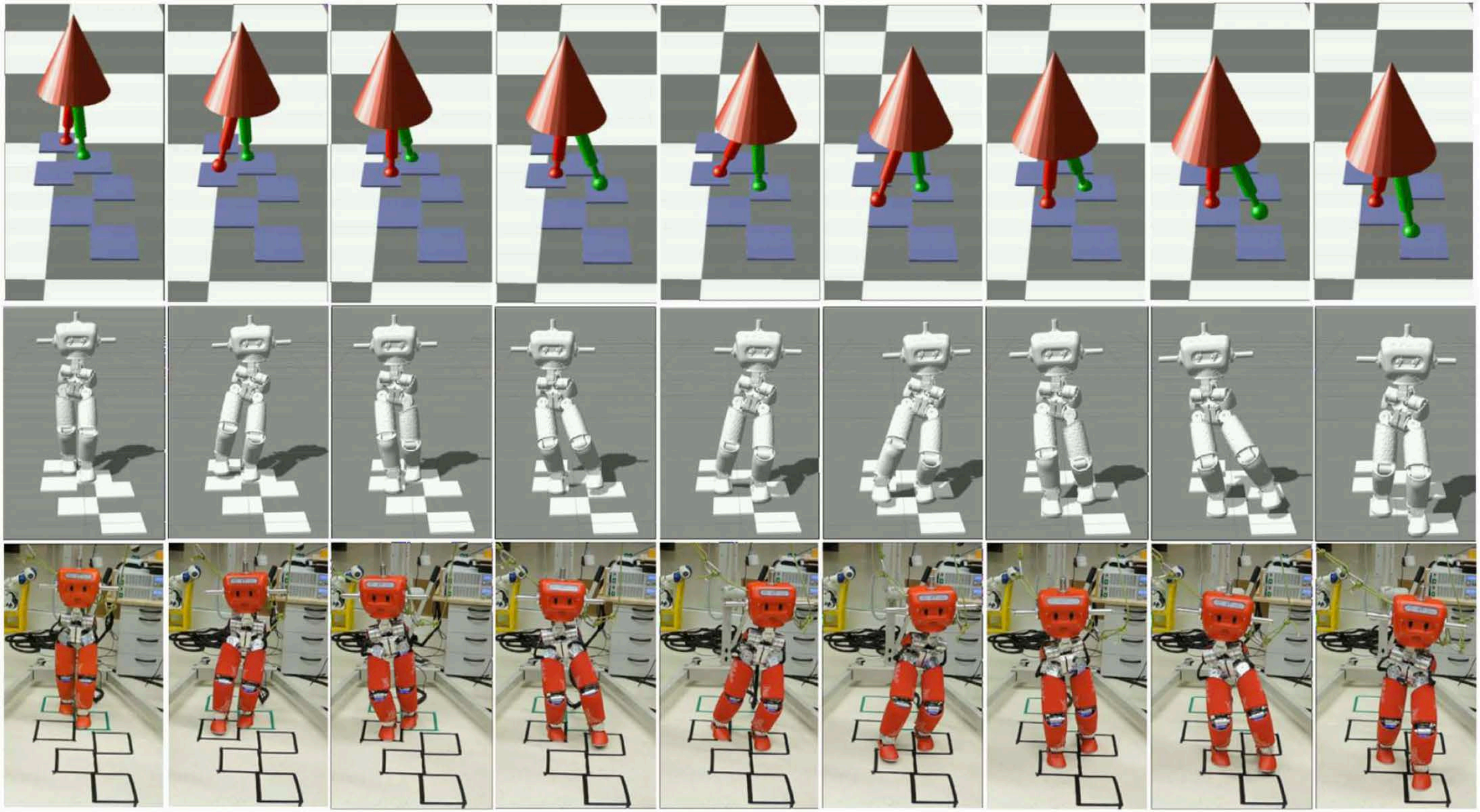






Different dynamic properties and different step stone env.

Generating HeiCub walking motions based on template models and optimal control



Summary - Take home message

- Mathematical models, optimization and control methods play an important role in
  - Gaining a better understanding of human motions
  - Improving motions of robotic systems

- The application of these methods is not limited to motion studies but can be generalize to all systems that take the same mathematical form

- Many things of the lecture today that may still seem difficult today, will not be a problem any more in a few months ☺

Outlook: next lectures

- Tuesday, April 30, 2019
  - Dynamic process modeling
- Monday, May 6, 2019
  - Summary: Modeling humans and robots as multibody systems


Thank you very much for your attention!