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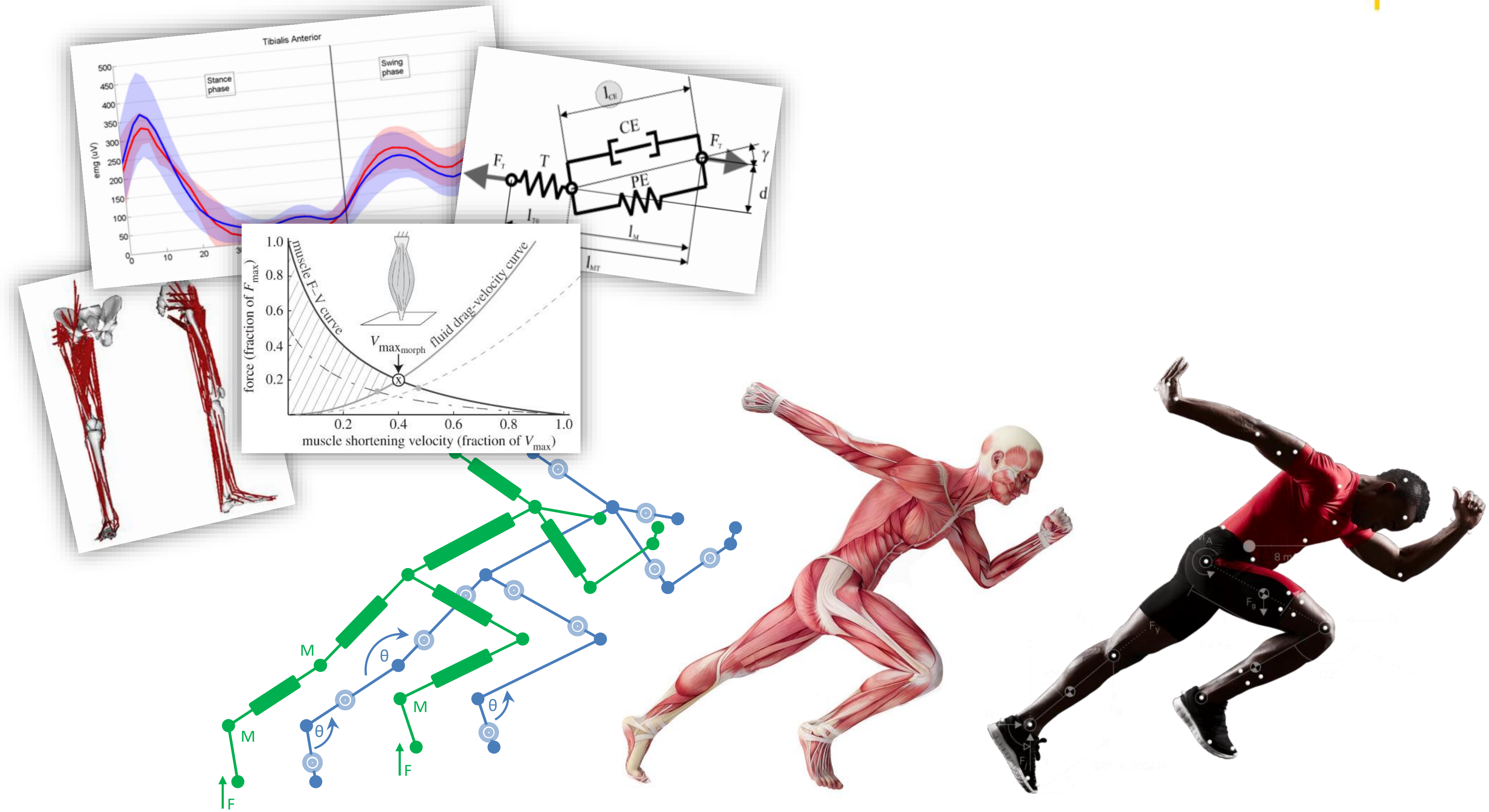

EMG Based Motion Capture [Seminar]

From Motion Capture to Musculoskeletal Simulation and back

Felix Laufer

Why Musculoskeletal Simulation?

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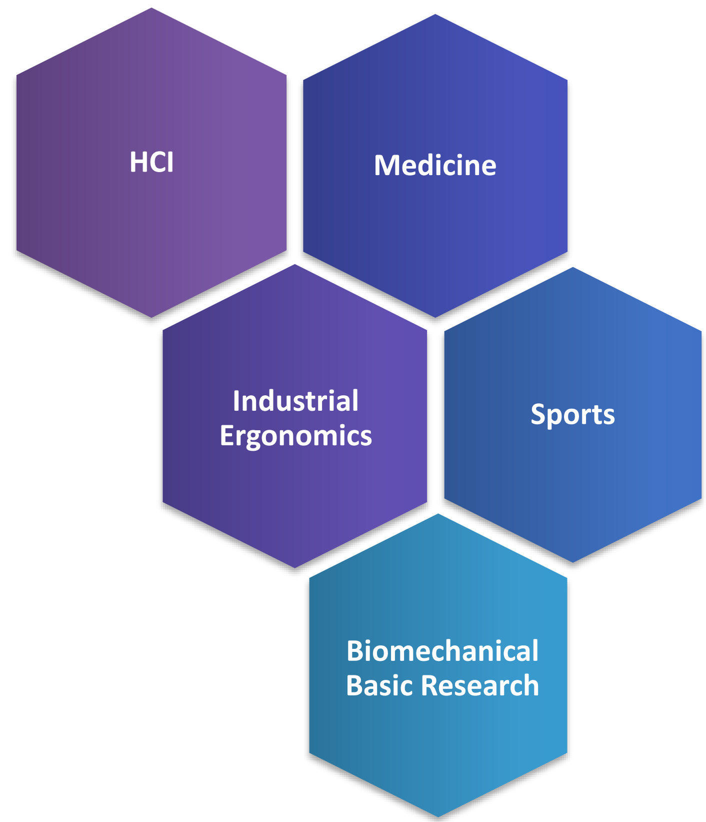
- Human Computer Interaction
- Design ergonomically safe environments
- Investigate and treat movement disorders
- Build wearable assistive devices (orthoses and prostheses)
- Analyze and improve athletic performance
- Understand the human locomotion system in detail



From MoCap to Musculoskeletal Simulation

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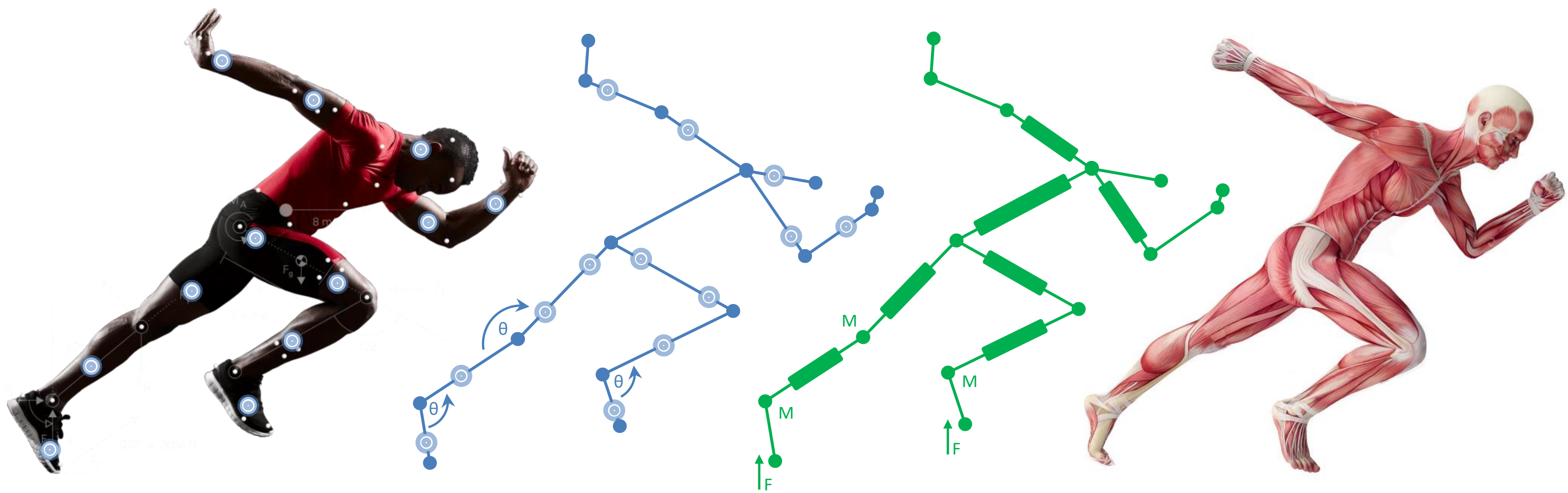

Motion **Cap**ture
marker trajectories

Inverse **K**inematics
joint angles

Inverse **D**ynamics
forces, torques

Musculoskeletal **S**imulation
muscle activation and forces

marker points

skeletal model, kinematic chain

external forces, GRF, …

body model, mass distribution, inertia matrix, …

?

Musculoskeletal Modelling

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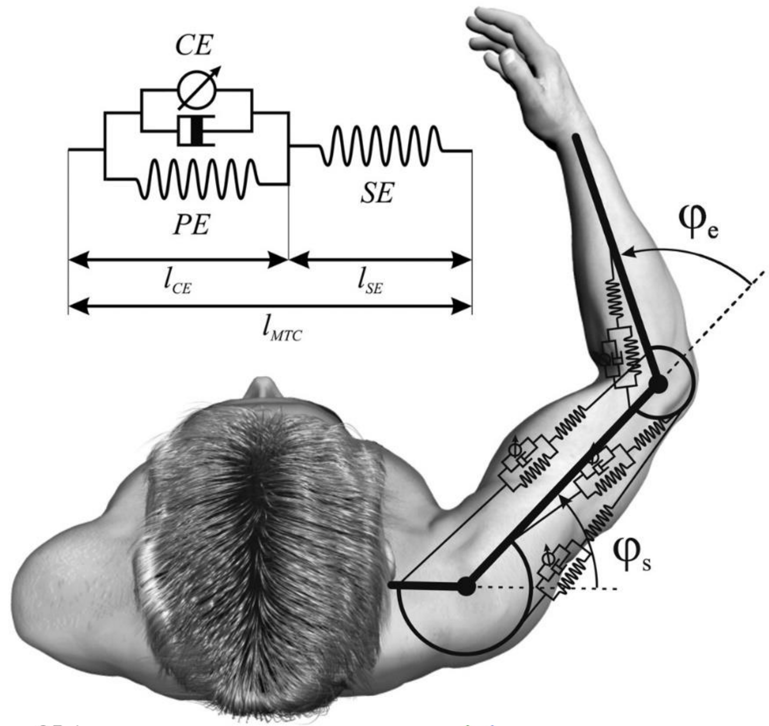
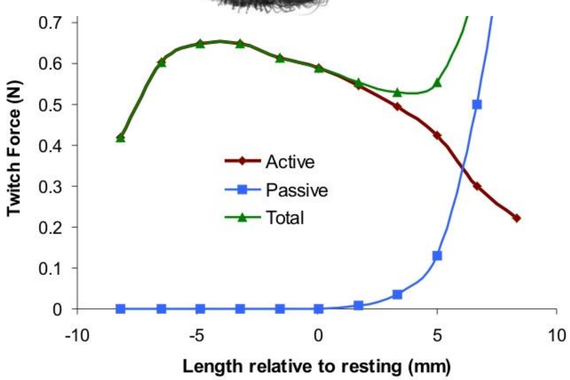
Hill's muscle model

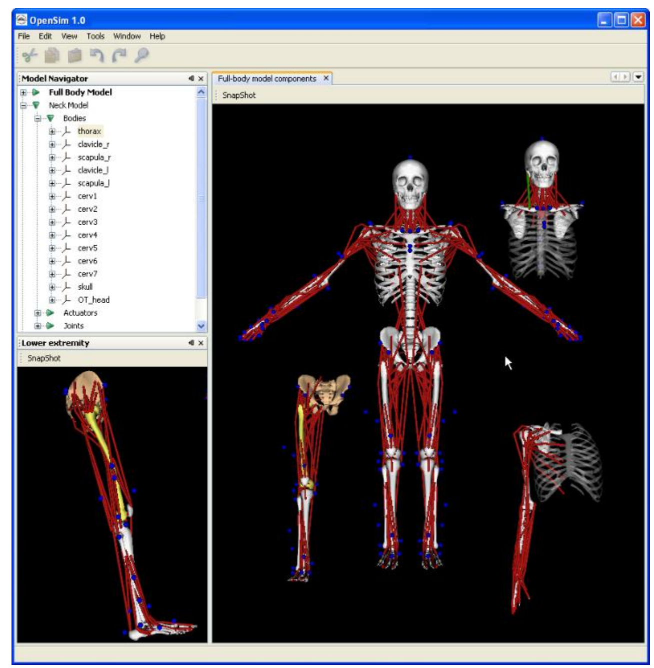




Musculo Tendon Unit (MTU) :=

abstract model of **motor neurons** including all **innervated muscle fibers** and the **tendon** of a **commonly controlled skeletal muscle based on hill's model**

Musculoskeletal Models



Muscular Redundancy and the DOF Problem

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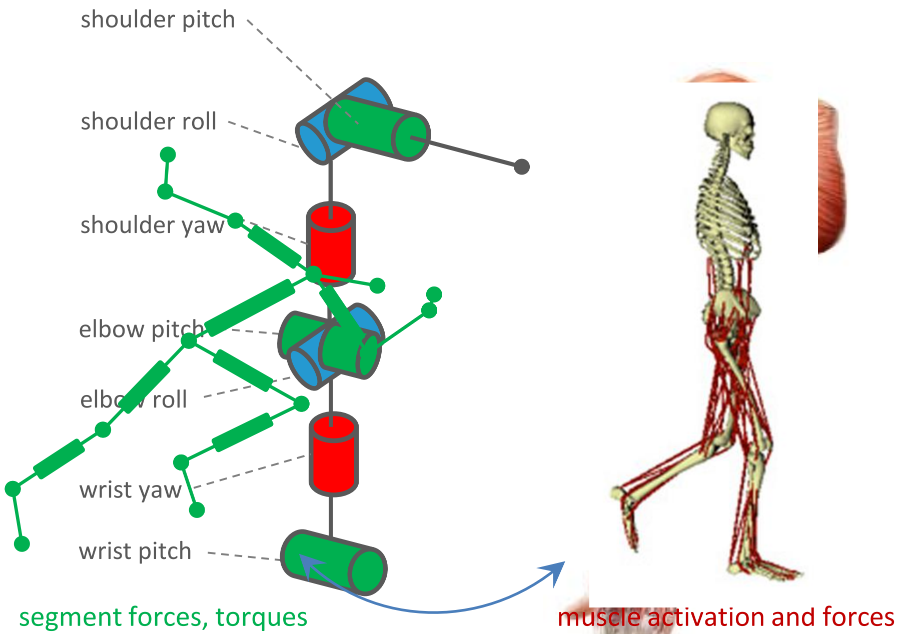

Arm excluding hand:

complex mapping!

7 kinematic DOF but > 20 skeletal muscles

joints are over-actuated ⇔ muscle system is underconstrained
⇔ multiple solutions of the inverse muscle Jacobian

The (classical) Optimization Approach

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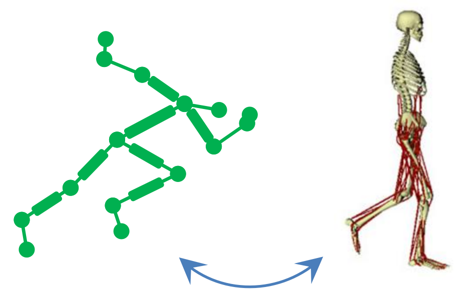
Idea: Pick the solution that minimizes total muscle stress!



Treat the desired / measured dynamics f_j as **constraints** and the sum of generating muscle forces / activation a_i of N_m muscles as a **global performance criterion** to be **minimized**

$$\sum_{i=1}^{N_m} (a_i)^2 \longrightarrow min$$

s.t.

$$\forall\, c_j := f^*{}_j - f_{j,\,exp} \approx 0$$

Always an appropriate method for estimating muscle forces / activation?

What about …

- co-contraction
- fine motor tasks with higher muscle tension
- extreme (fast) movements
- (temporal / pathological) muscle fatigue … ?

neurophysiological redundancy
⇔ several MTU recruitment strategies for different motor tasks

EMG Data for Estimating Muscle Activation

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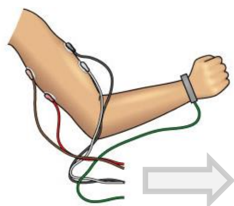
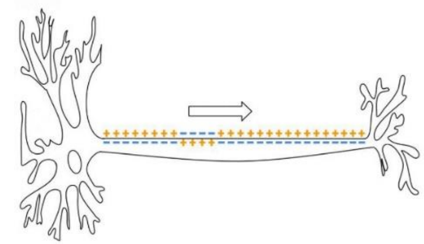
Electromyography (EMG) $:=$

Electrodiagnostic technique for detecting accumulated **action potentials** of a **skeletal muscle (group)** generated by the **associated motor neurons**





Signal Processing

Idea: Use EMG data for estimating the wanted muscle activation!

Treat the EMG data $a_{k,emg}$ corresponding to the wanted muscle activation a_k as **additional contraints**

$$\sum_{i=1}^{N_m}(a_i)^2 + \sum_{j=1}^{N_{c_j}} \omega_j (f^*_j - f_{j,exp})^2 + \sum^{N_{c_k}} \omega_k (a_k - a_{k,\,emg})^2 \longrightarrow min$$

solvability!

s.t.

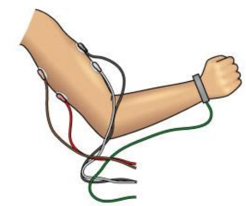
$$\forall\, c_j := f^*{}_j - f_{j,\,exp} \approx 0$$

$$\forall\, c_k := a_k - a_{k,\,exp} \approx 0$$

The other Way round – EMG Forward Simulation

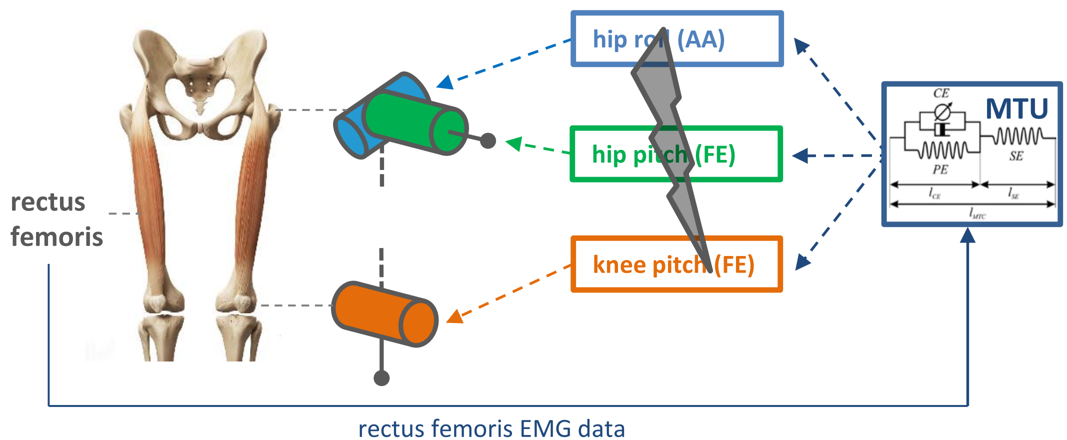
Motion Simulation	Forward Kinematics	Forward Dynamics	Musculoskeletal Modelling
marker trajectories	joint angles	forces, torques	muscle activation and forces

Idea: Use EMG data to directly drive a model's forward dynamics!



Common Approach: **Single DOF Model** :=

Model predicting the joint moment at one **single calibrated DOF** from EMG data recorded at the associated MTU



Again, the redundancy / DOF problem!
Single DOF models can address neurophysiological redundancy for a certain DOF but not muscular redundancy in terms of multiple DOF.

EMG Forward Simulation – Multi DOF Model

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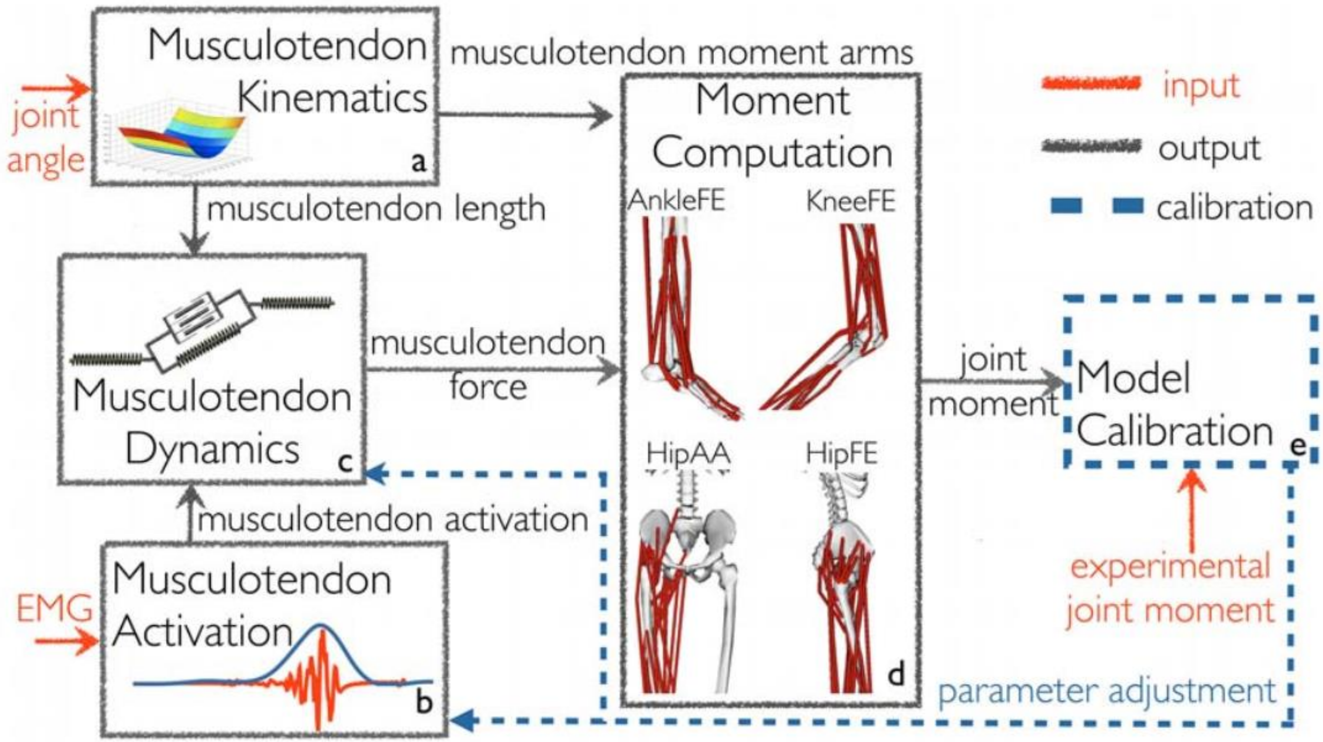
Idea: Build a Multi DOF Model calibrated for several DOF ➔ consistent force solution!



optimization

Multi DOF Model – Results

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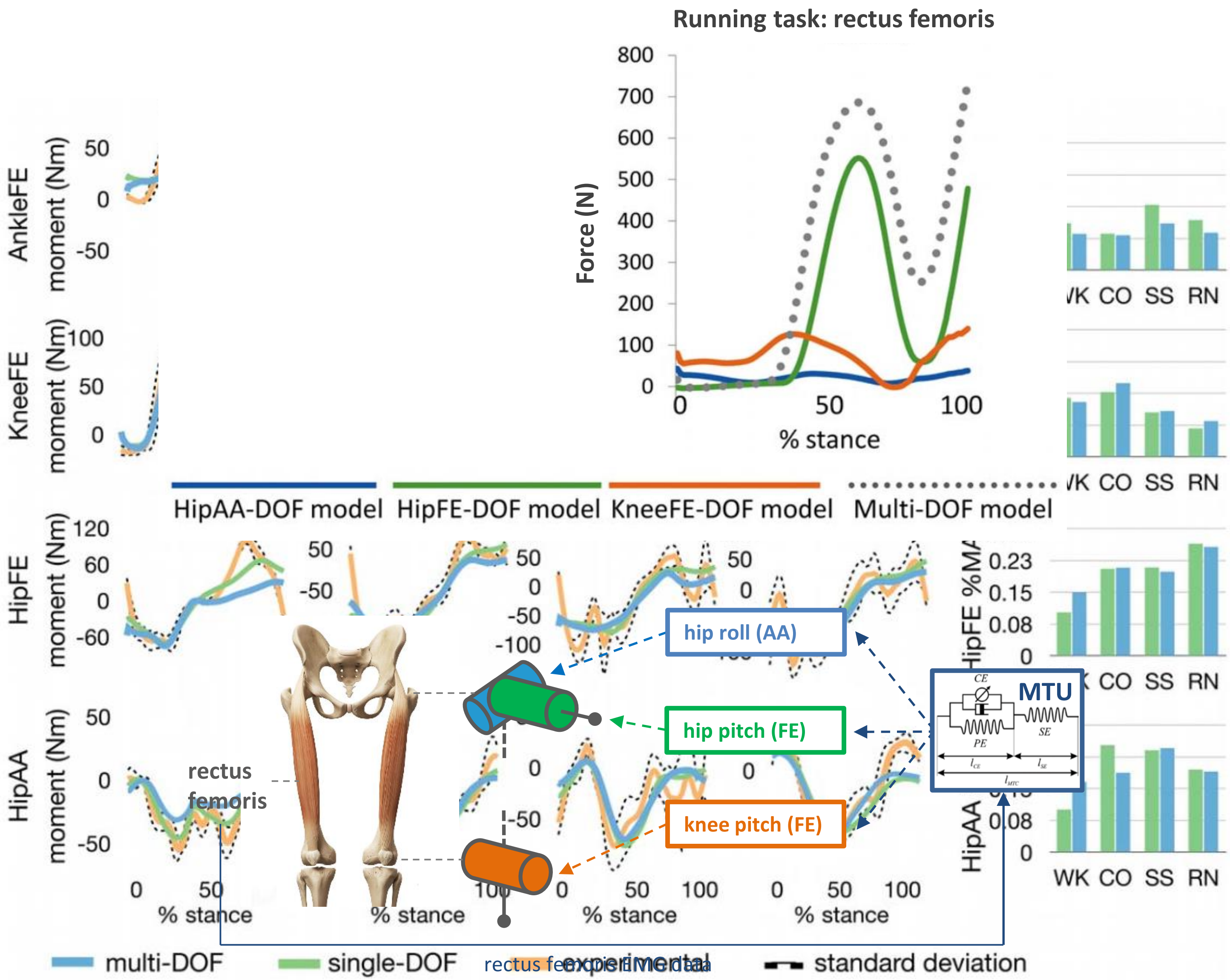

General Difficulties and Sources of Error

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marker placement & tracking
- real vs. virtual markers
- tracking accuracy
- repeatability

inverse kinematics
- drift of markers
- joint modelling
- numerical errors

inverse dynamics
- measure of external forces
- distribution of body mass
- numerical errors

Motion Capture
marker trajectories

Inverse Kinematics
joint angles

Inverse Dynamics
forces, torques

Musculoskeletal Simulation
muscle activation and forces

model scaling
- marker points
- distribution of body mass
- …

MTU modelling
- tendon slack length, optimal fiber length and maximum isometric force
- …

generalizability (subject ⇔ model)
- individual neural drive and activation strategies
- MTU params highly dependent on subject

(neuro)muscular redundancy
- **muscular** := several muscles for one joint or muscles spanning multiple joints
- **neurophysiological** := task-dependent activation strategies or multiple neurons innverating the same muscle
- **co-contraction**

EMG ⇔ muscle activation ⇔ muscle forces
- mapping poorly understood,
- no reliable models

Motion Simulation
marker trajectories

Forward Kinematics
joint angles

Forward Dynamics
forces, torques

Musculoskeletal Modelling
muscle activation and forces

EMG extraction and processing
- surface EMG only (no deeper MTUs)
- characterizing frequency bandwidths
- ➔ generalizability?

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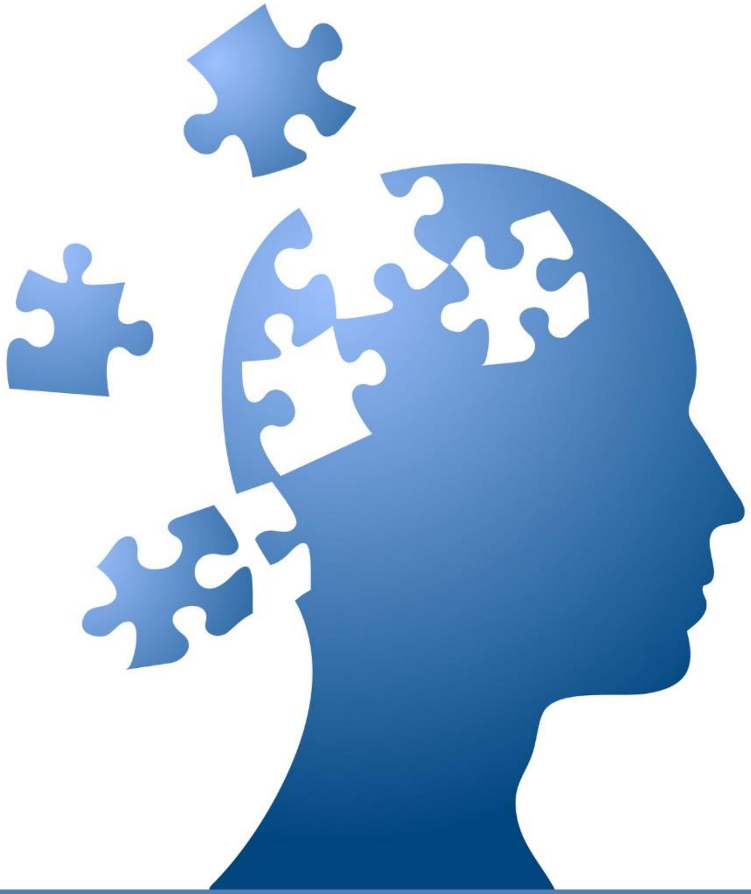

Questions?

Thanks for your attention!

From Motion Capture to Musculoskeletal Simulation and back

Appendix – Hybrid Approach

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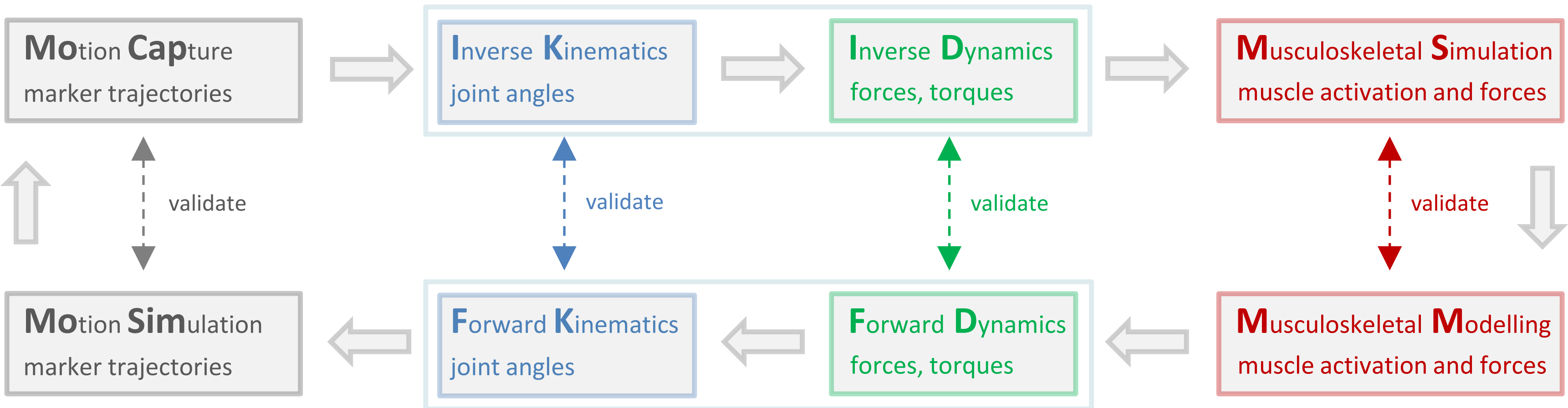

Idea: Combine both forward and inverse simulation in order to obtain, validate and refine internal parameters and models at any point in time!

➔ successively estimate unknown model components and drive prediction errors to zero