Computational Biomechanics 2017

Lecture 04:
Forward vs. Inverse Multi Body Dynamics

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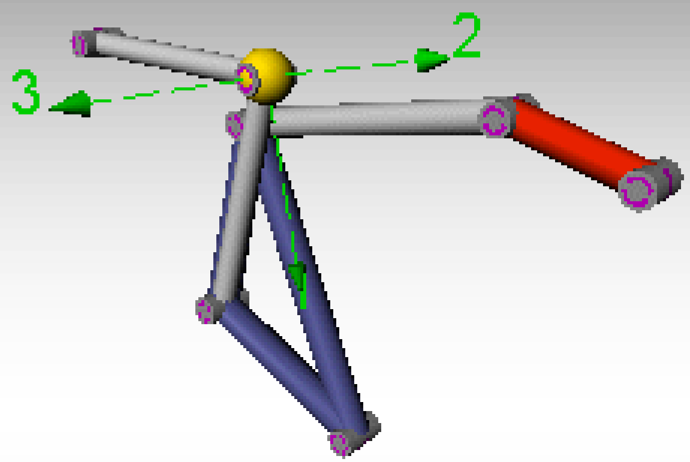
Mehrkörpersysteme (MKS):



Quelle: IFM, TU Chemnitz, alaska

Quelle: UFB, Forster&Simon

Zum Merken:

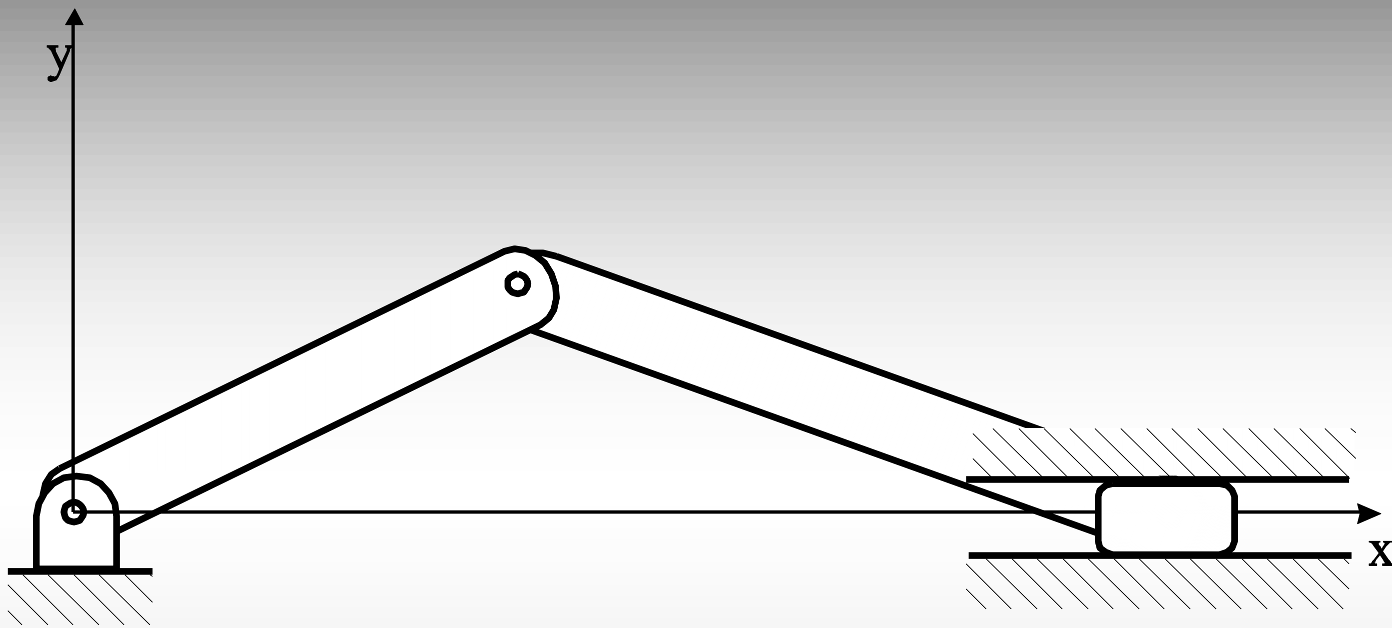
MK-Modelle bestehen aus:

- Starrkörpern (mit Massen, Massenmomente)
- Gelenken (Bindungen)

Beispiel: Kurbelantrieb

Raddampfer, New Orleans

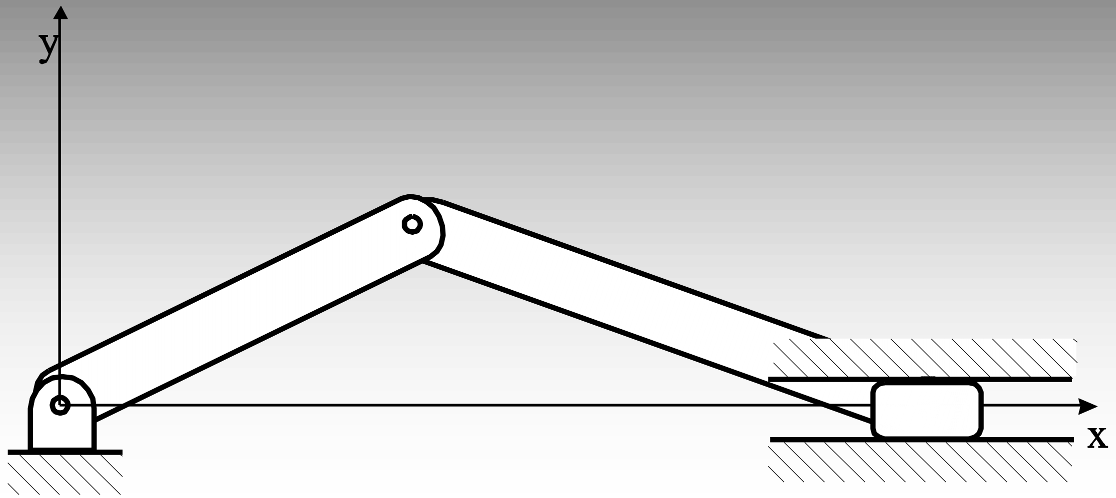
2D MK-Modell



Modellbildung:

- 2 starre Körper:
- 3 Gelenke:

Freiheitsgrade und Bindungen



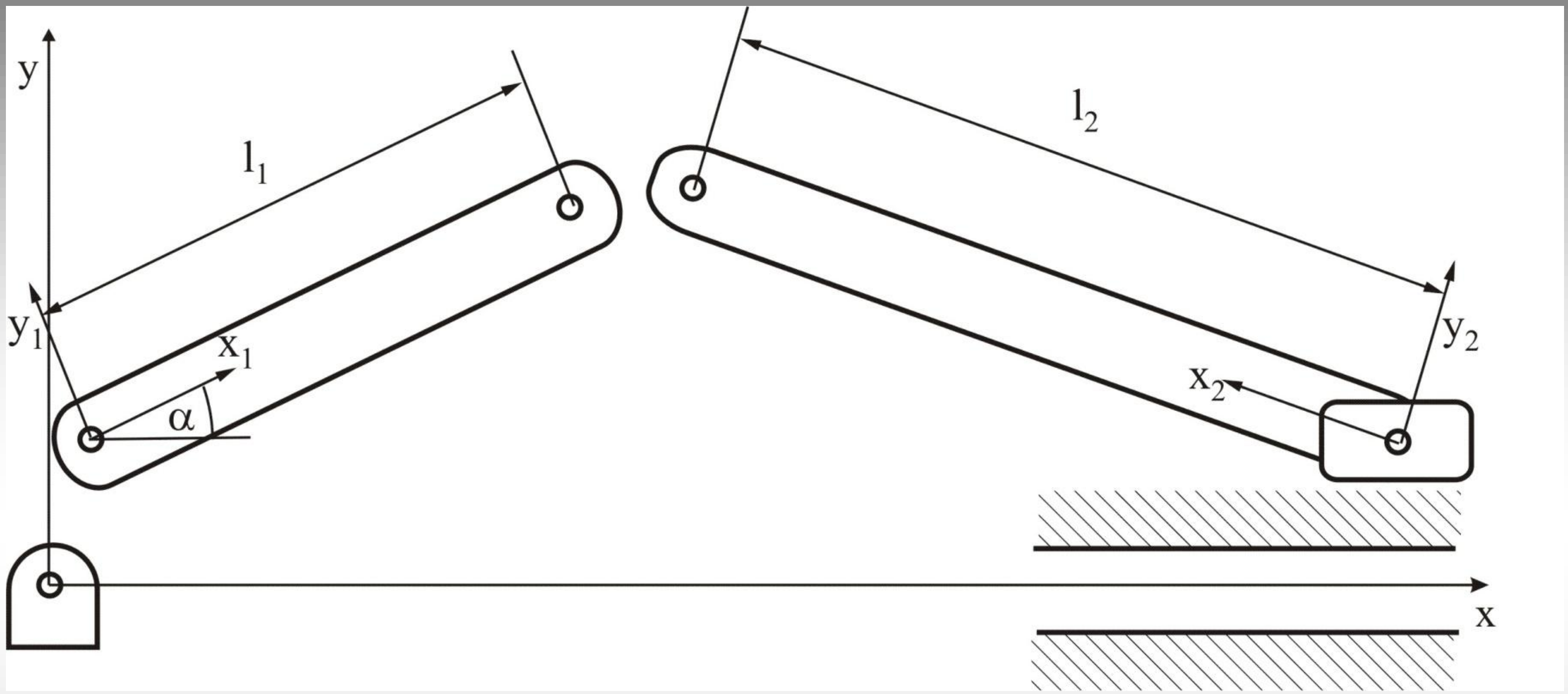
Zum Merken:

Gelenke sind Bindungen; sie reduzieren FG des Systems:

2D: FG Gesamtsystem = Anzahl Körper x 3 – Anzahl Bindungen

3D: FG Gesamtsystem = Anzahl Körper x 6 – Anzahl Bindungen

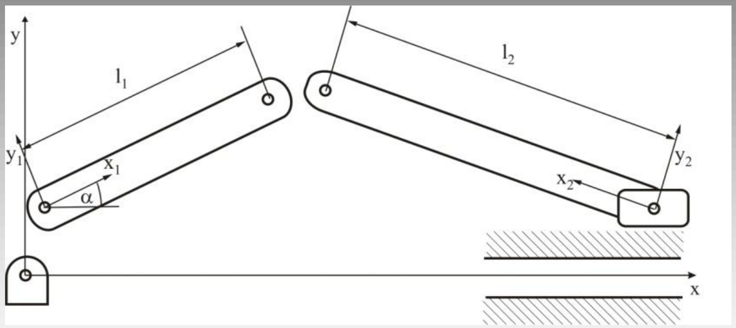
Kinematik im 2D-Raum



Zusammenbau-Bedingungen:

- Gelenk A:
- Gelenk B:
- Gelenk C:

Bindungsgleichungen (constraint equations)



Gelenke: kinematische-Bindungen
(kinematic constraints)

$$\begin{bmatrix} x_{P1} \\ y_{P1} \\ x_{P1} - x_{P4} + l_1 \cos\alpha + l_2 \sin\beta \\ y_{P1} - y_{P4} + l_1 \sin\alpha - l_2 \cos\beta \\ y_{P4} \end{bmatrix} = \underline{0}$$

Antrieb: Rheonome Bindungen
(driver constraints)

$$\alpha - \Omega t = 0$$

(Vorwärts-)Dynamik / Inverse Dynamik

(Vorwärts-)Dynamik

Gegeben: MKS mit FG > 0, eingeprägte (äußere) **Kräfte**

Gesucht: **Bewegung** des MKS

Lösung: Numerische (Vorwärts-)Integration

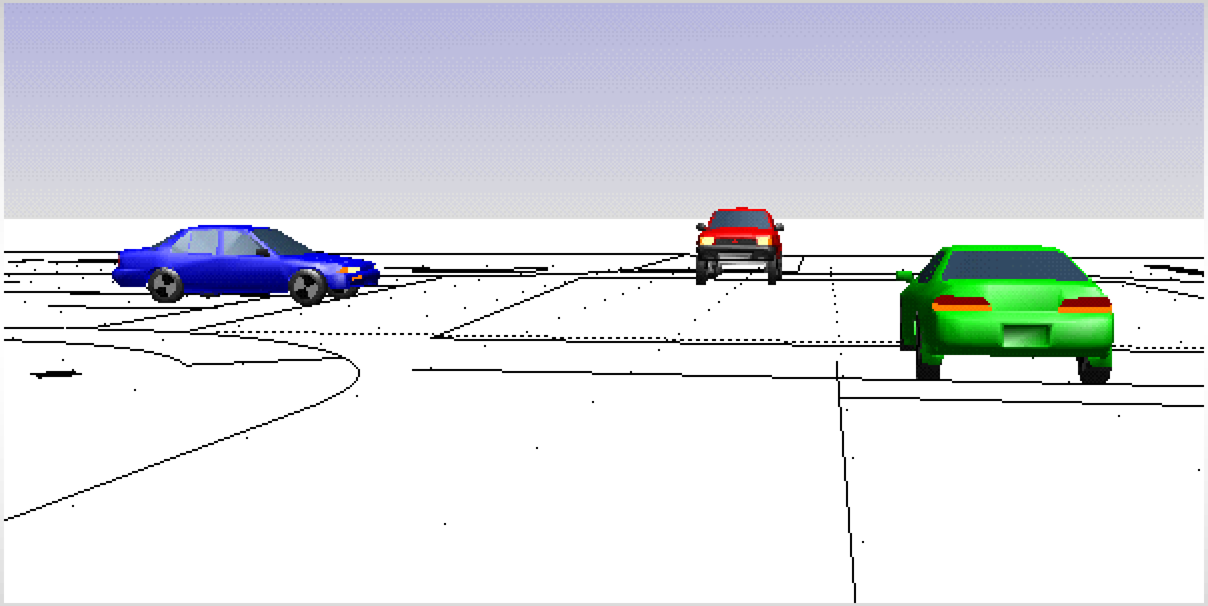
Inverse Dynamik

Gegeben: MKS mit FG = 0, (Gemessene) **Bewegung** (z.B.: *Ganganalyse*)

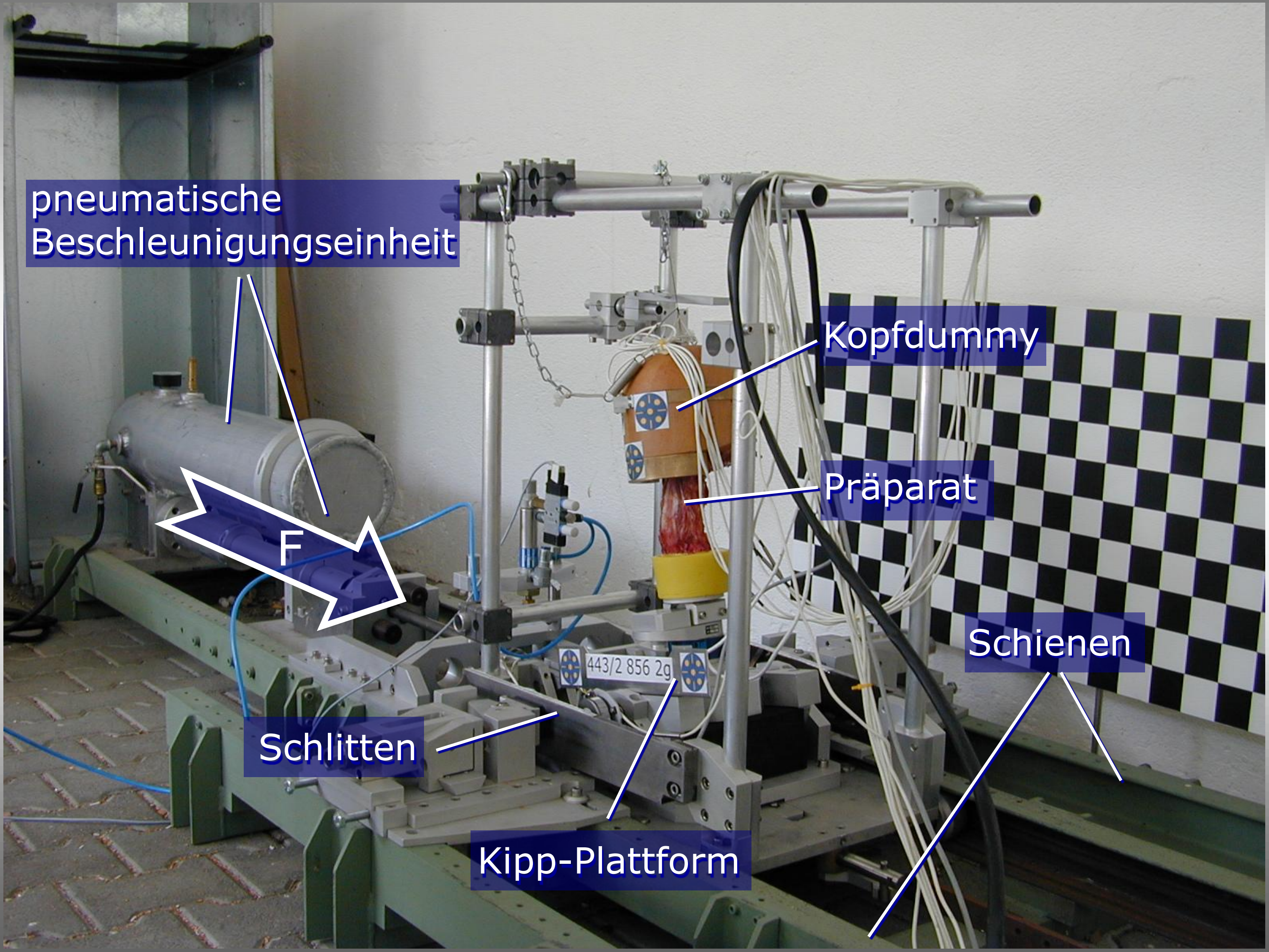
Gesucht: **Kräfte** als Ursache der Bewegung (z.B.: *Muskelkräfte*)

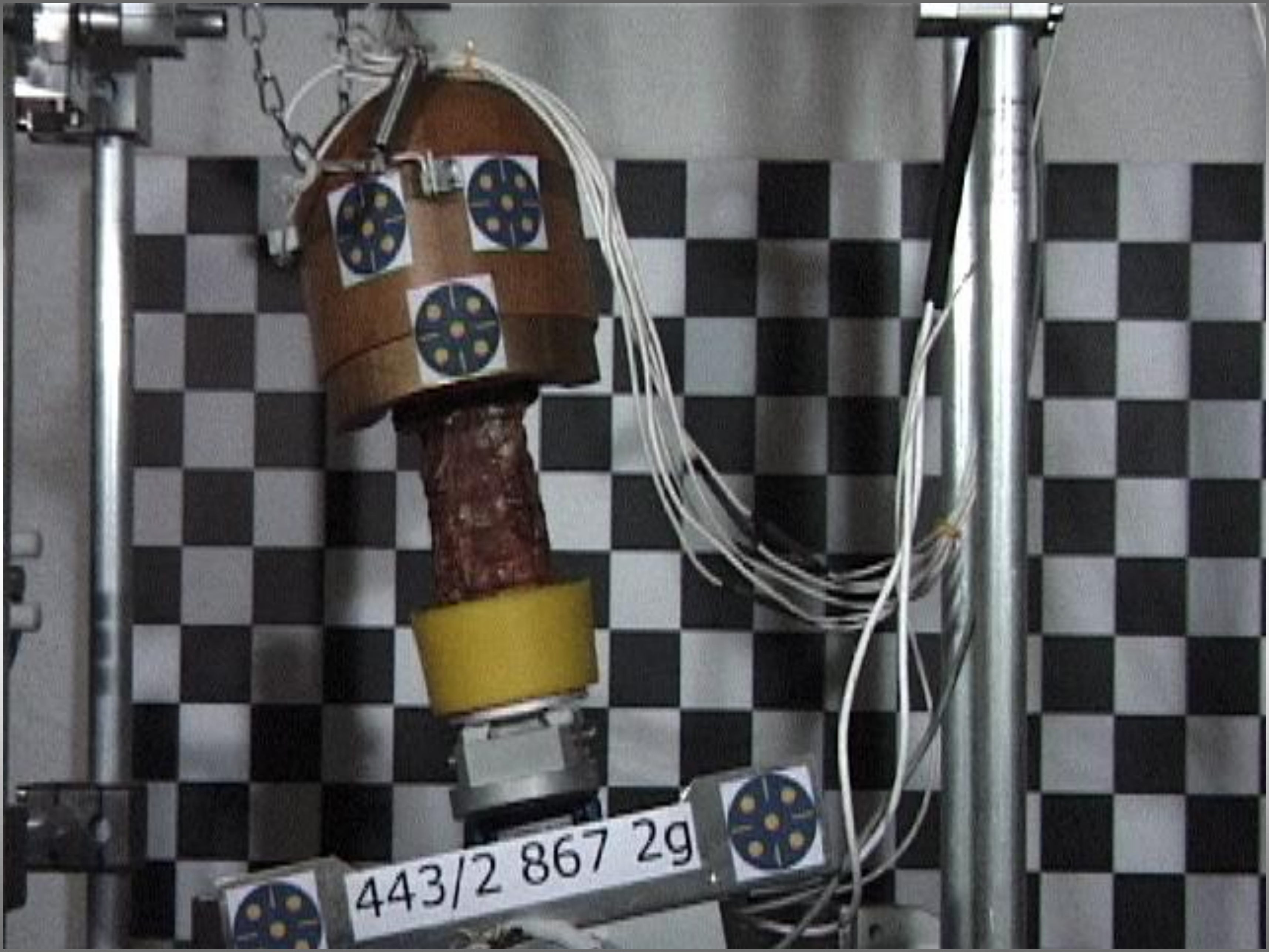
Lösung: Numerisches Differenzieren, nichtlineare Gleichungssysteme, evtl. Optimierungverfahren

(Vorwärts-)Dynamik in der Unfallforschung:



Beispiel: Eigener Versuchsstand zum Schleudertrauma

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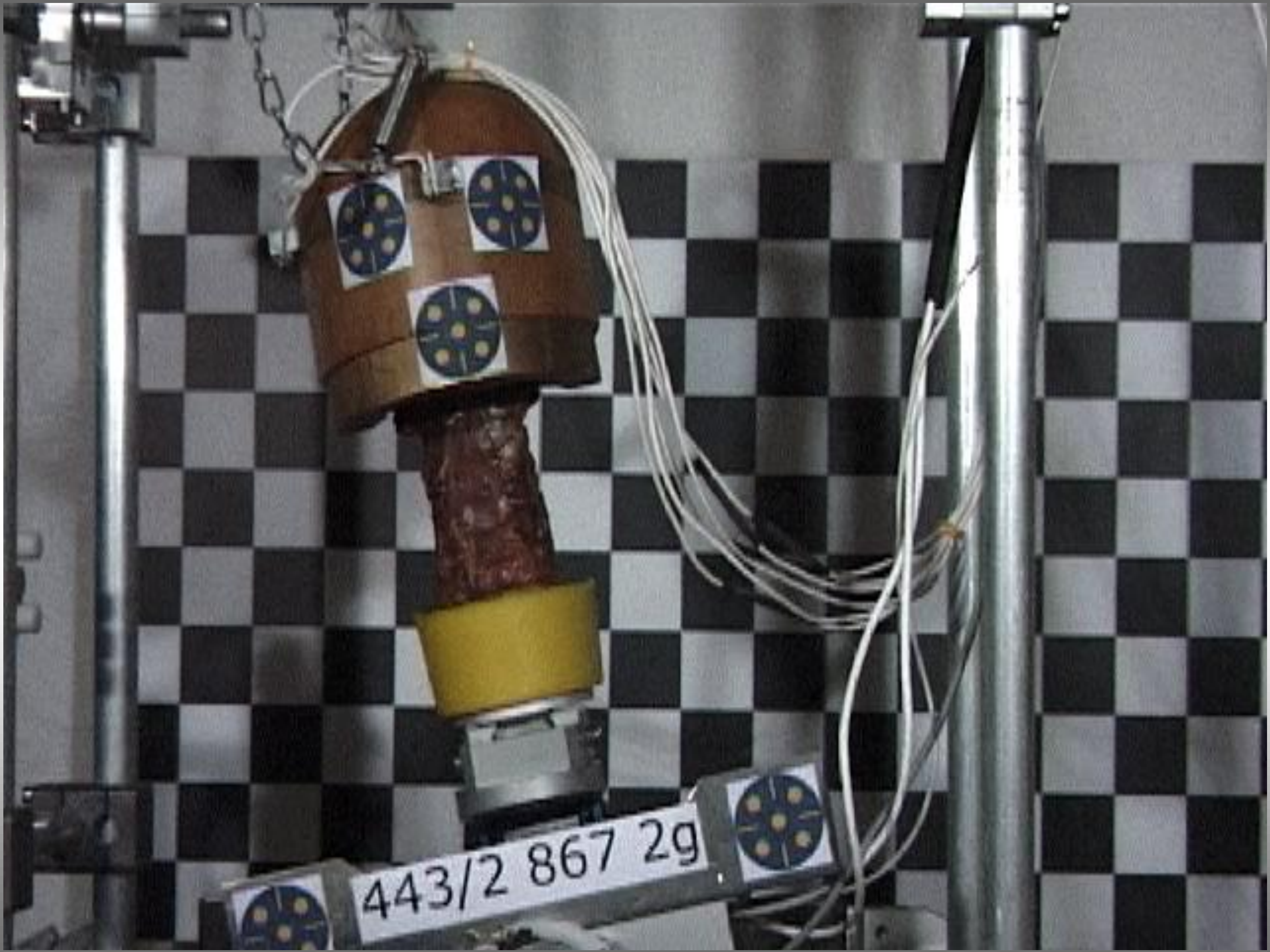
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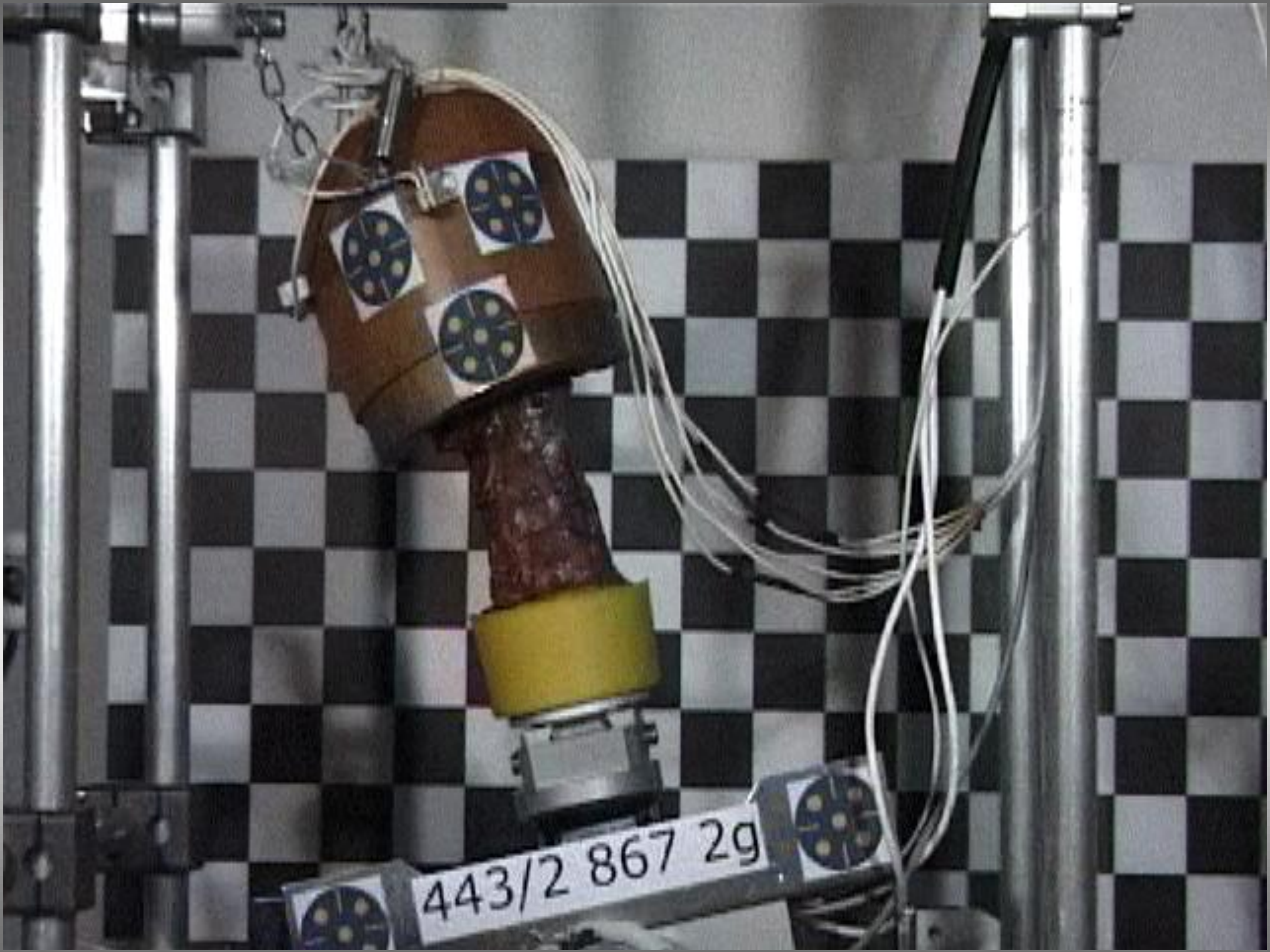
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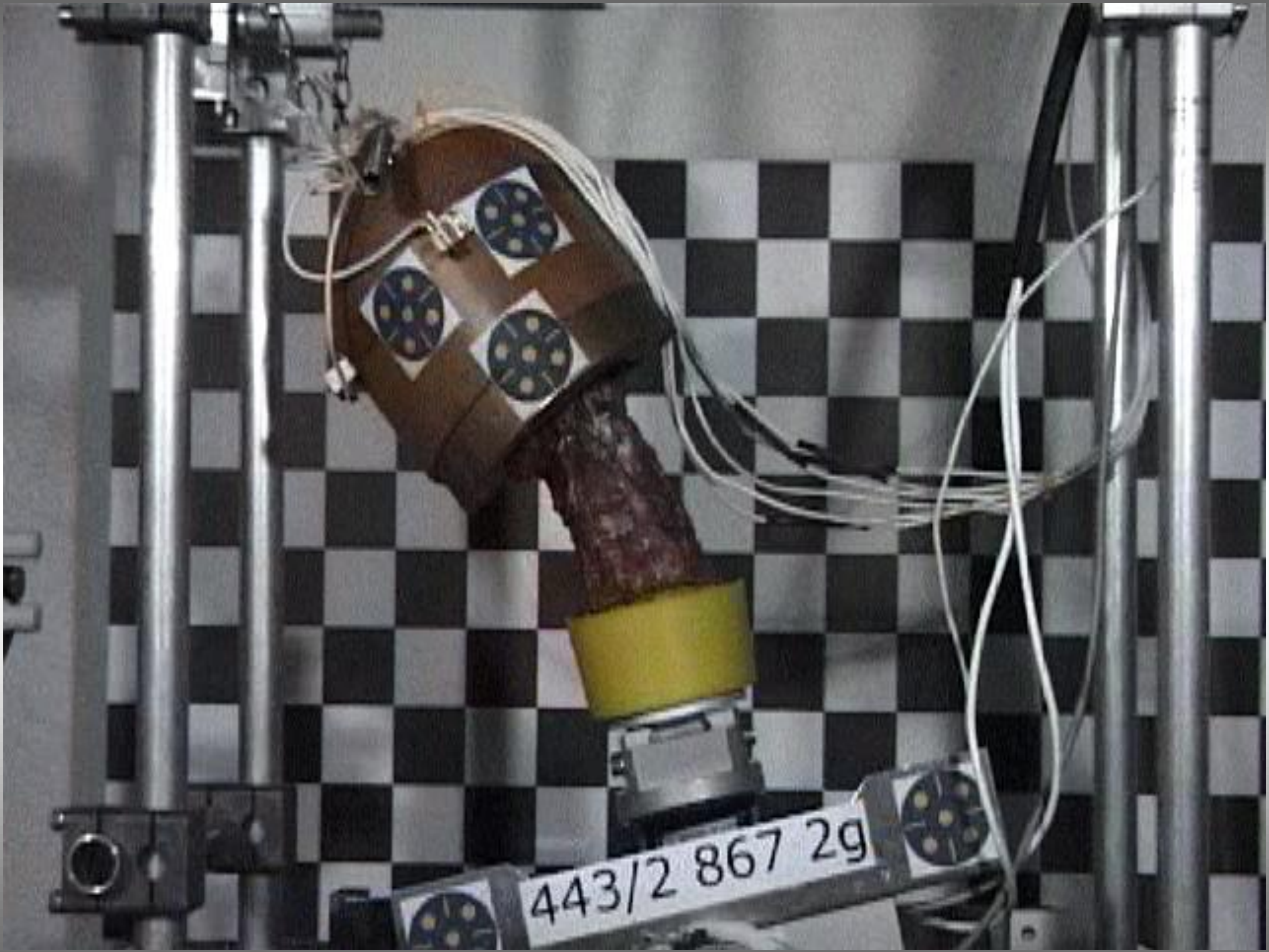
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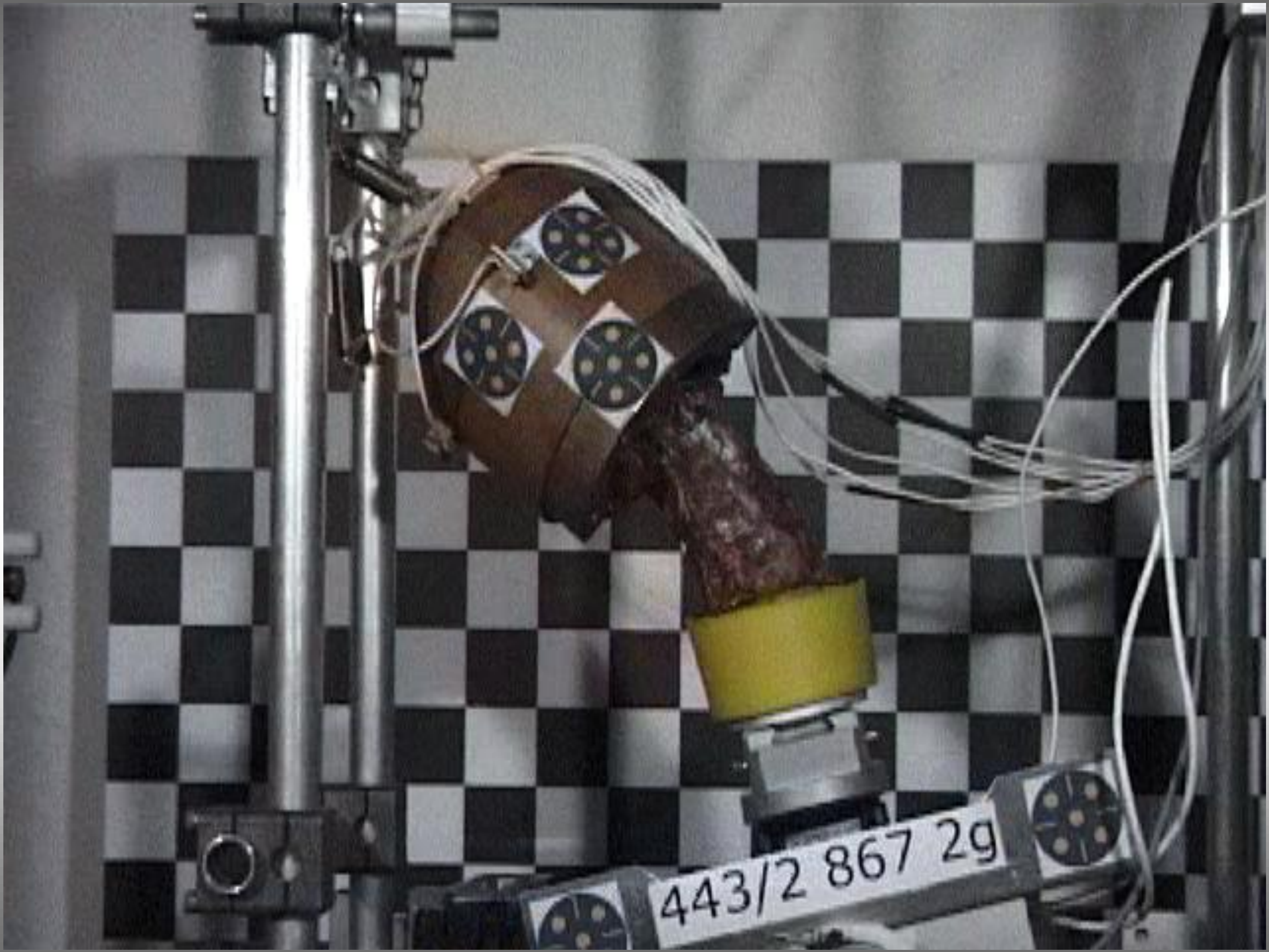
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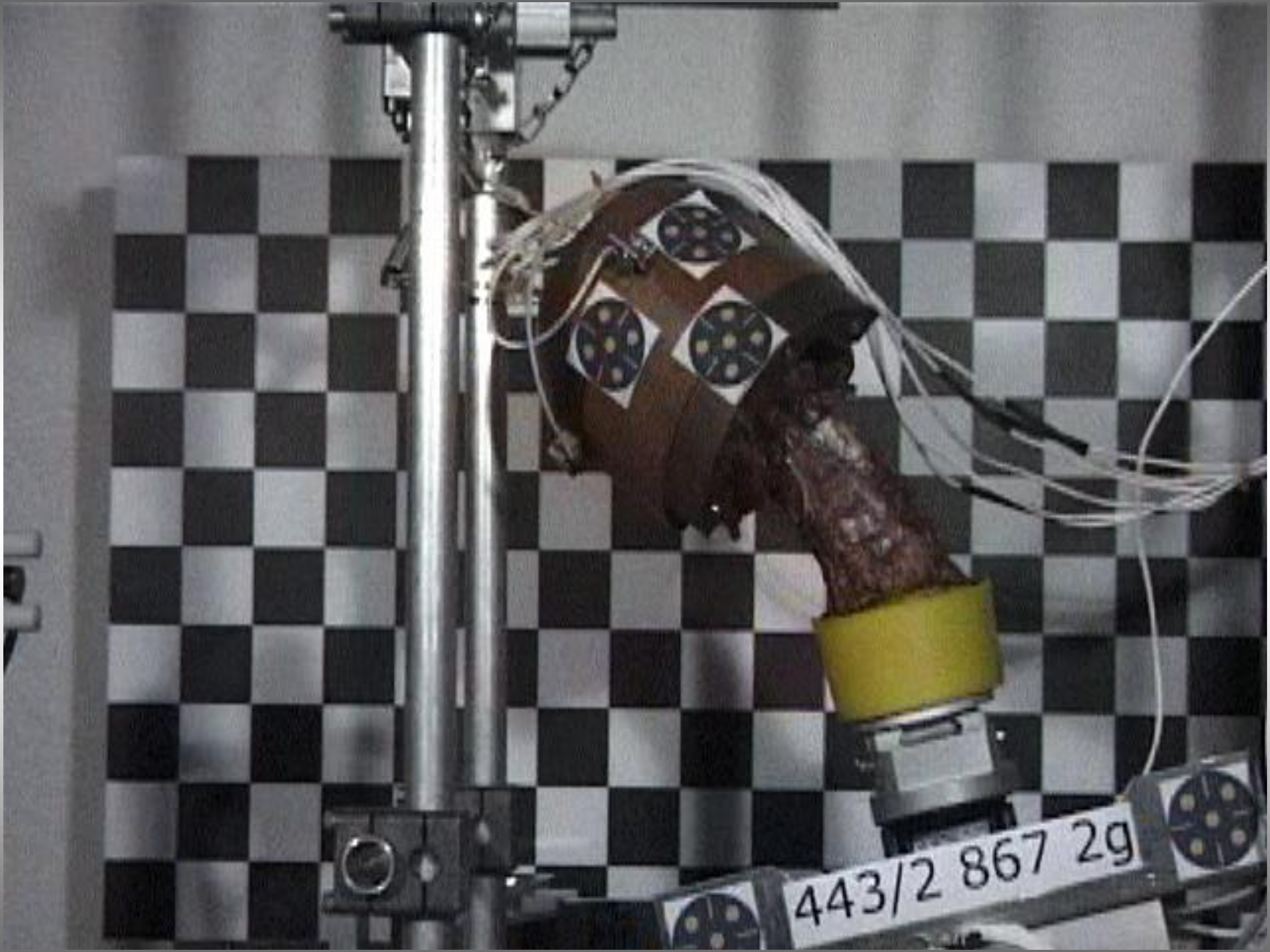
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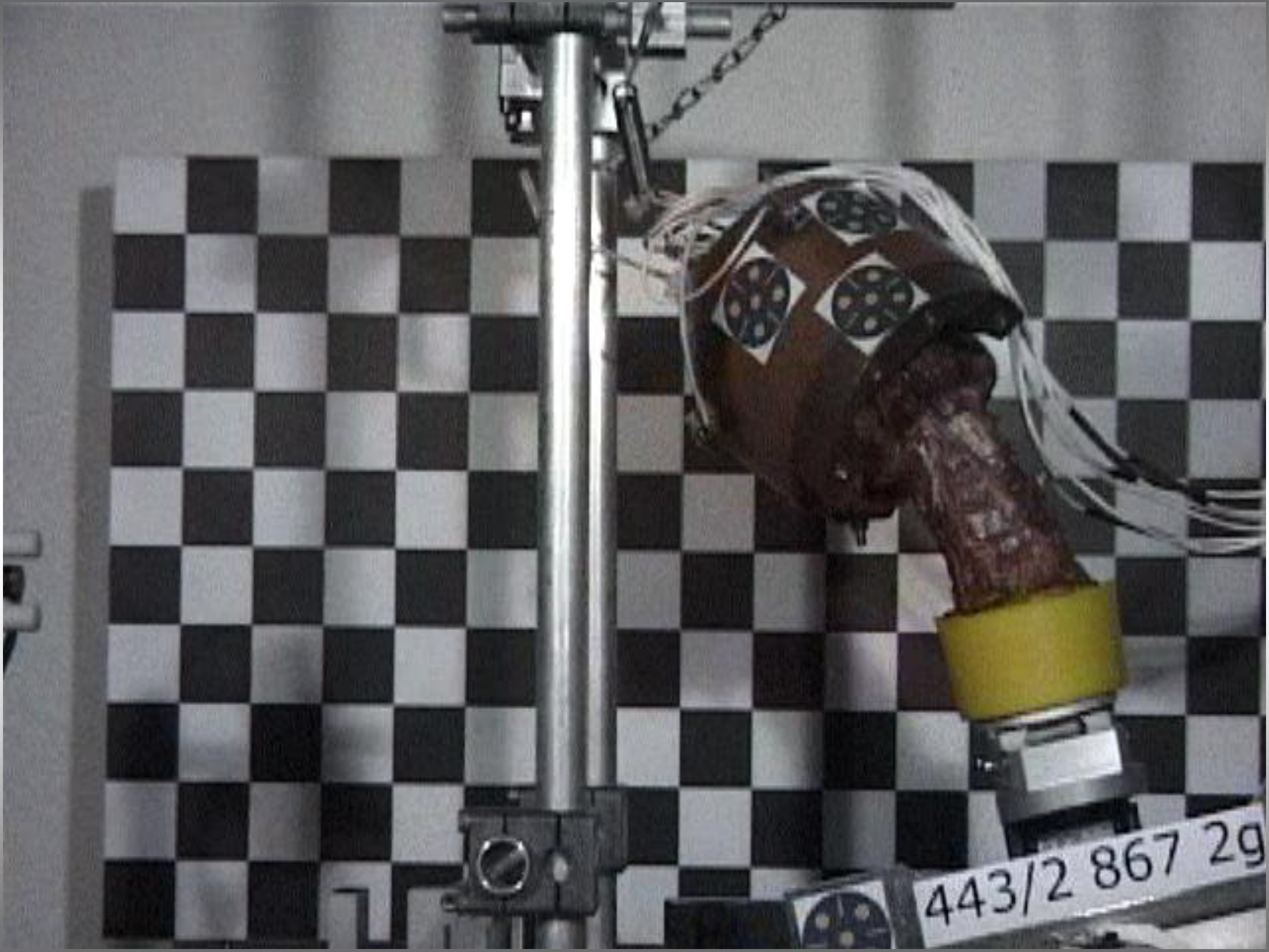
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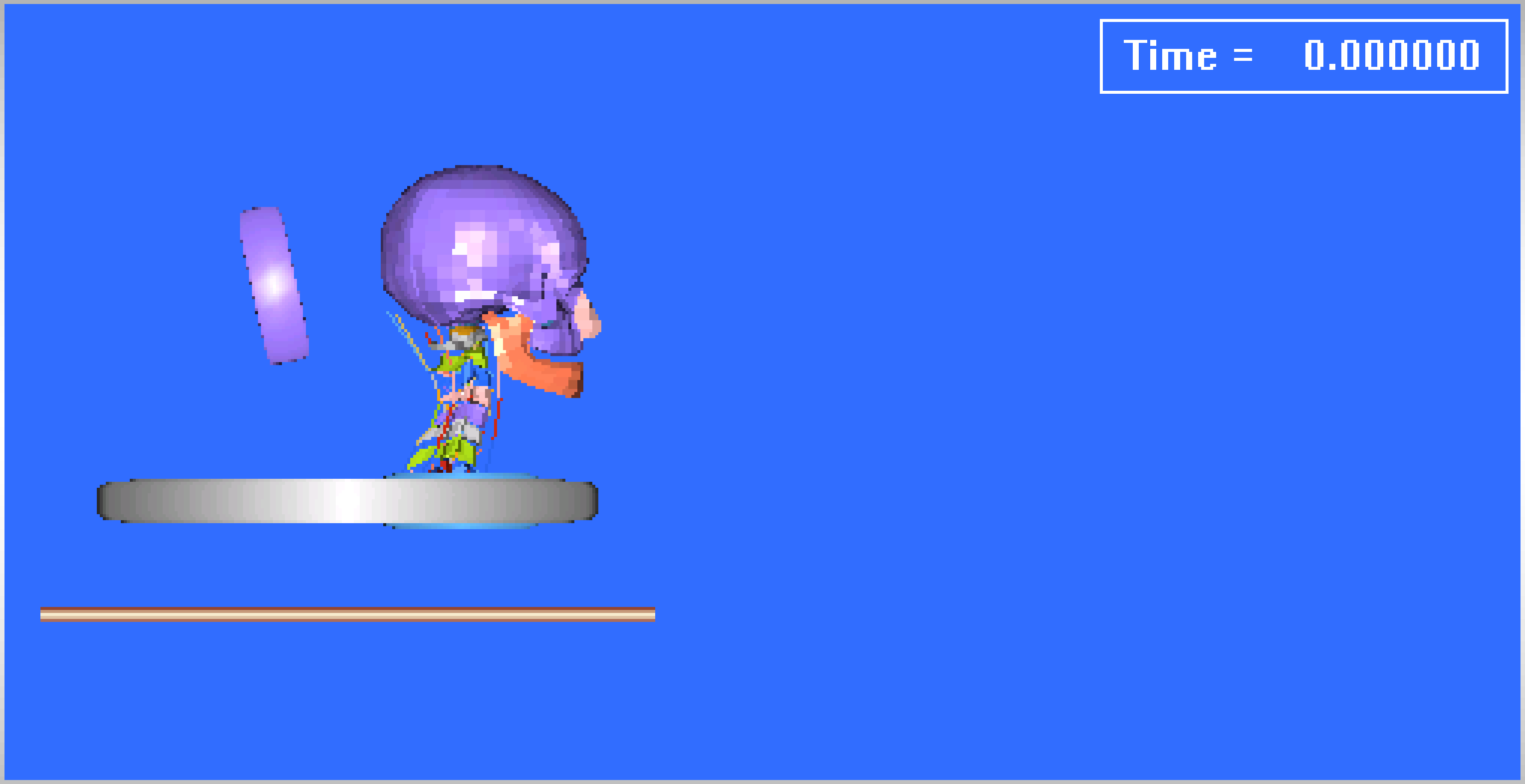
Beispiel: Simulation des Experiments mit „Madymo“



Musculoskeletal Models

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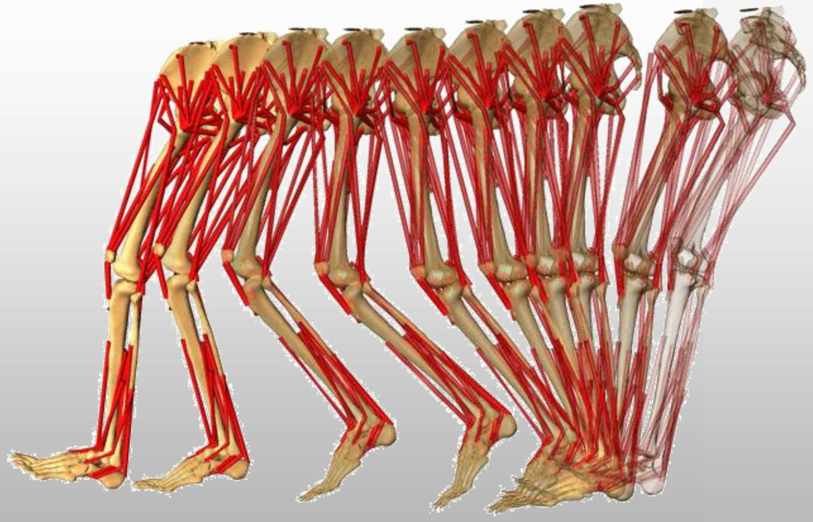
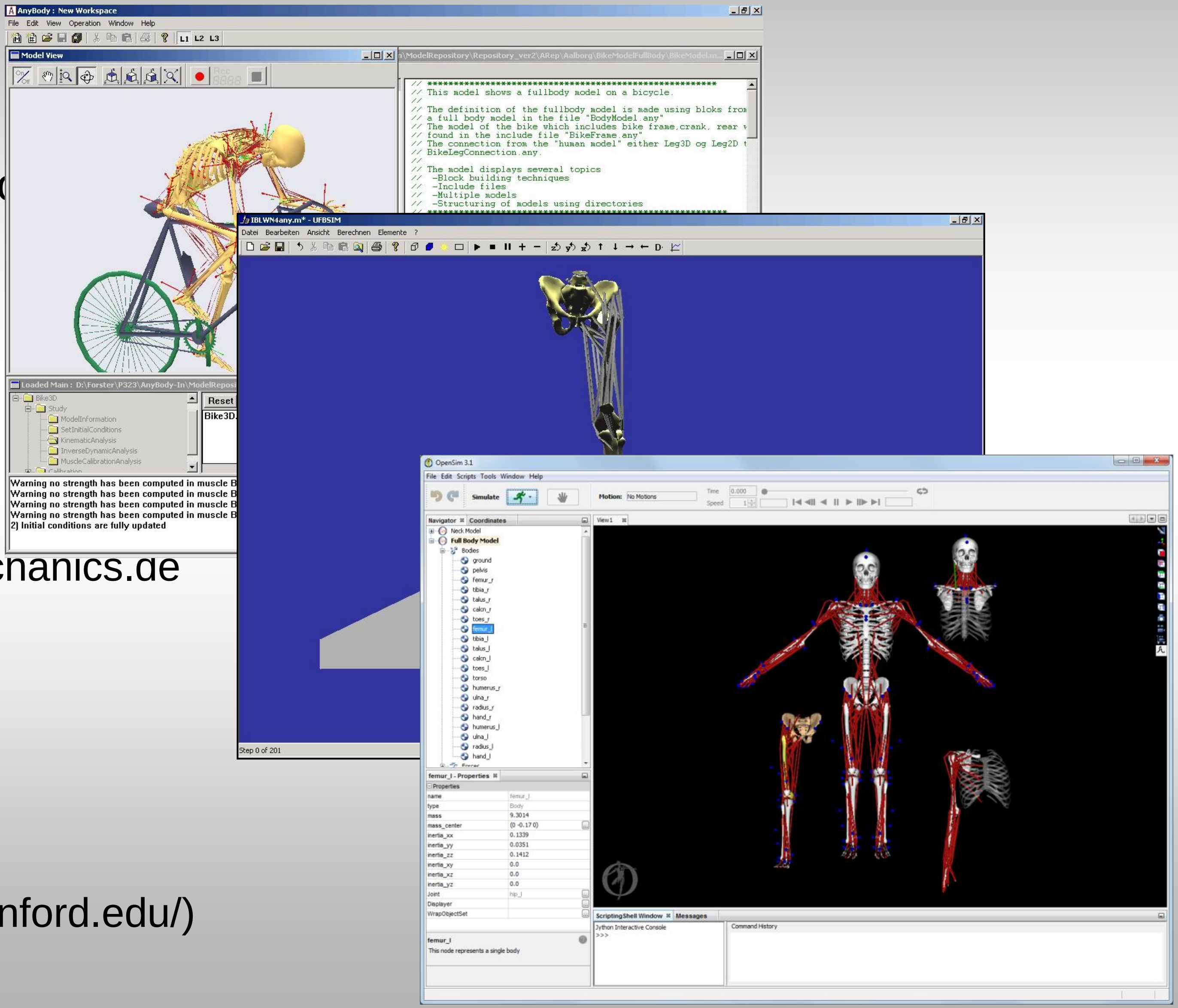
Inverse Dynamics & Optimization



Software

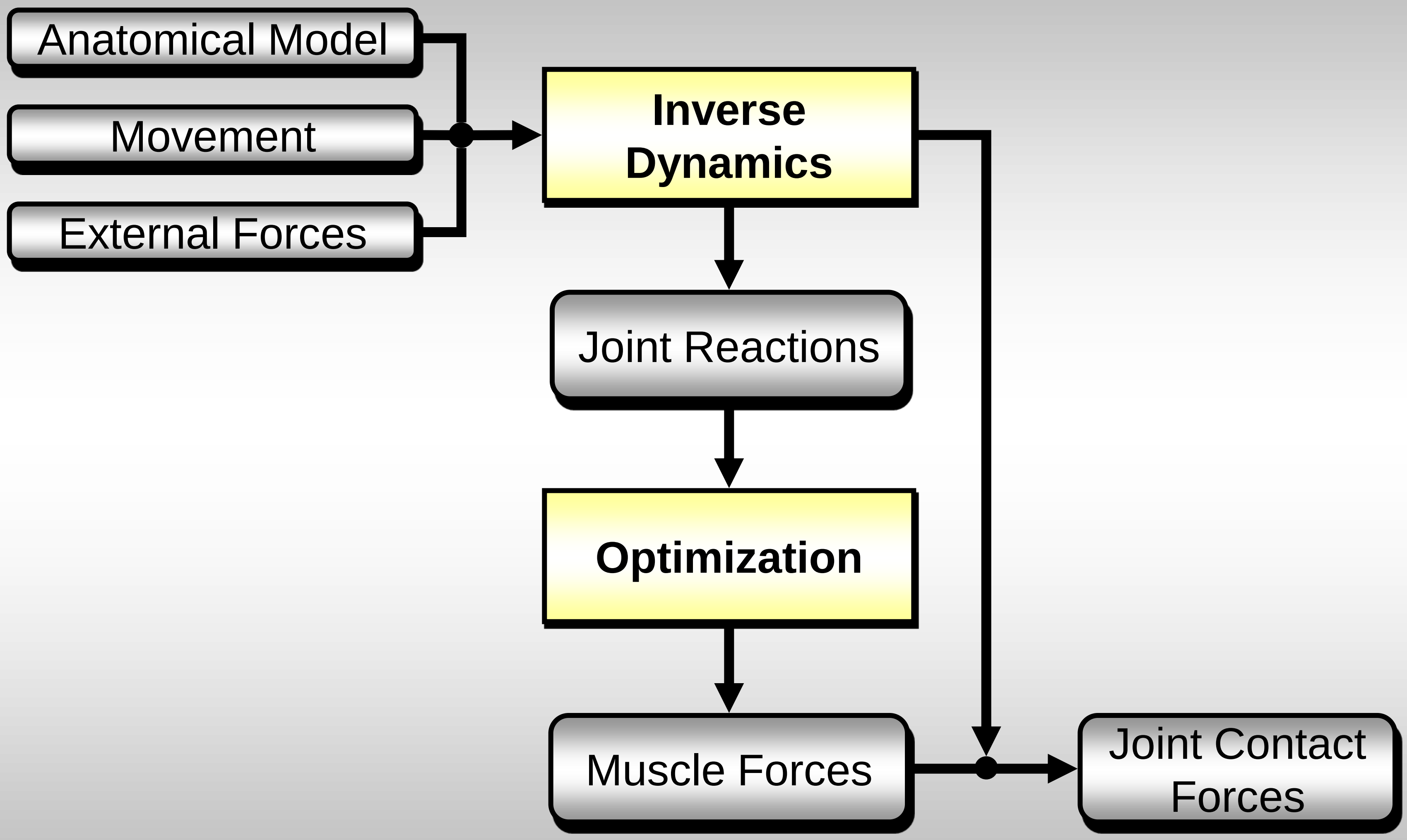
AnyBody
(http://www.anybo

Selfe-developed:
UFBSIM
(http://www.biomechanics.de
→ www.uzwr.de)
Von Erik Forster



OpenSim
(http://opensim.stanford.edu/)

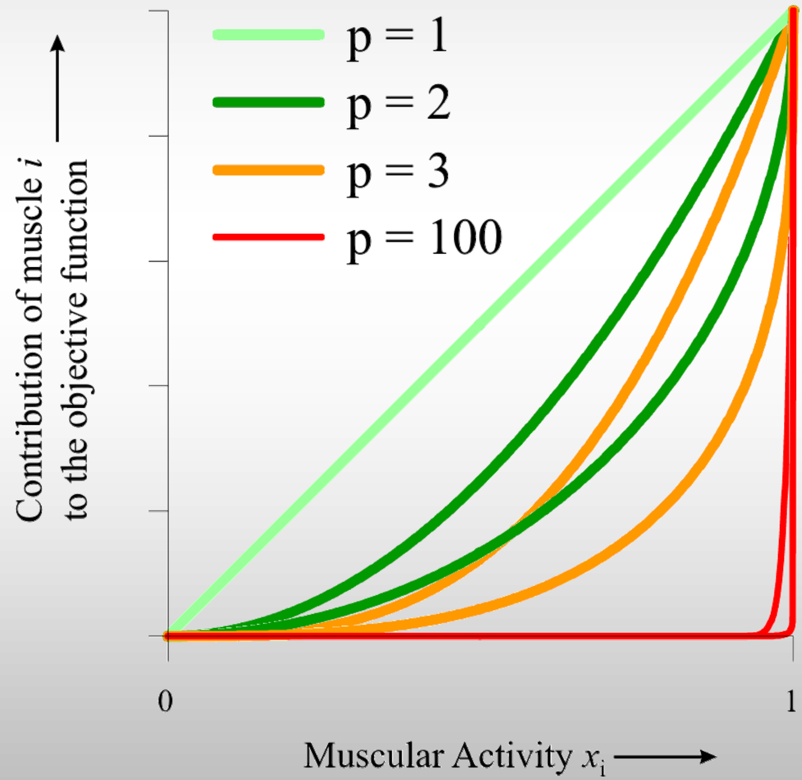
Inverse Dynamics & Optimization



Optimization

Optimization Criterion:

$$\mathbf{G} = \min$$



Polynomial Criterion:

$$\mathbf{G} = \sum_i \left(\frac{f_i}{f_{\max,i}} \right)^p$$

Soft Saturation Criterion:

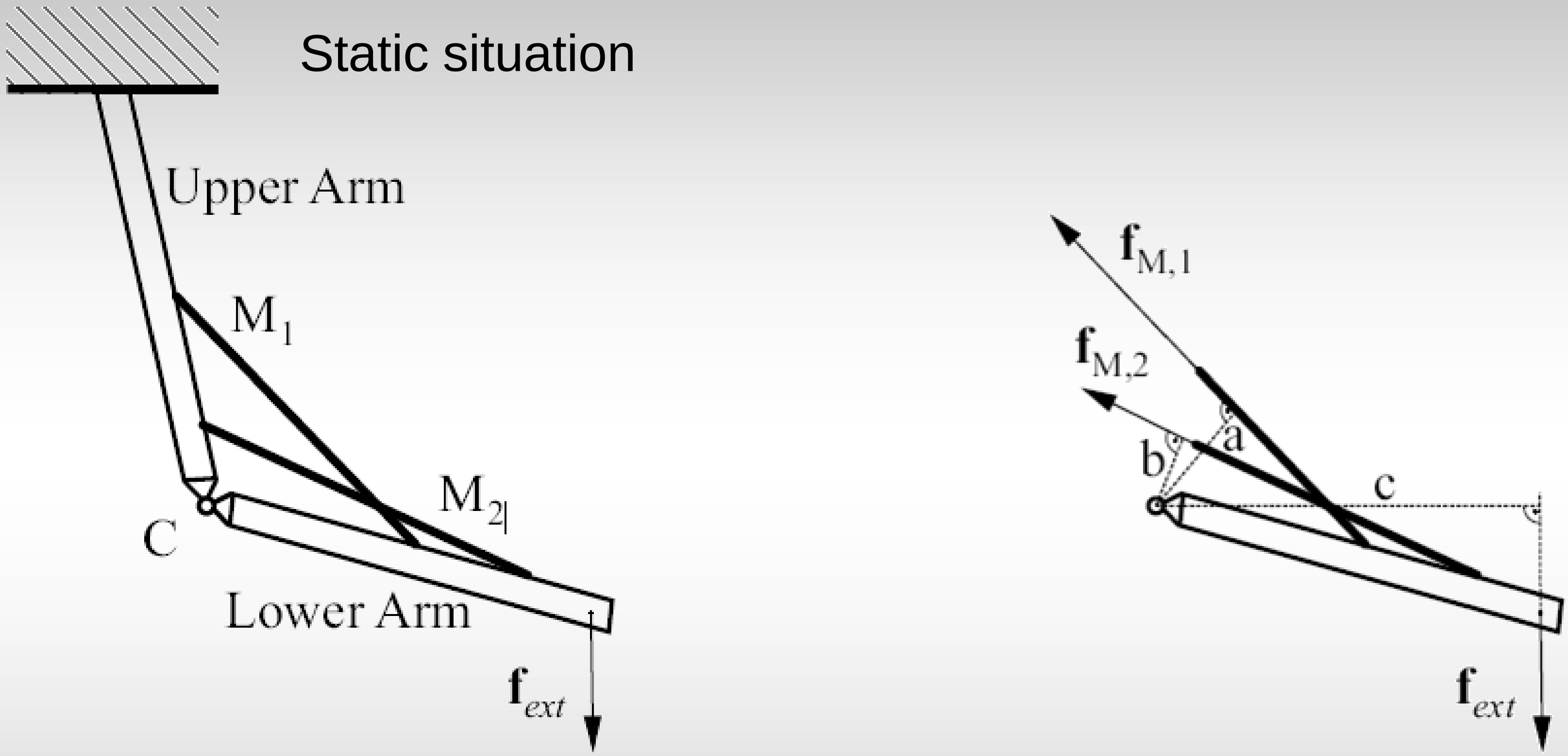
$$\mathbf{G} = -\sum_i \sqrt[p]{1 - \left(\frac{f_i}{f_{\max,i}} \right)^p}$$

min/max Criterion:

$$\mathbf{G} = \max \left(\frac{f_i}{f_{\max,i}} \right)$$

Two-Muscle Example, Synergy

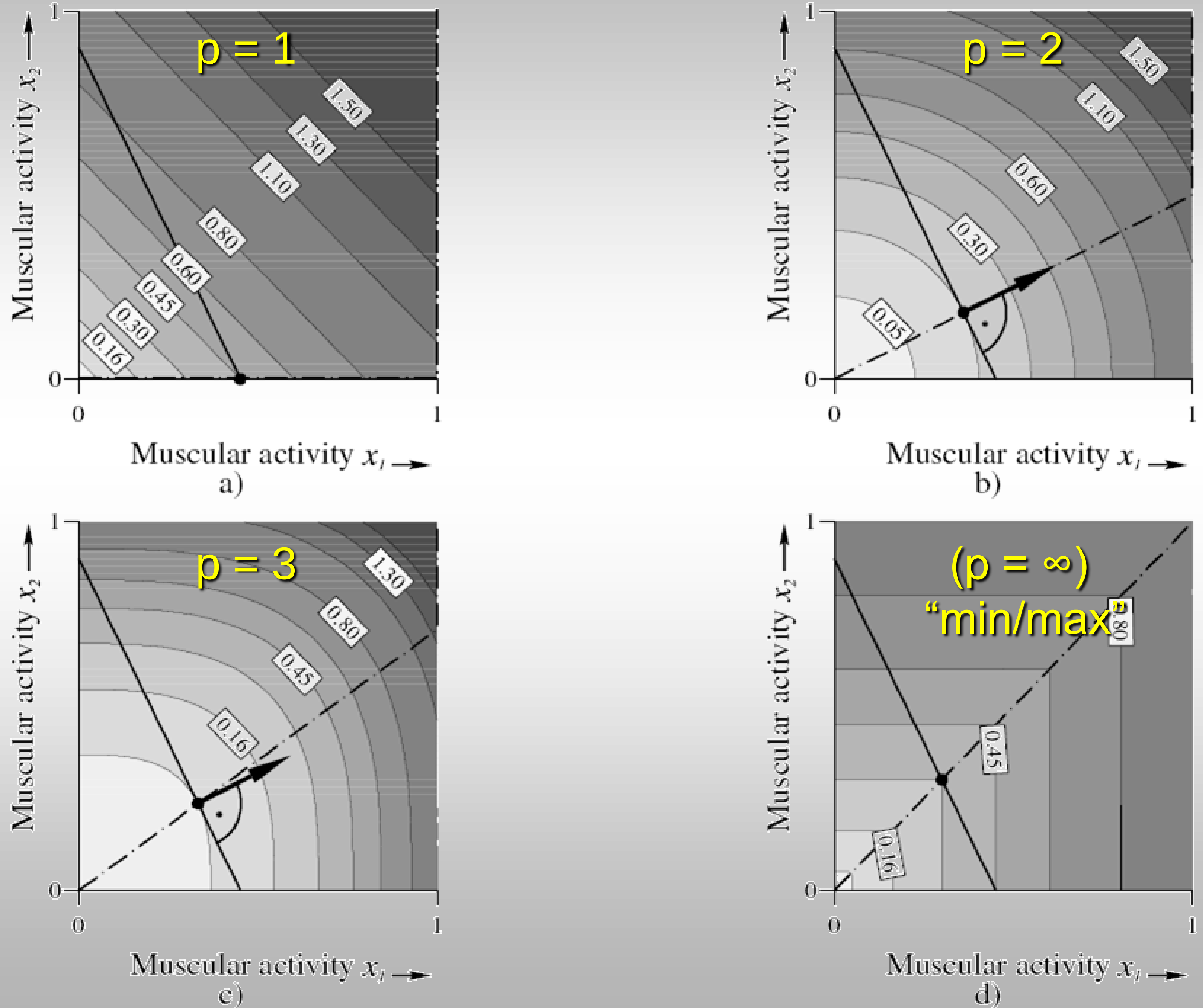
Static situation



Moment equilibrium: $$f_{M1} \cdot a + f_{M2} \cdot b = f_{ext} \cdot c$$

$$f_{M2} = f_{ext} \cdot \frac{c}{b} - f_{M1} \cdot \frac{a}{b}$$

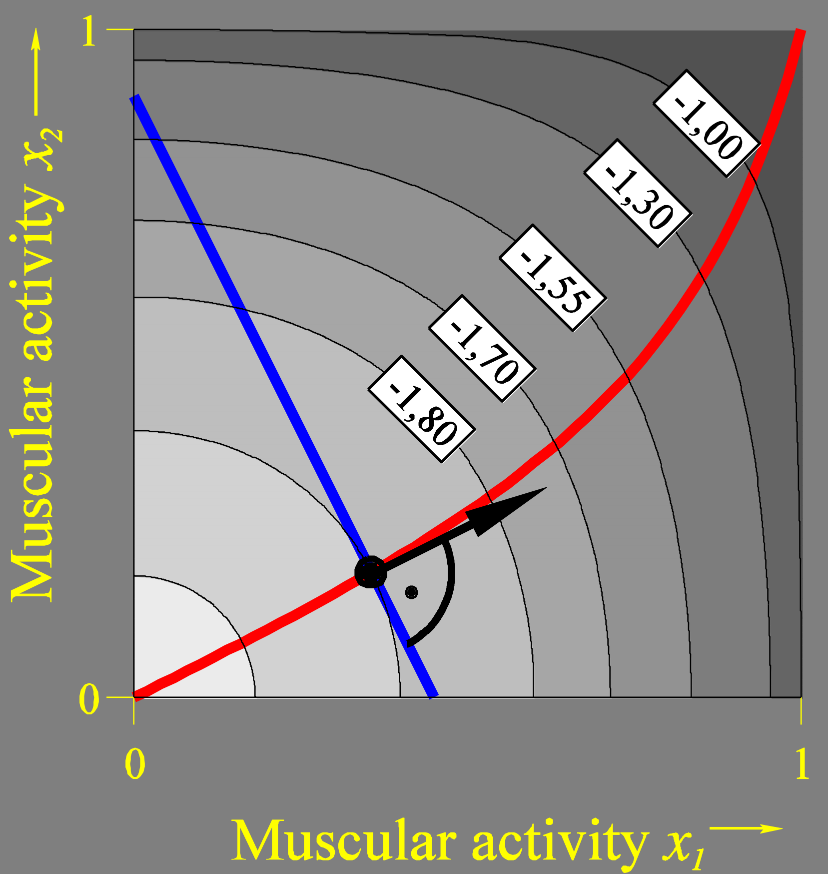
Objective Function in the Activation Space



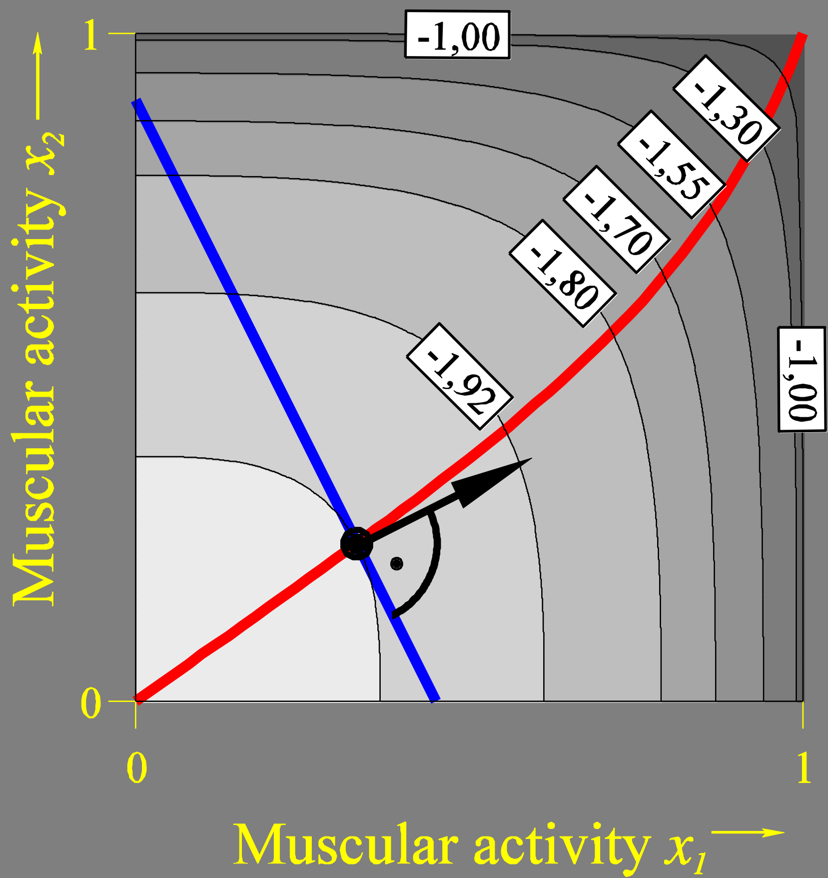
Soft Saturation

$$\mathbf{G} = -\sum_i \sqrt[p]{1-\left(\frac{f_i}{f_{\max,i}}\right)^p}$$

p = 2



p = 3



Problem: Predicting antagonistic muscle activity

Shift Factor ("Night and Fog Factor")

Forster et al., J Biomech 2004

Optimization criterion:

$$\mathbf{G} = \min$$

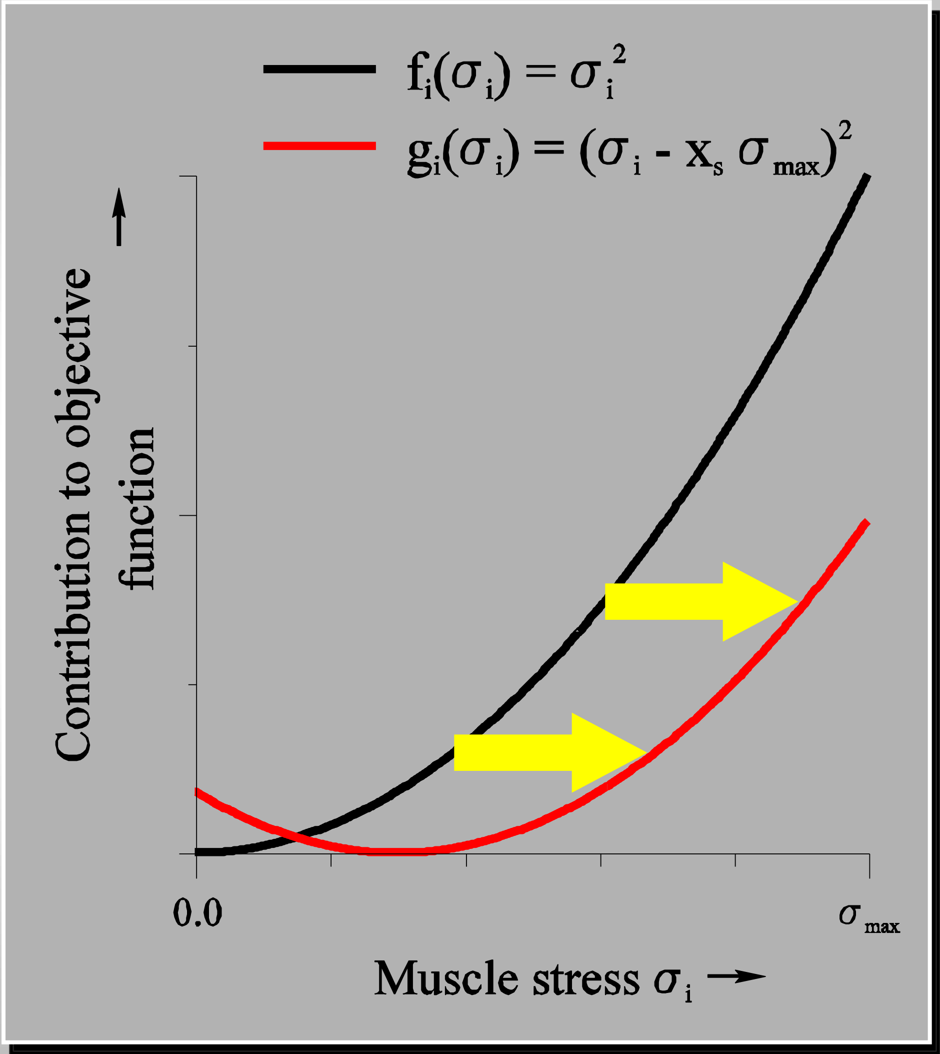
Objective function:

$$\mathbf{G} = \sum_i f_i(\sigma_i)$$

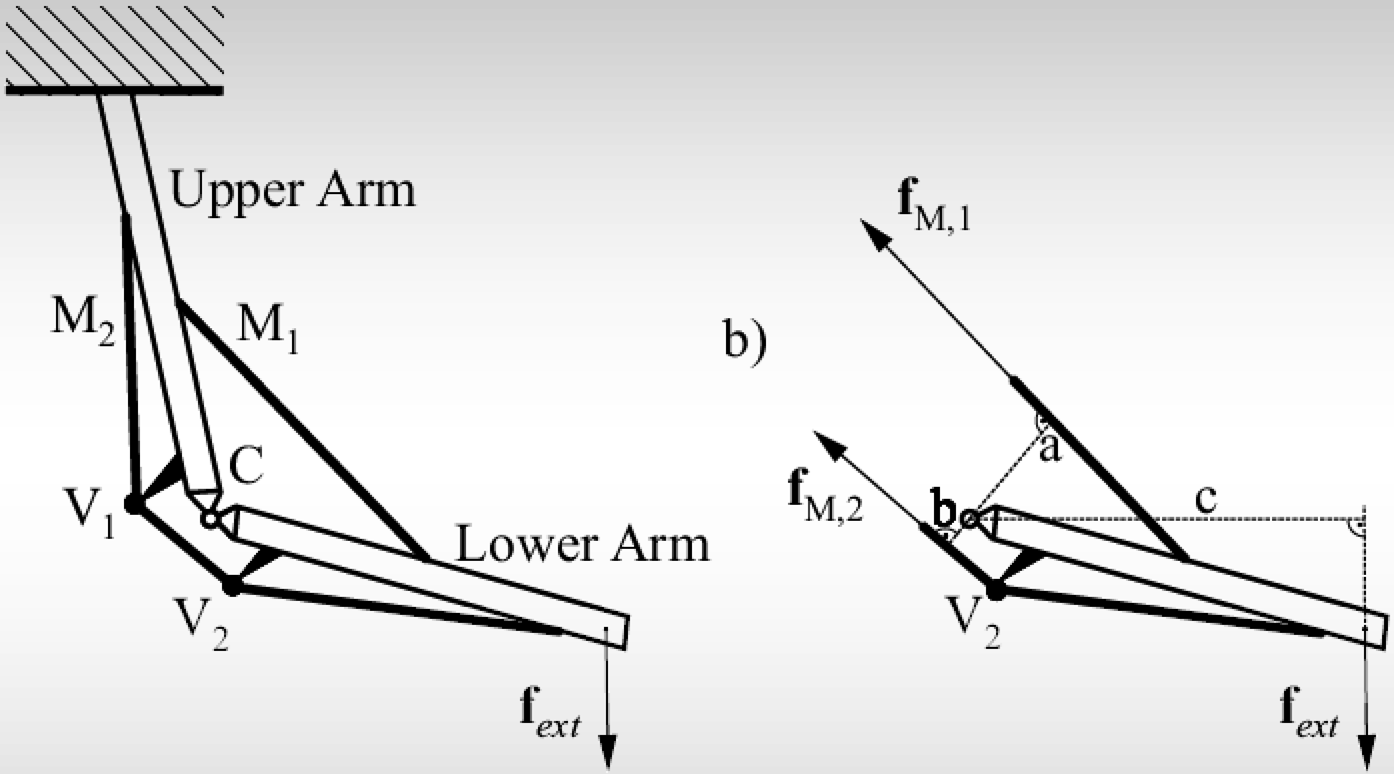
Extension:

$$(\sigma_i) \rightarrow (\sigma_i + x_s \sigma_{max})$$

x_S – Shift parameter



Two-Muscle Example, Co-Contraction

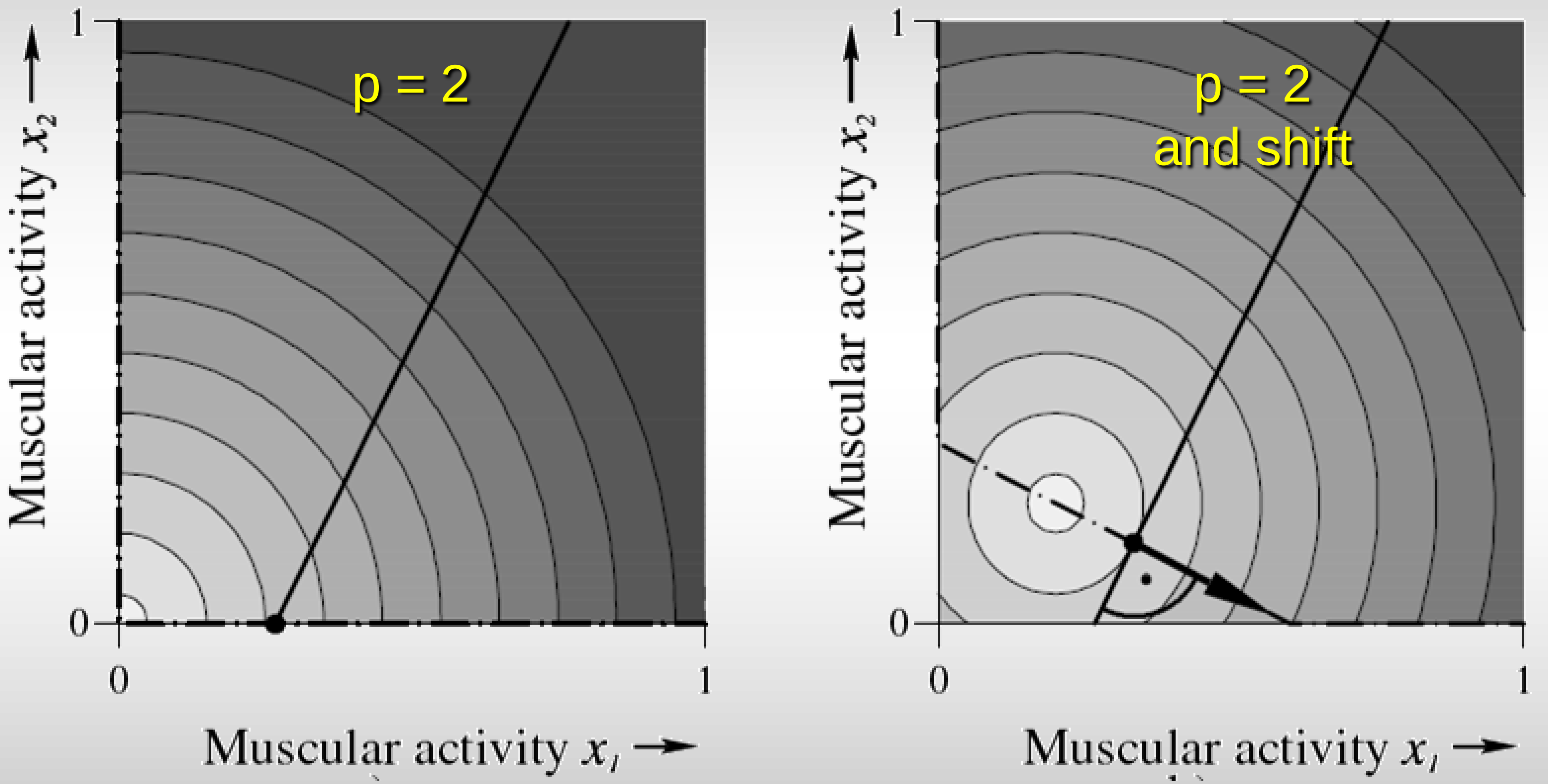


Moment equilibrium:

$$f_{M1} \cdot a - f_{M2} \cdot b = f_{ext} \cdot c$$

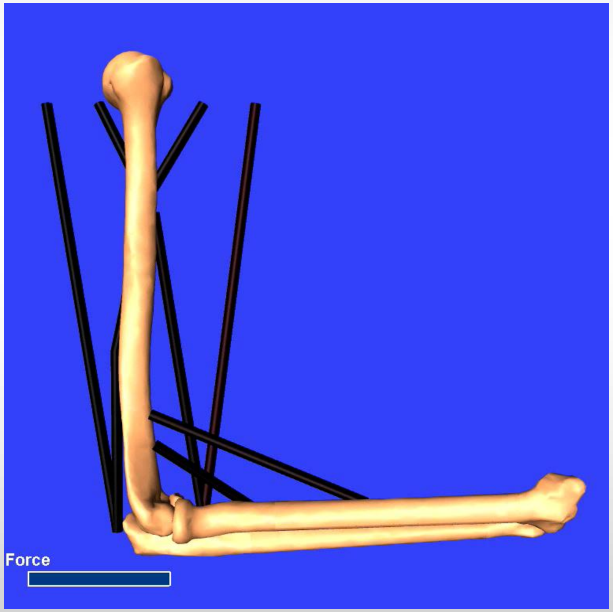
$$f_{M2} = -f_{ext} \cdot \frac{c}{b} + f_{M1} \cdot \frac{a}{b}$$

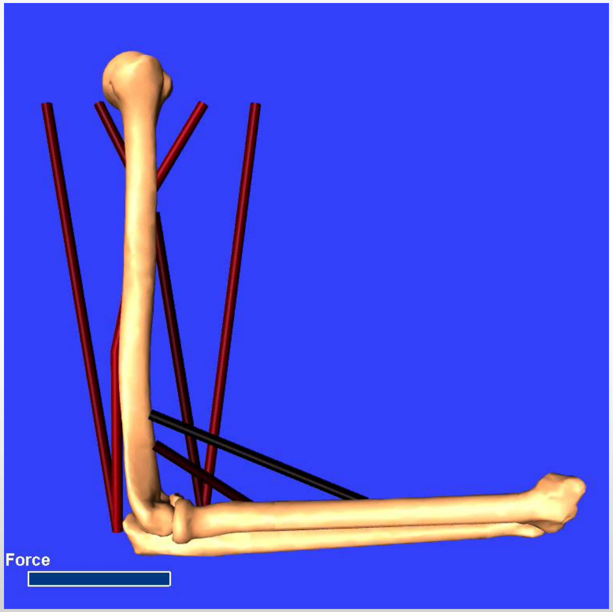
Objective Function in the Activation Space

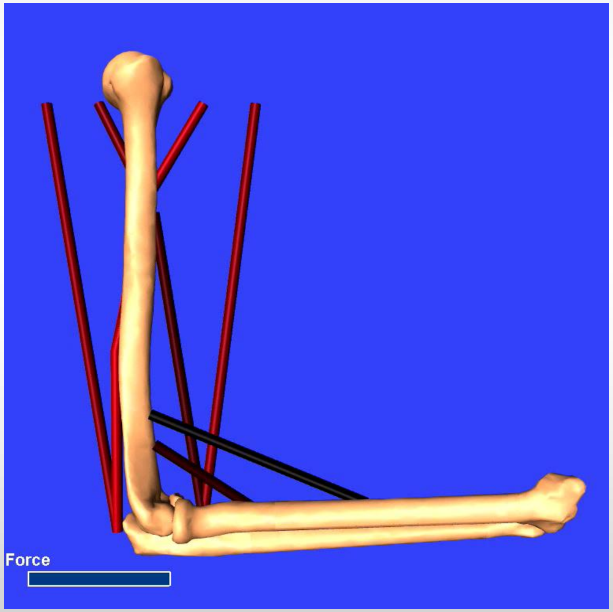


Results: Muscle Activity

Conventional Quadratic Criterion	Quadratic Criterion with Extension	
x_s=0.0	x_s=0.2	x_s=0.4





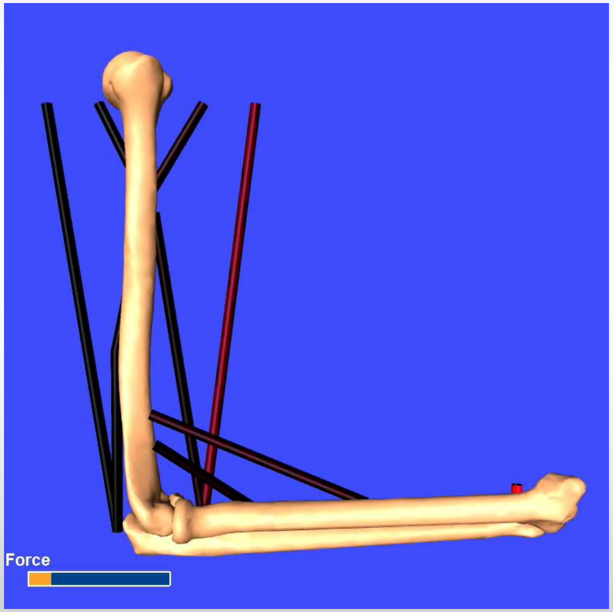


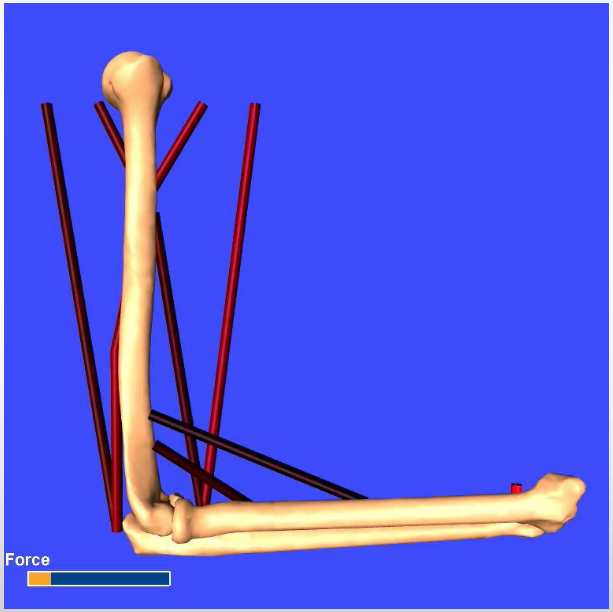
Flexor activity only

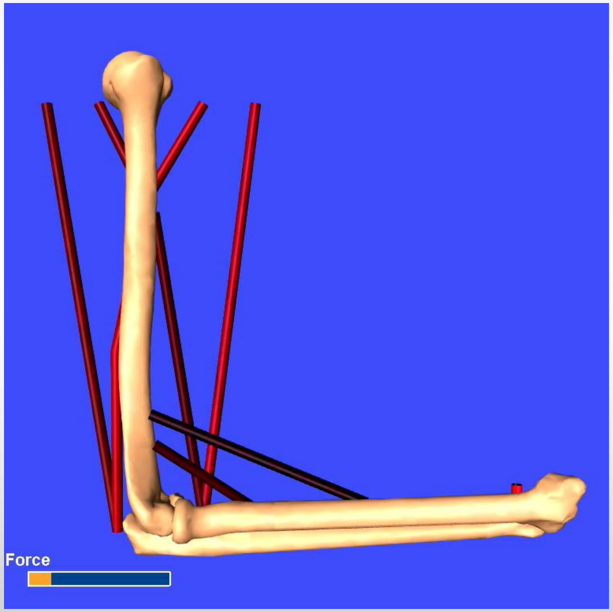
Flexor and extensor activity

Results: Muscle Activity

Conventional Quadratic Criterion	Quadratic Criterion with Extension	
x_s=0.0	x_s=0.2	x_s=0.4





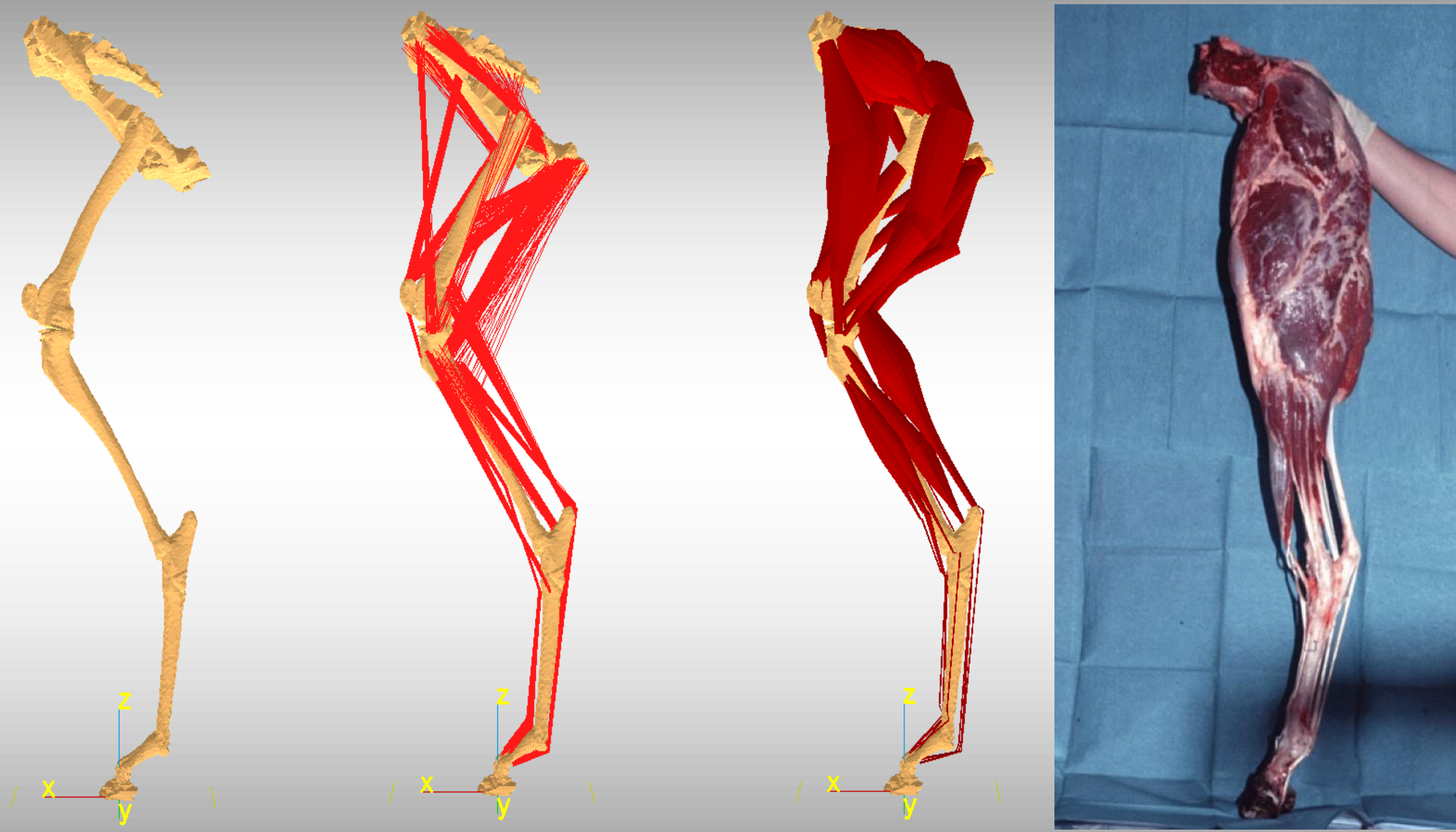


Flexor activity only

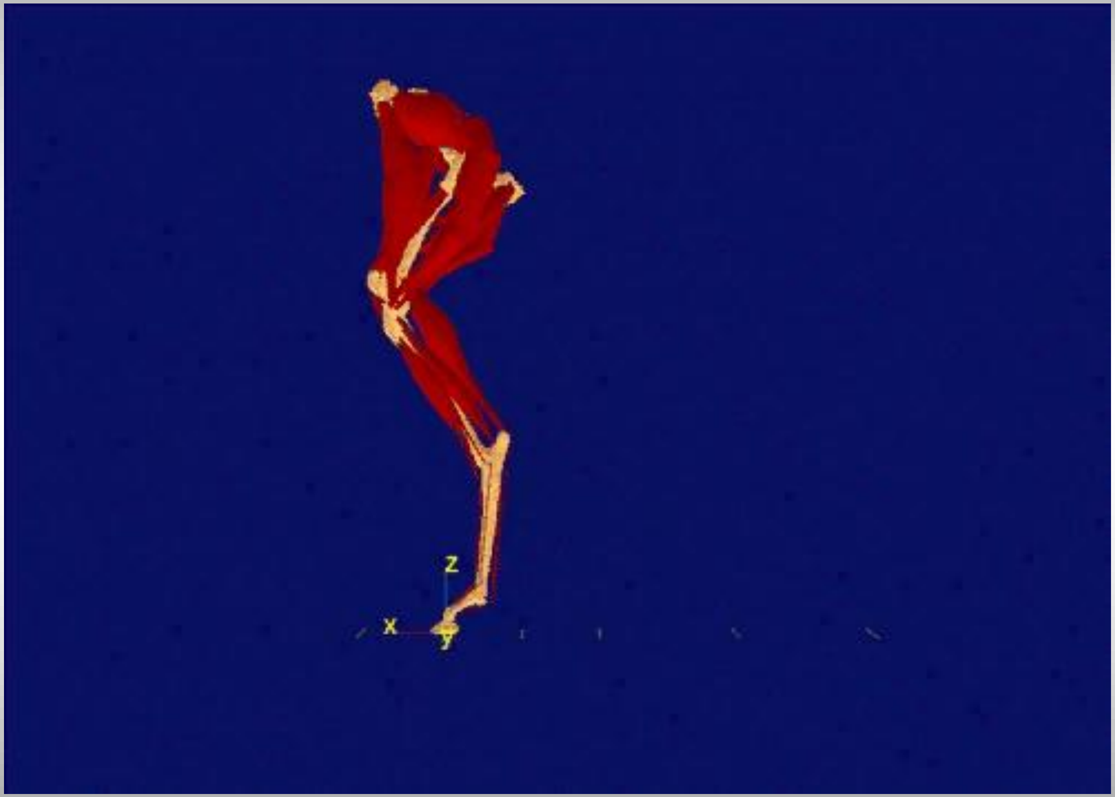
Flexor and extensor activity

Preloading of joint

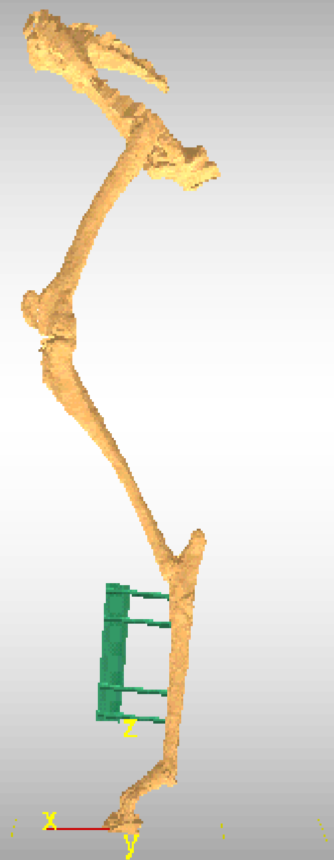
Schaf: Anatomie

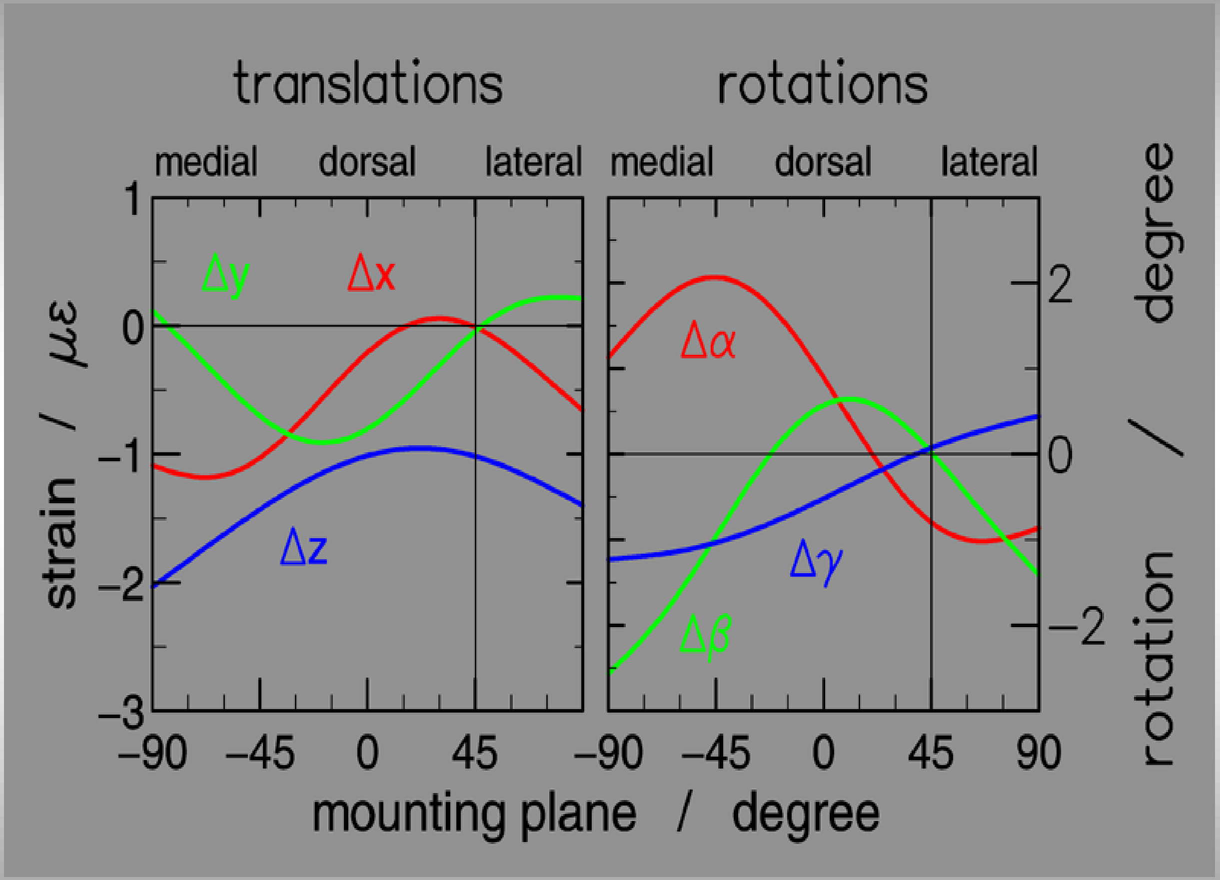


Schaf: Gangzyklus

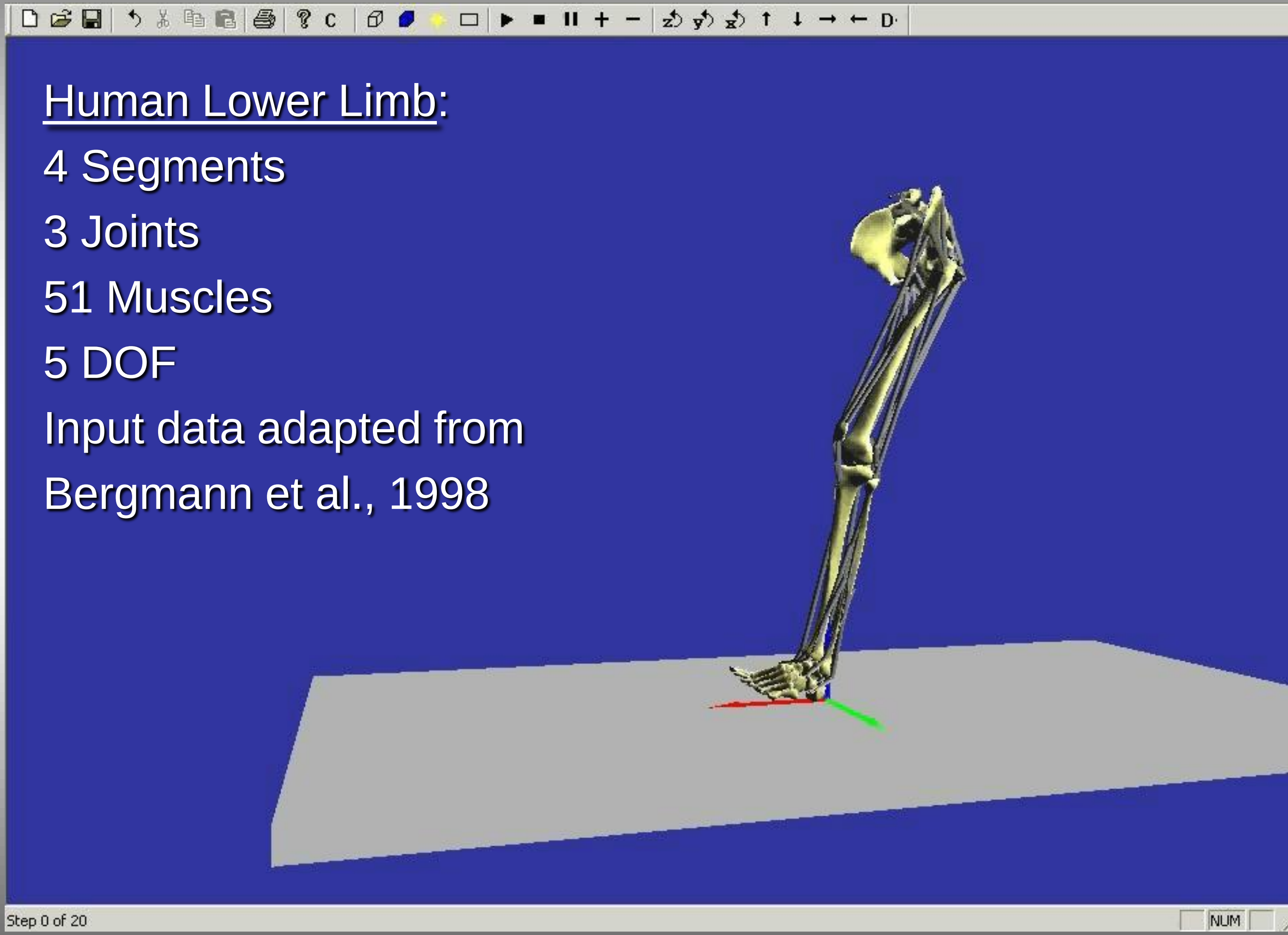


Schaf: Interfragmentäre Bewegung

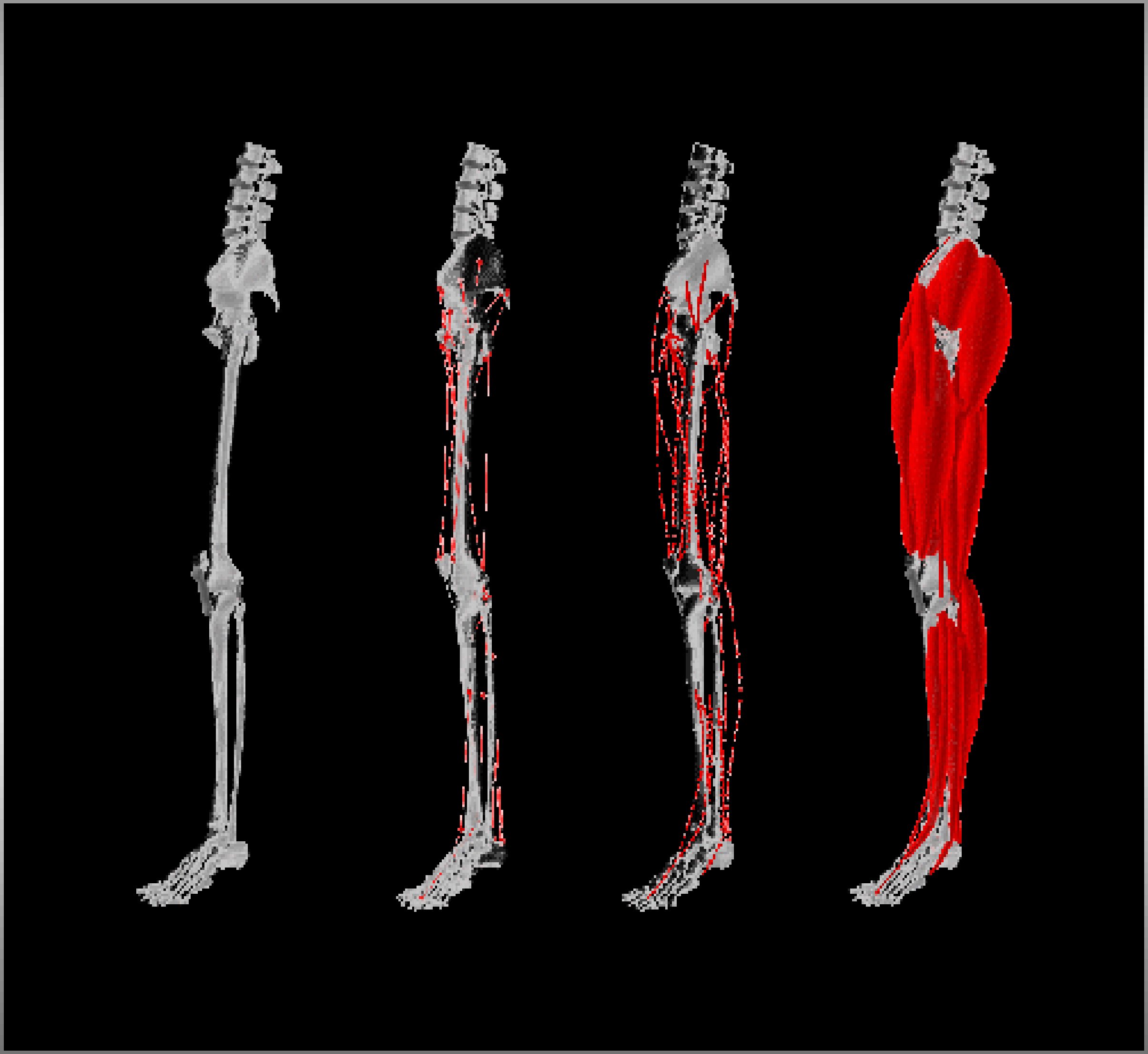




Musculoskeletal Model: UFBSim Example

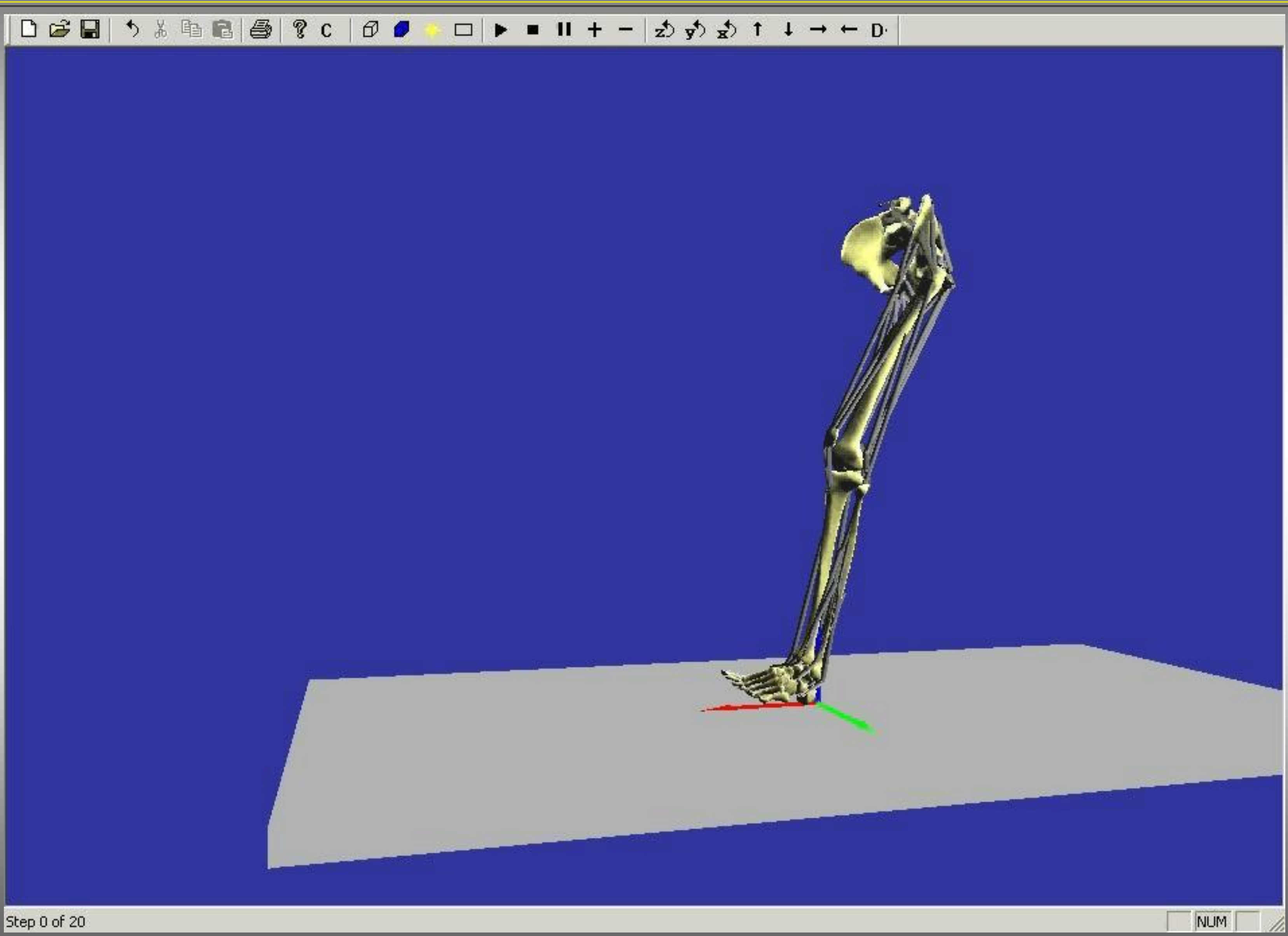


Human: Anatomie



Human: Ganganalyse

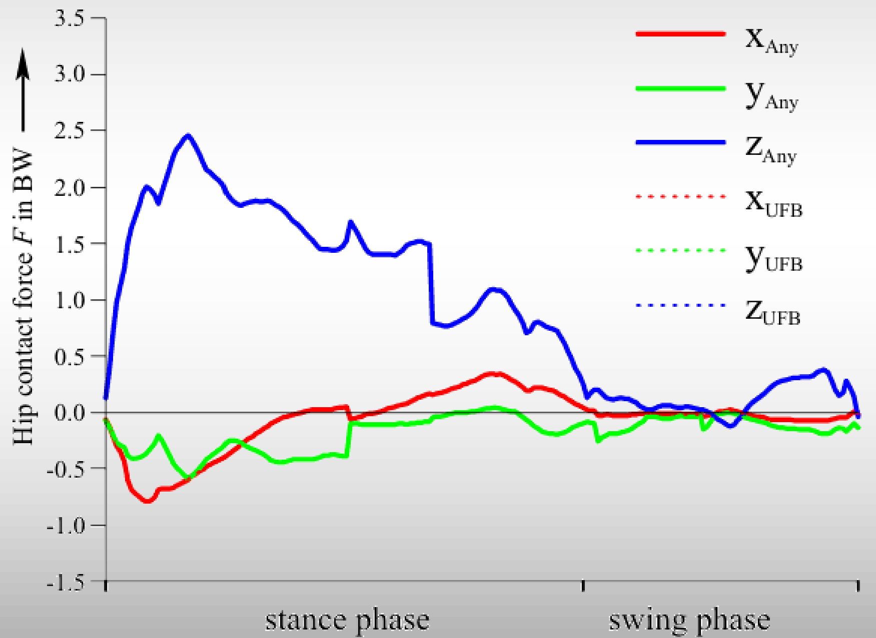
Human: Gangzyklus



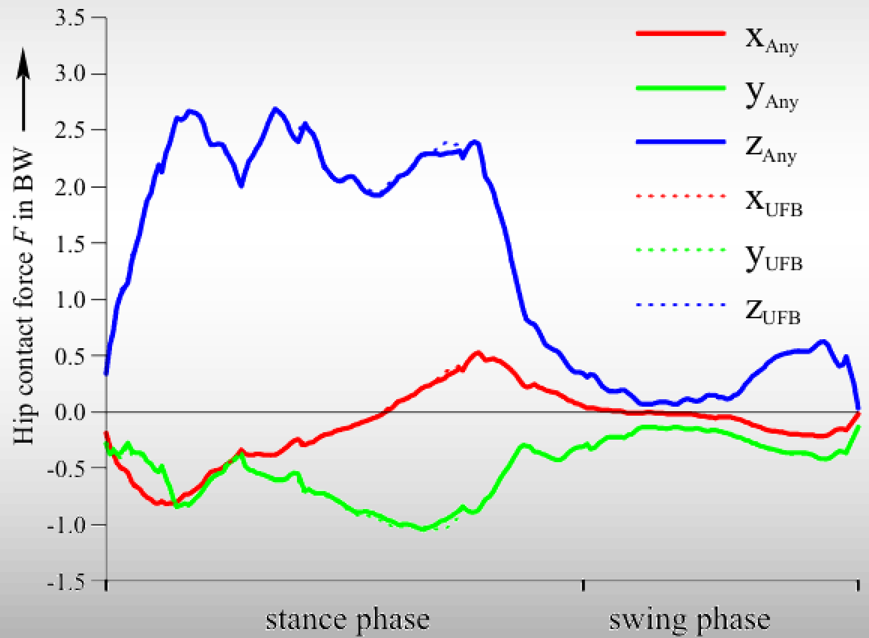
Results

Predicted hip contact forces during normal walking

of one trial of normal walking for one subject over time



linear



min/max

Item 1: Bachelor thesis Dominik Vogelaar

Improvements:

- 18 segments (bones)
- 47 muscles
- 25 joints
- 32 DOF