Chair of Applied Mechanics
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# Biorobotic Analysis of the Swing Leg Catapult in Human Walking

## Neuromuscular Modeling and Robot Model Development

### Motivation

A catapult has three main components: an elastic element, a block, and a catch. The key characteristic is passive power amplification, i.e. a slow energy storage phase followed by rapid unloading when firing the projectile. In human walking an impulsive power output at the ankle joint is observed in late stance preceded by a slower energy storage phase [see figures]. Thus the leg exhibits all properties of a catapult [2]. The complex interplay between the thigh-shank-foot segment chain and muscle-tendon-units makes the mechanism hard to understand. Especially the catch and release mechanism has not been fully identified in the human leg yet and the catapult's existence and function in humans is discussed controversially [3]. The functional understanding of the catapult bears great potential to improve prostheses, legged robots, and gait rehab as it is assumed to contribute to the high efficiency and fundamental leg dynamics observed in human walking.

### Project Goal

We want to develop a functional understanding of the catapult by combining two approaches: evolving a neuromuscular simulation model [1] and building a robotic model in cooperation with the Max-Plank-Institute in Stuttgart. Of particular interest is to understand the catch and release mechanism and its transfer to technical systems.

### Project Partner

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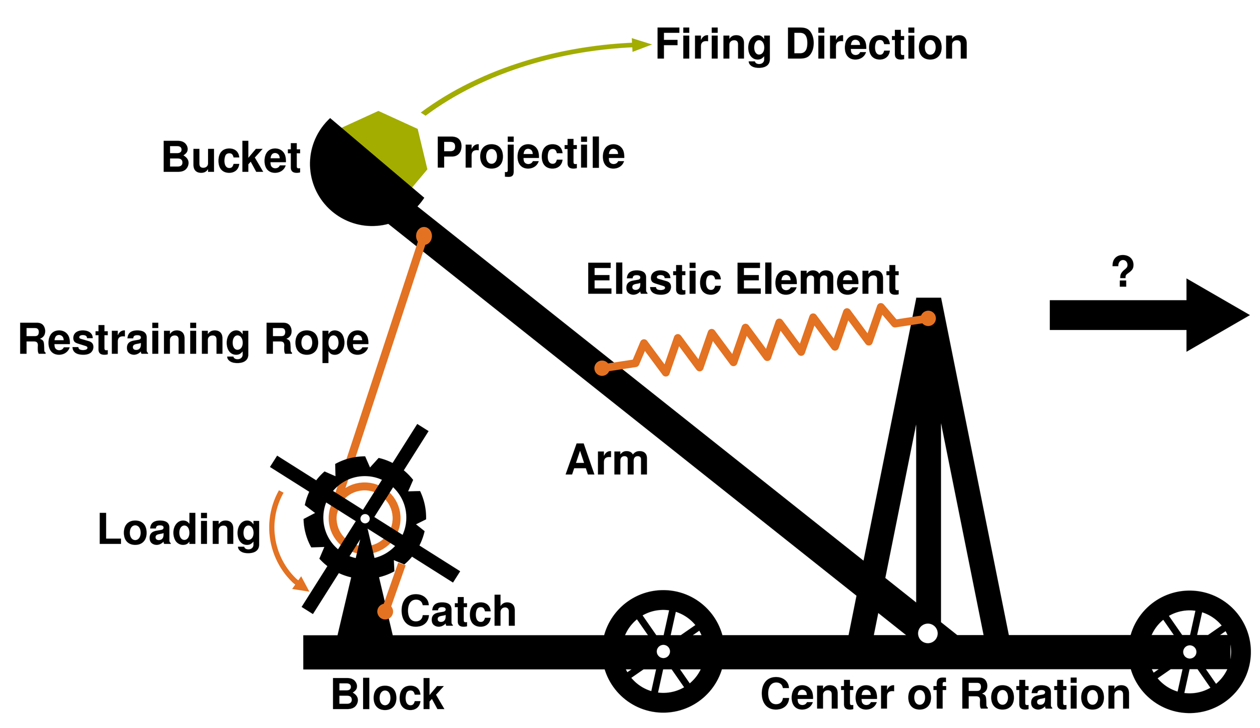
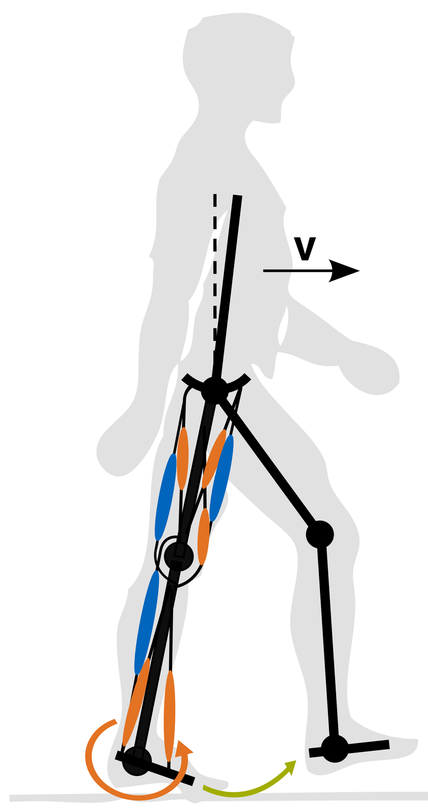
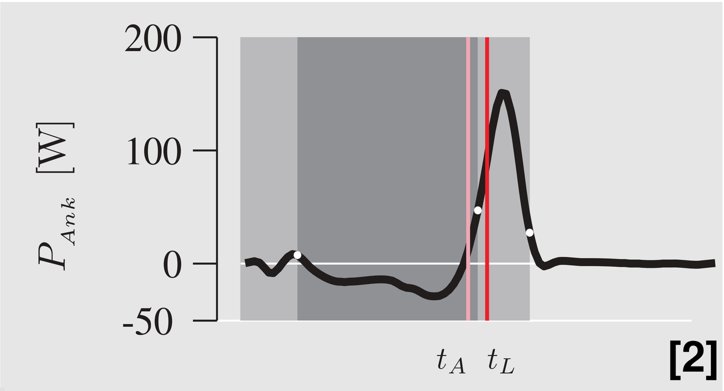
## Motivation - The Catapult in Human Walking



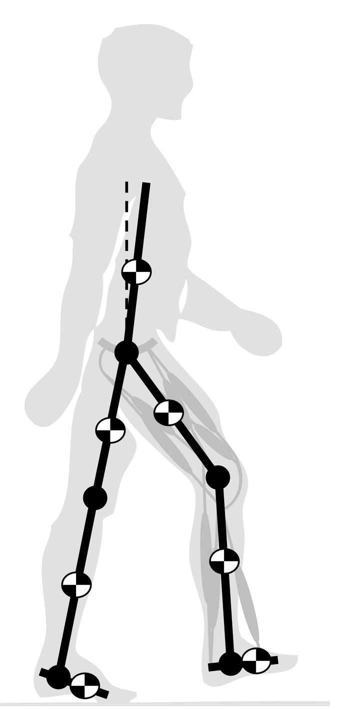




***Locking and Release (Catch):***
***- System Control vs. Mechanics?***
***- Role of Biarticular Muscles?***
***- Influence of Walking Speed?***
***- Segment Synchronization?***



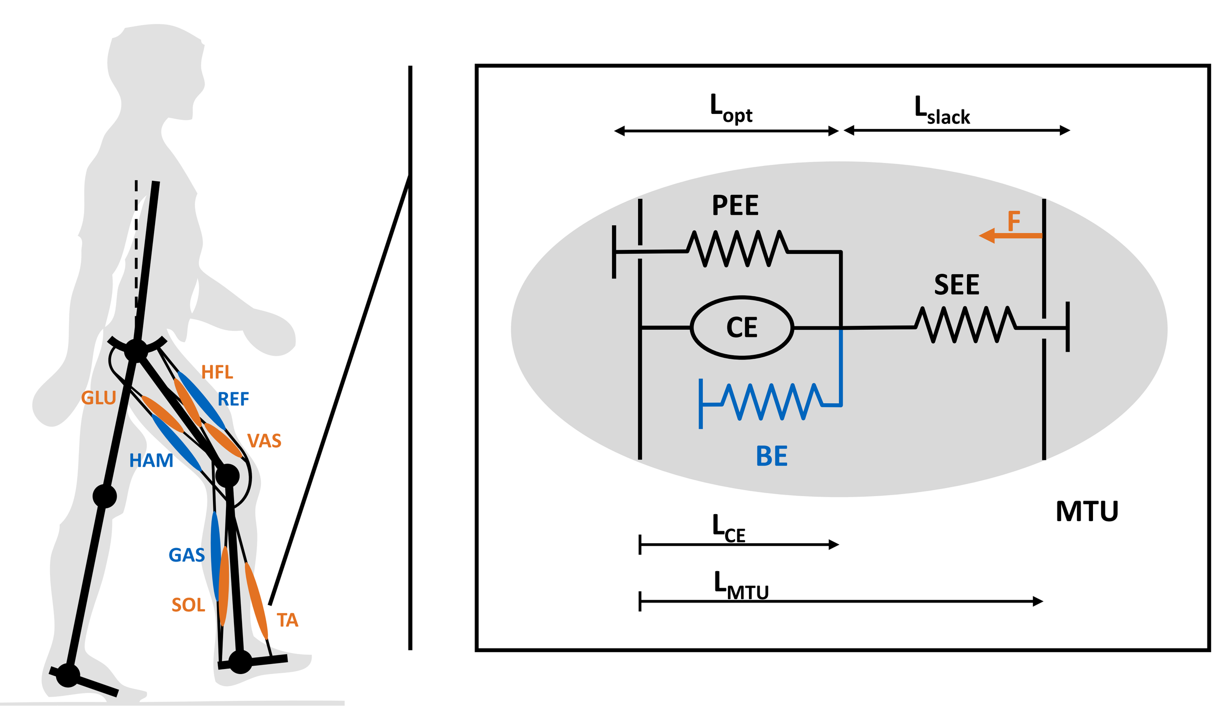

## Methods - Neuromuscular Modeling

**Body Mechanics**



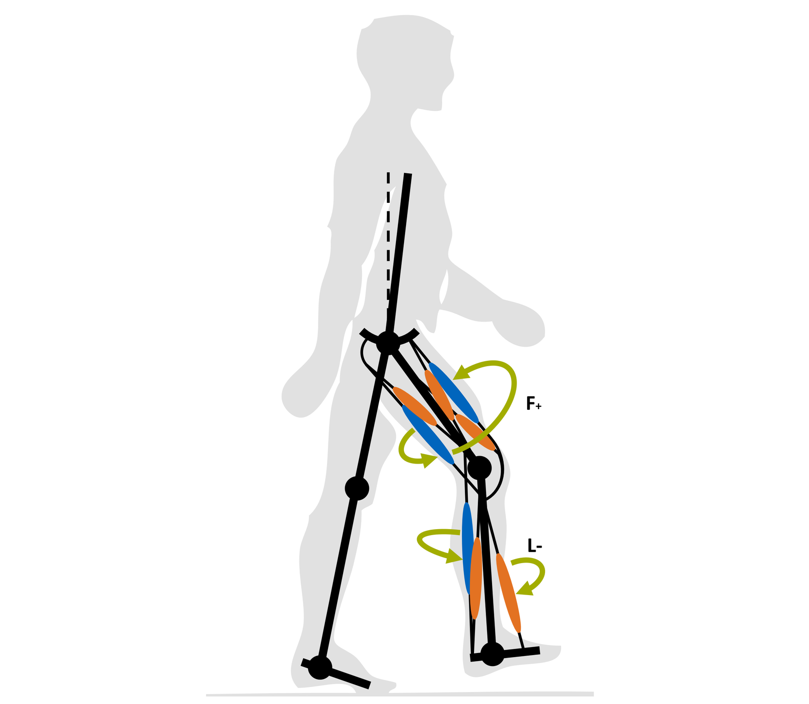
$$\sum_i F_i = m\ddot{x}$$
$$\sum_i M_i^S = \Theta^s \ddot{\varphi}$$

**Hill Muscle Model**



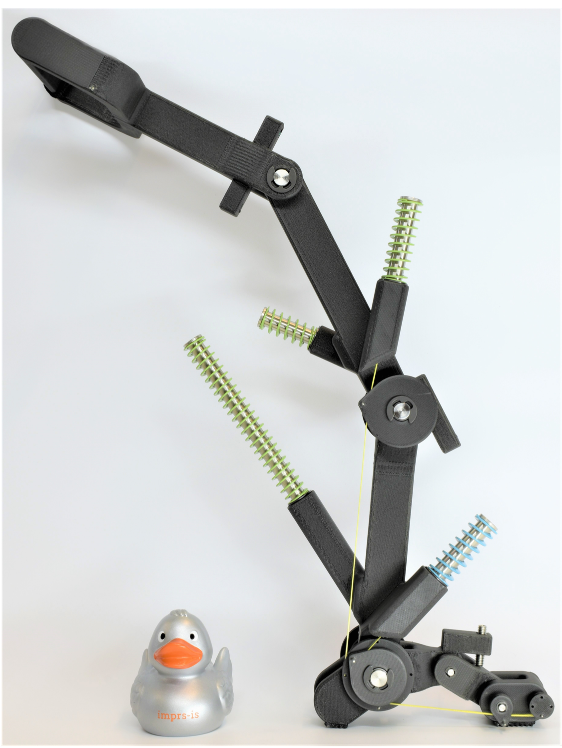

$$F_{CE,m}(ACT_m, l_{CE,m}, v_{CE,m}) = ACT_m F_{max,m} f_1(l_{CE,m}) f_2(v_{CE,m})$$
$$M_{j,m} = F_{CE,m} r_{j,m} = F_m r_{j,m}$$

**Neural Control**



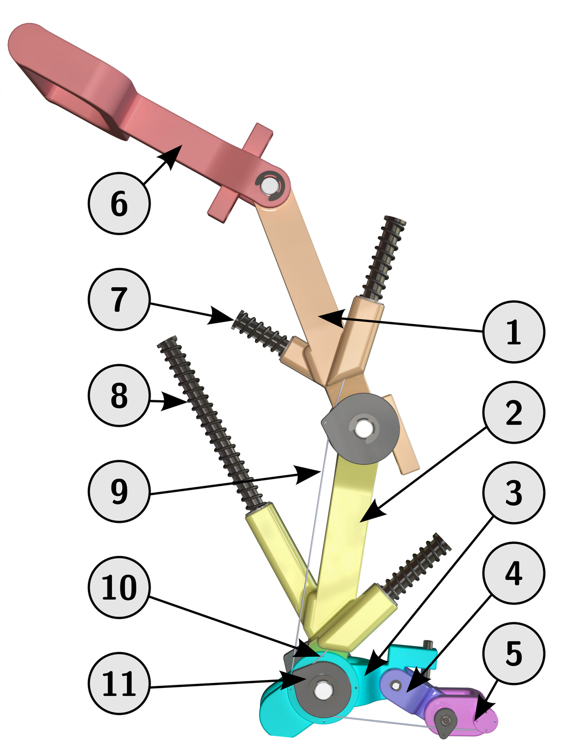
$$\tau \frac{dACT_m(t)}{dt} = STIM_m(t) - ACT_m(t)$$
$$STIM_m(t) = STIM_{0,m} \pm G_m P_m(t-\Delta_P)$$

## Methods - Biorobotic Approach



We will develop a robotic model of the human leg to test the reliability of the simulation results. Simulation and robotic model are continuously synchronized.

This dual, biorobotic approach improves accessibility of our findings to develop new gait rehabilitation devices, prosthesis and legged robots.




| | |
|---|---|
| 1 Thigh | (orange) |
| 2 Shank | (yellow) |
| 3 Heel - GC | (cyan) |
| 4 Mid-foot | (purple) |
| 5 Toes - GC | (magenta) |
| 6 Handle | (red) |
| 7 VAS | (spring & tendon) |
| 8 TA | (spring & tendon) |
| 9 GAS | (spring & tendon) |
| 10 SOL | (spring & tendon) |
| 11 CAM profiles | (black) |

### References

[1] Geyer, H. and Herr, H. "A muscle-reflex model that encodes principles of legged mechanics produces human walking dynamics and muscle activities". In: *IEEE transactions on neural systems and rehabilitation engineering* 18.3 (2010), pp. 263–273.

[2] Lipfert, S. W., Günther, M., Renjewski, D., and Seyfarth, A. "Impulsive ankle push-off powers leg swing in human walking". In: *Journal of Experimental Biology* 217.8 (2014), pp. 1218–1228. ISSN: 1477-9145.

[3] Zelik, K. E. and Adamczyk, P. G. "A unified perspective on ankle push-off in human walking". In: *Journal of Experimental Biology* 219.Pt 23 (2016), pp. 3676–3683. ISSN: 1477-9145. DOI: 10.1242/jeb.140376.

### Acknowledgments

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