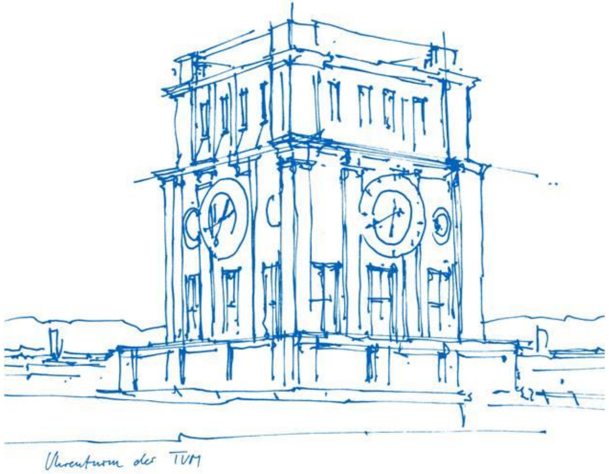
Lehrstuhl für Produktentwicklung und Leichtbau
TUM School of Engineering and Design
Technische Universität München

# Numerical optimization for robot design and control – Day 04
# Co-design of robots

Akhil Sathuluri

Prof. Dr. Markus Zimmermann




Garching, 08th of September 2022

# Day-4: Co-design of robots: Overview

**Completing tasks from the previous days**

1. Questions, discussion and coding

**Part-1: Co-design of robots: Theory and introduction**

1. Motivation and introduction
2. Setting up the problem

**Part-2: Co-design as an optimization problem**

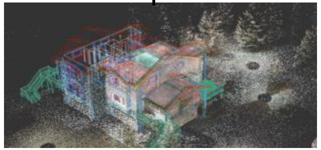
1. Problem formulation
2. Problem solving methods
3. Discussion

# Part-1: Co-design of robots

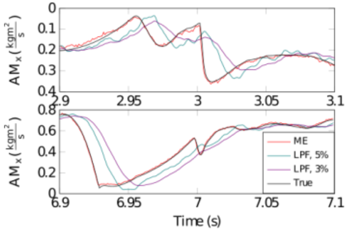
Remember it from day-1!

# Motivation and introduction

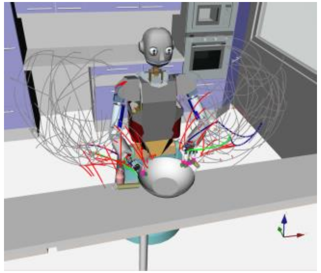
Perception



Estimation




Planning

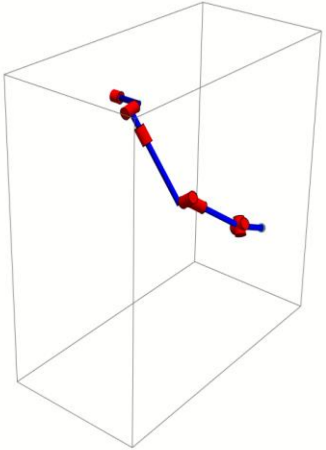


- Design of robotic systems has primarily been a sequential process

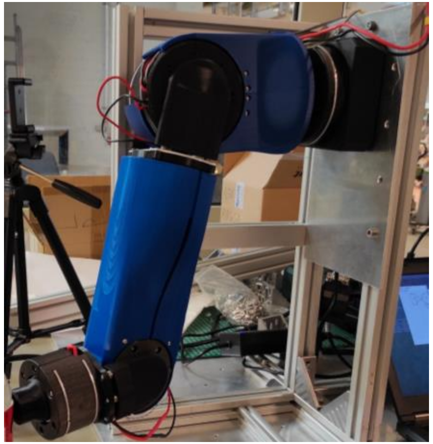
Concept Design

Detail Design

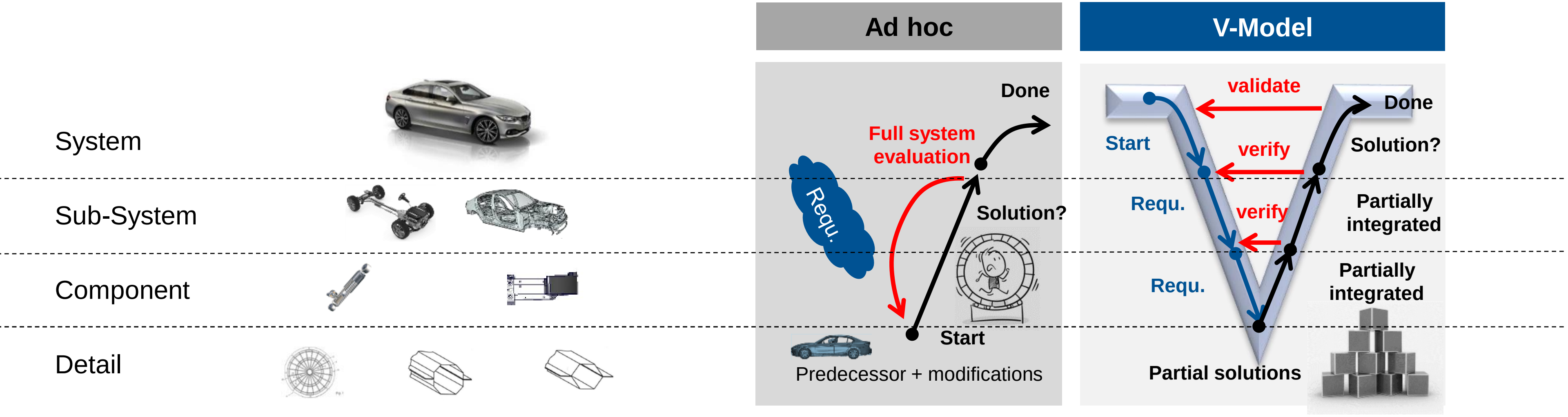
Simulation and Control



Prototype



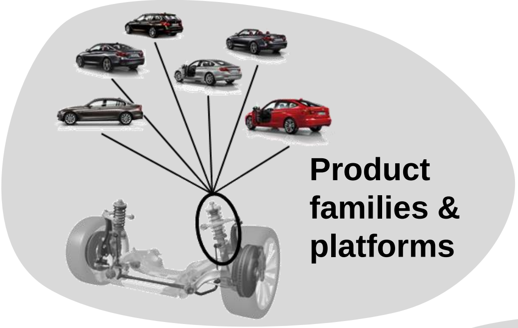
# Motivation and introduction

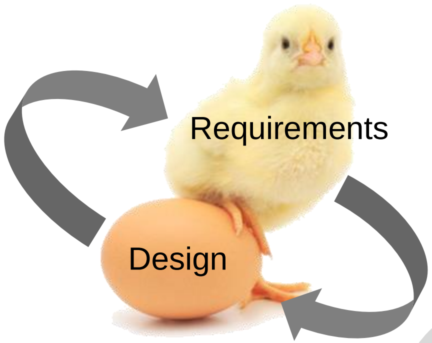


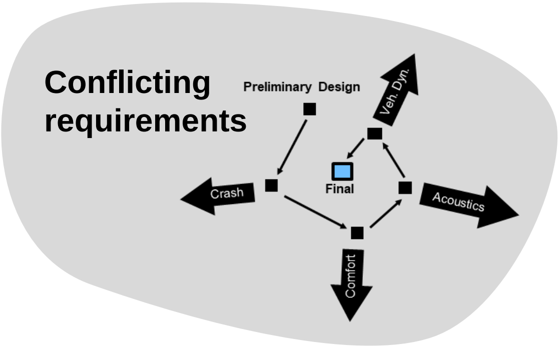

- Ad hoc systems design (typically bottom-up) can be extremely expensive until you get to a satisfactory solution.
- Alternative V-model: Systematic development of requirements → first dependency model by introducing an order.
- **Remaining problem:** How to formulate quantitative requirements that *simultaneously* (1) guarantee that the overall design goal is reached AND (2) provide freedom/can be satisfied? The trouble maker is …

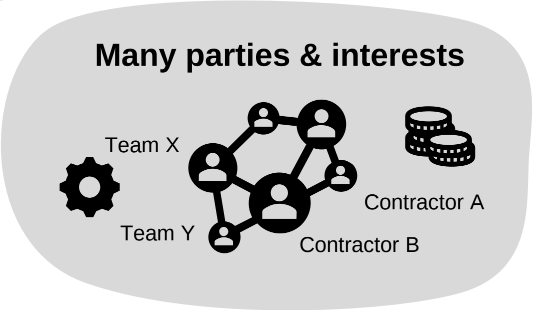
Courtesy of BMW

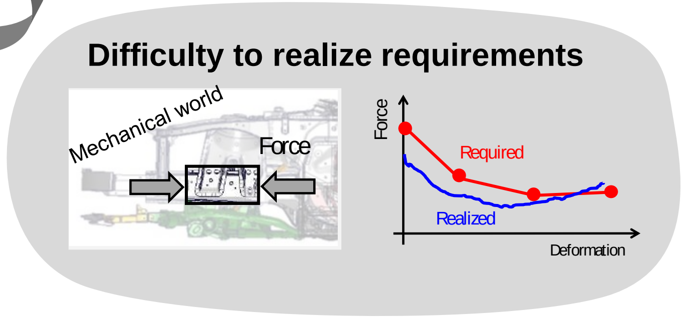
# Motivation and introduction




- You should know (1) what can be realized, (2) other requirements, (3) other interests, (4) other products… but you don‘t.

→ **uncertainty, complexity, ambiguity …** → **How to apply the V-model to the mechanical world?**

Courtesy of BMW

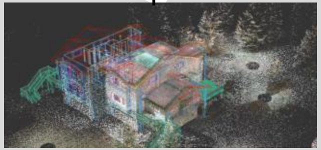
# Motivation and introduction

- So for a pure top-down procedure, we would have to consider all of these factors at the beginning of the design

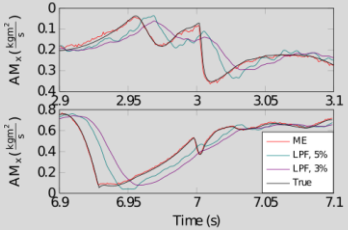
- Such designs would be extremely lean and on point for the set of requirements chosen

- However, that might not always be possible

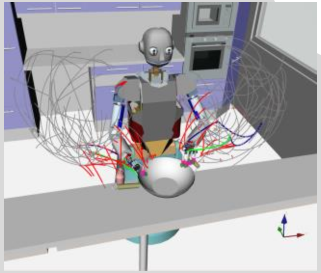
Perception



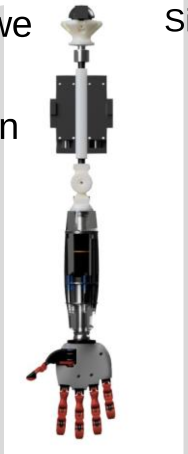
Estimation



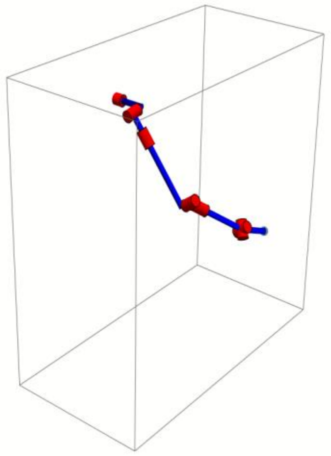

Planning



Detail Design

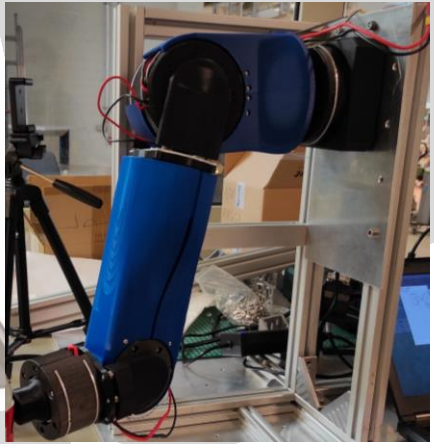


Simulation and Control



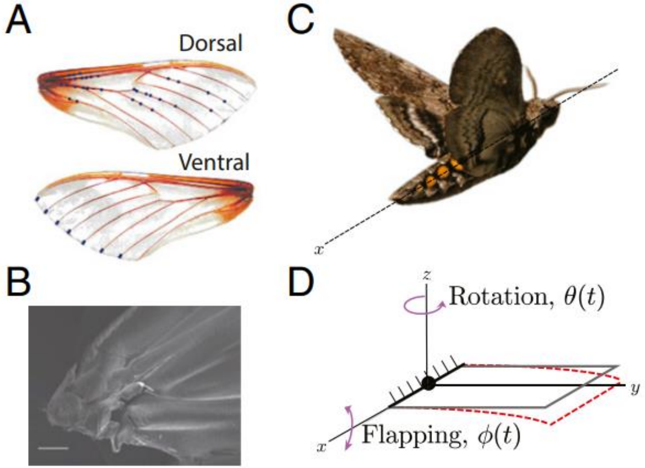
Concept Design

Prototype



# Motivation and introduction

- However, this sequential process might not be the optimal way of dealing with design of complex systems


Combined interaction between control and mechanics

Combined interaction between sparse sensor placement and control


Hale, Melina E. "Making sense of sparse data with neural encoding strategies." *Proceedings of the National Academy of Sciences* 115.42 (2018): 10545-10547.

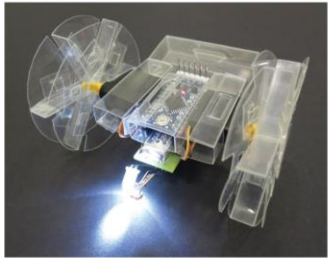
Webb, Paul W. "The swimming energetics of trout: II. Oxygen consumption and swimming efficiency." *Journal of Experimental Biology* 55.2 (1971): 521-540.

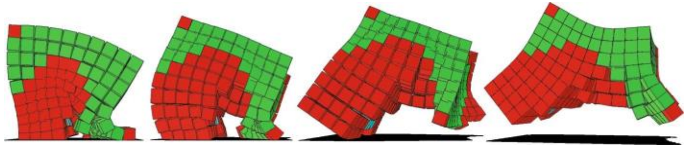
# Motivation and introduction

- Several researchers have proposed methods to expand the design space of robots by combining one or more of the steps together to view them as a holistic process

Concept Design + Prototyping

Mehta, Ankur, Joseph DelPreto, and Daniela Rus. "Integrated codesign of printable robots." Journal of Mechanisms and Robotics 7.2 (2015): 021015.

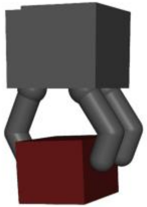




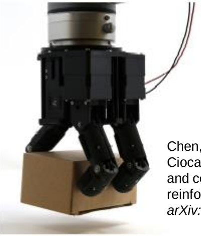
Cheney, Nick, et al. "Unshackling evolution: evolving soft robots with multiple materials and a powerful generative encoding." *ACM SIGEVOlution* 7.1 (2014): 11-23.

Concept Design + Control

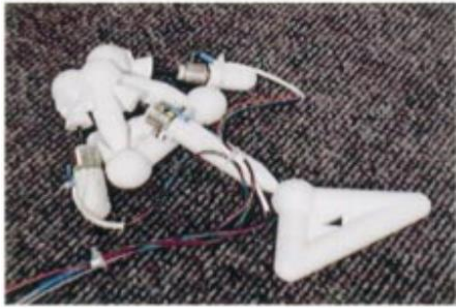
Sims, Karl. "Evolving virtual creatures." *Proceedings of the 21st annual conference on Computer graphics and interactive techniques*. 1994.



Hardware + Control

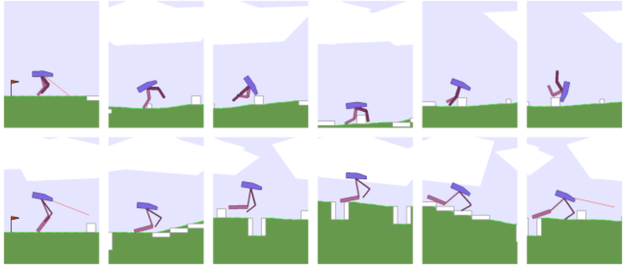


Chen, Tianjian, Zhanpeng He, and Matei Ciocarlie. "Hardware as policy: Mechanical and computational co-optimization using deep reinforcement learning." *arXiv preprint arXiv:2008.04460* (2020).



Concept Design + Control + Prototyping

Lipson, Hod, and Jordan B. Pollack. "Automatic design and manufacture of robotic lifeforms." *Nature* 406.6799 (2000): 974-978.



Detail Design + Control

Ha, David. "Reinforcement learning for improving agent design." *Artificial life* 25.4 (2019): 352-365.

# Part-2: Co-design as an optimization problem

# End of Day-4