

# Systems and Control Specialisation

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AUTOMATIC  
CONTROL  
LABORATORY 

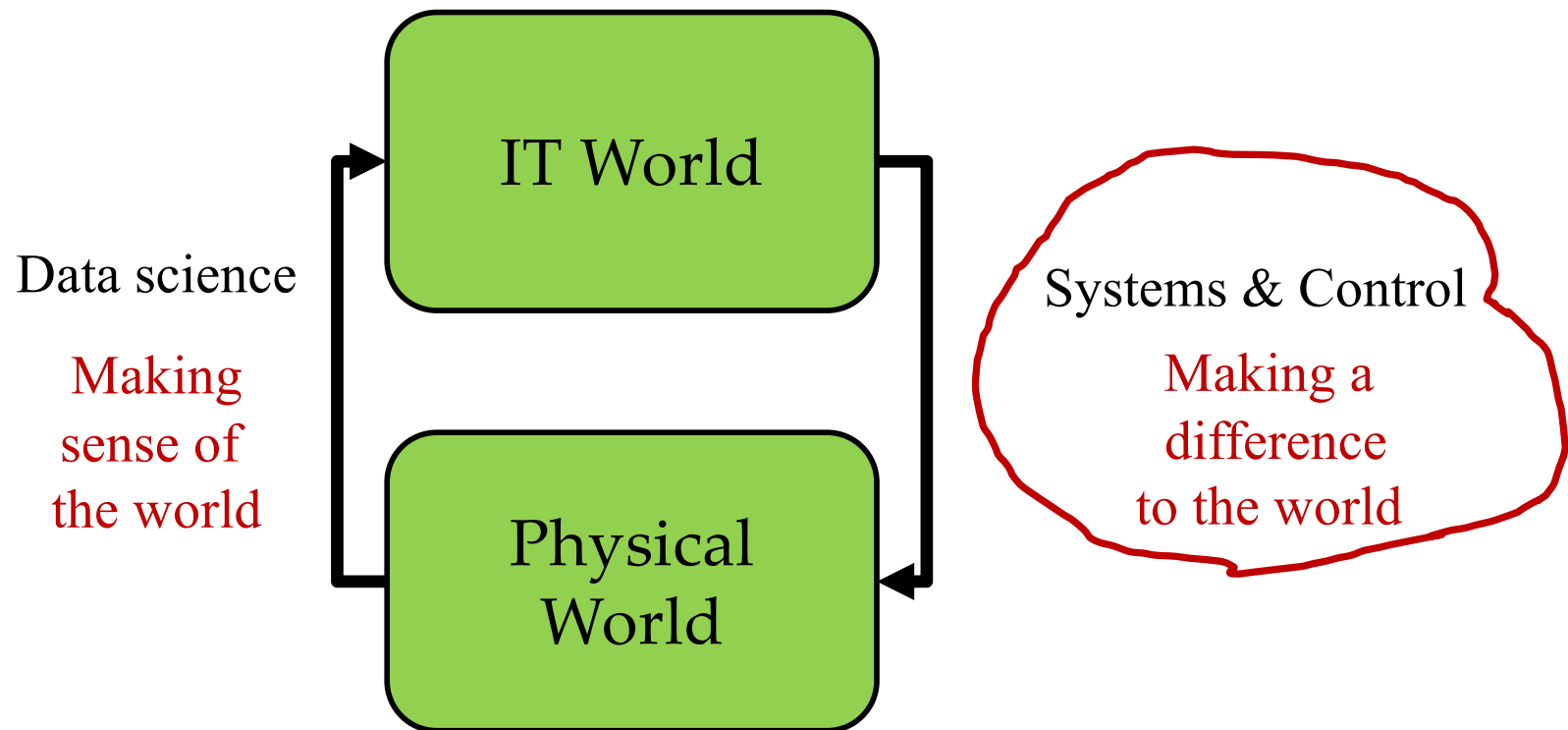
[WWW.CONTROL.ETHZ.CH](http://WWW.CONTROL.ETHZ.CH)



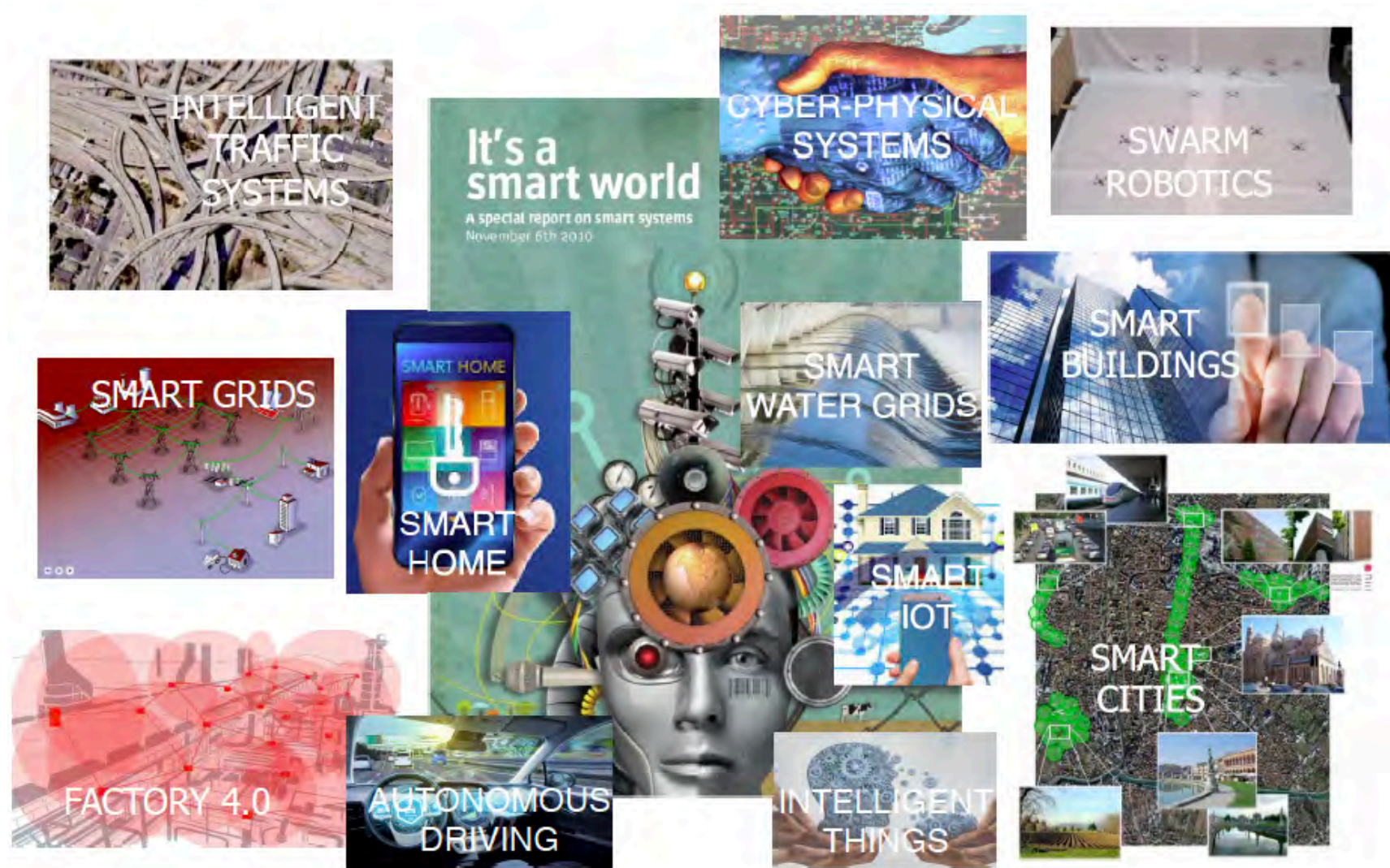
# Systems and control

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- Digitalisation, Cyber-Physical Systems, ...
- Digital world meets the physical world



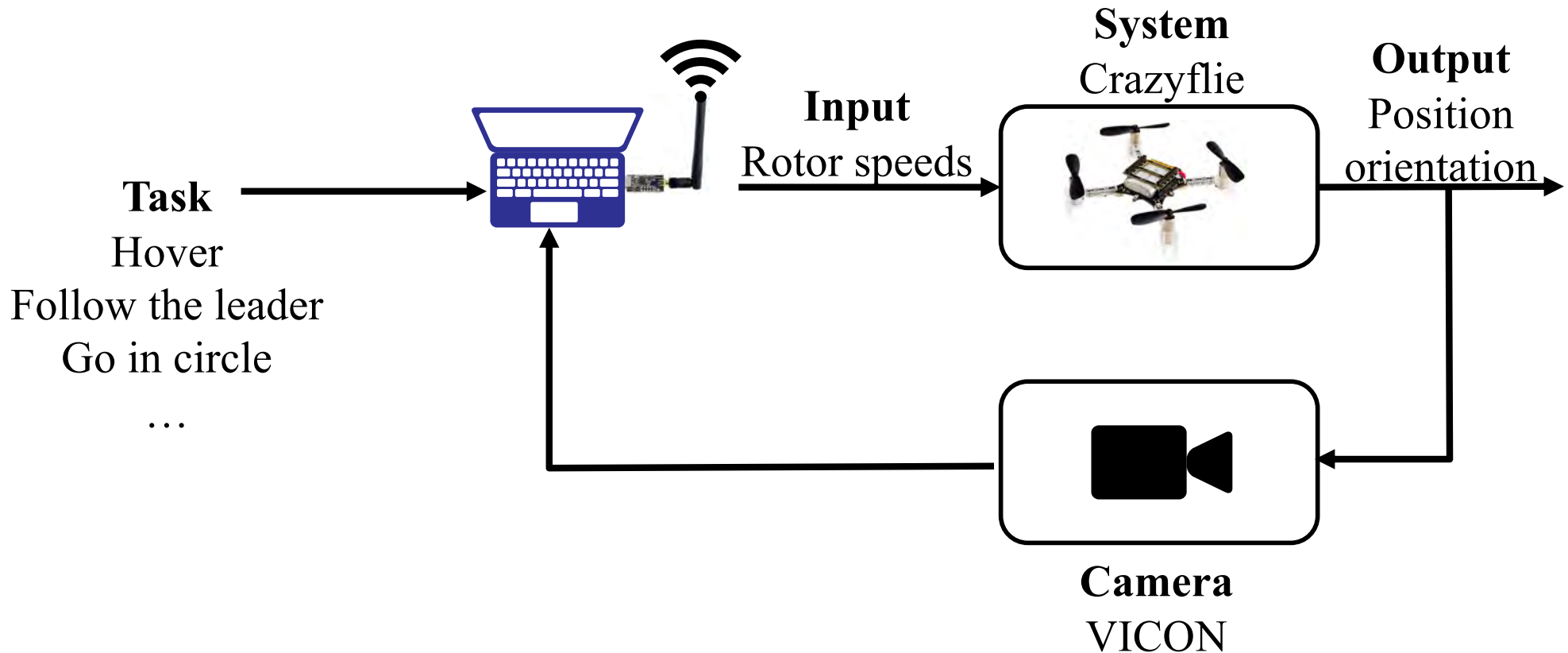
# An ubiquitous principle



Smart & Intelligent = Systems & Control

# Example: Quadrotor control

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# Control people found in many places

## At ETH

- D-ITET: Dörfler, Lygeros, Smith
- D-MAVT: D'Andrea, Frazzoli, Onder, Zeilinger
- D-BSSE: Khammash

## Recent graduates from our lab ended up in

- Industry: Engineering, automotive, power, chemical, pharma, ...
- Finance, Management Consulting, Legal services
- Founded 5 start-ups
- Became professors

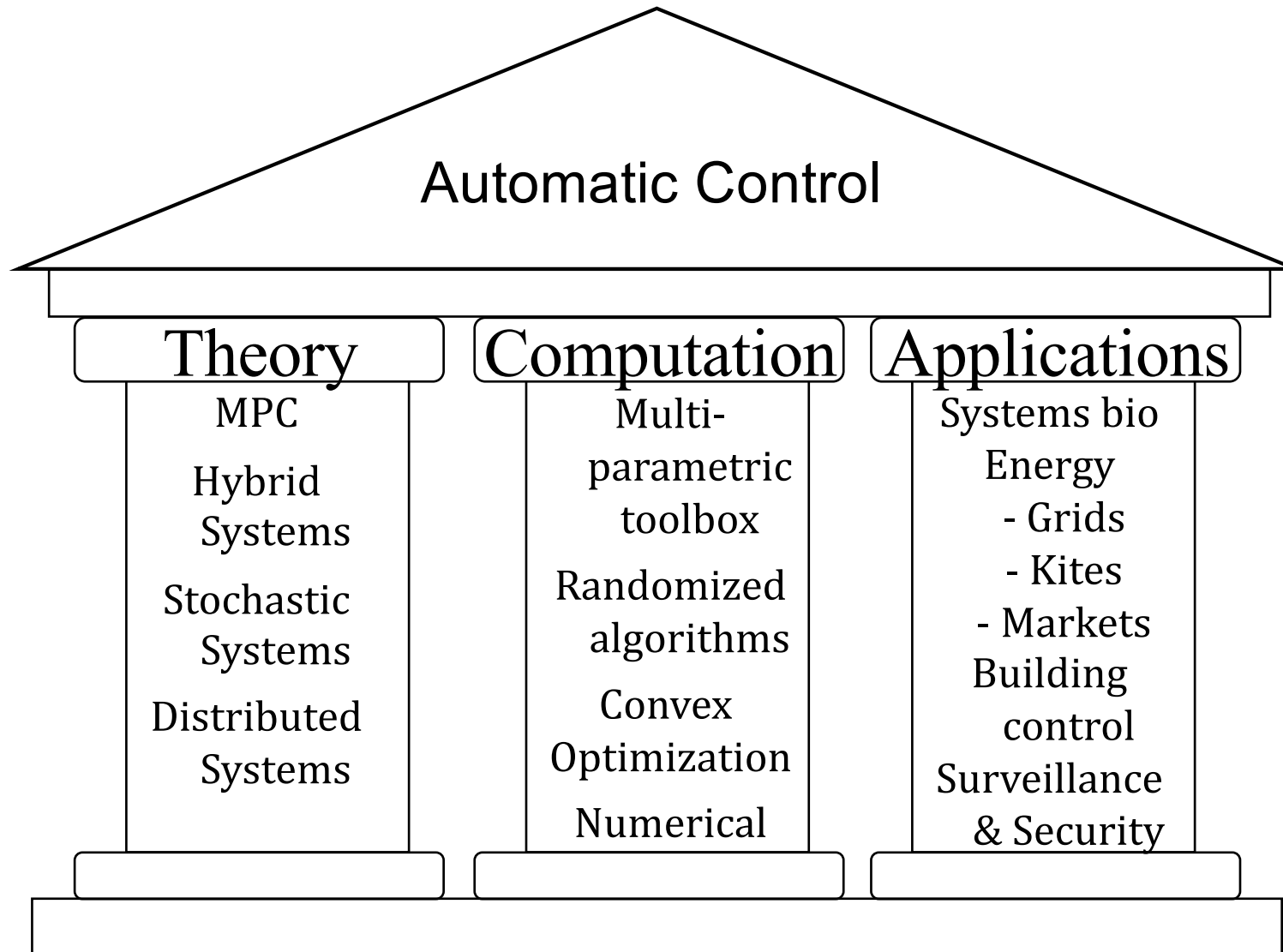
# Control people teach many courses

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## Offered at CSE

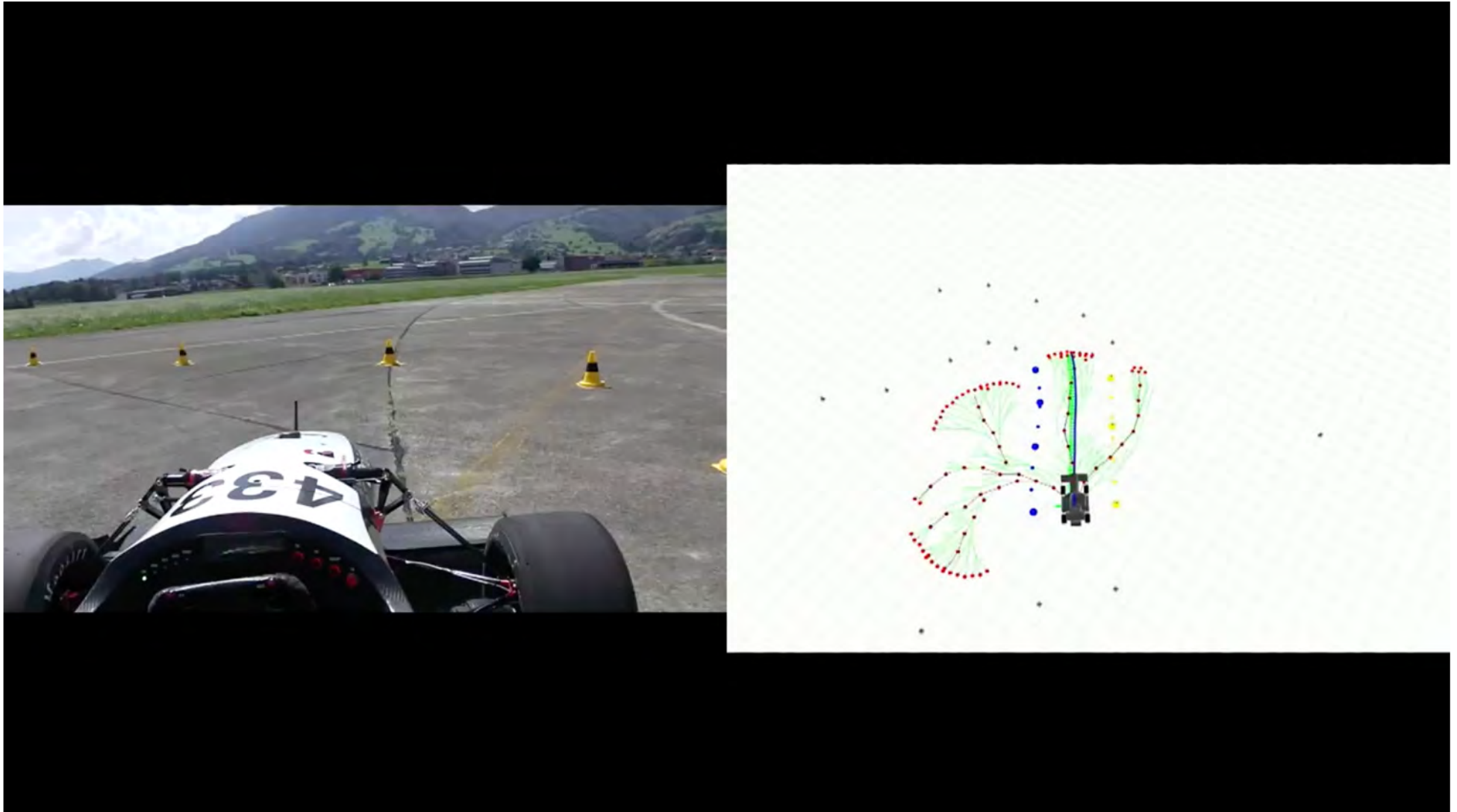
- Control Systems I (HS)
- Control Systems II (FS)
- Linear System Theory (HS)
- Signals and Systems (HS)
- Dynamic Programming and Optimal Control (HS)
- Nonlinear Systems and Control (FS)
- Machine Learning (HS)
- Advanced Topics in Control (FS)
- Seminar in Systems and Control for CSE (HS/FS)

# Control people occasionally do research



# AMZ Student Formula Team



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# How does this work?

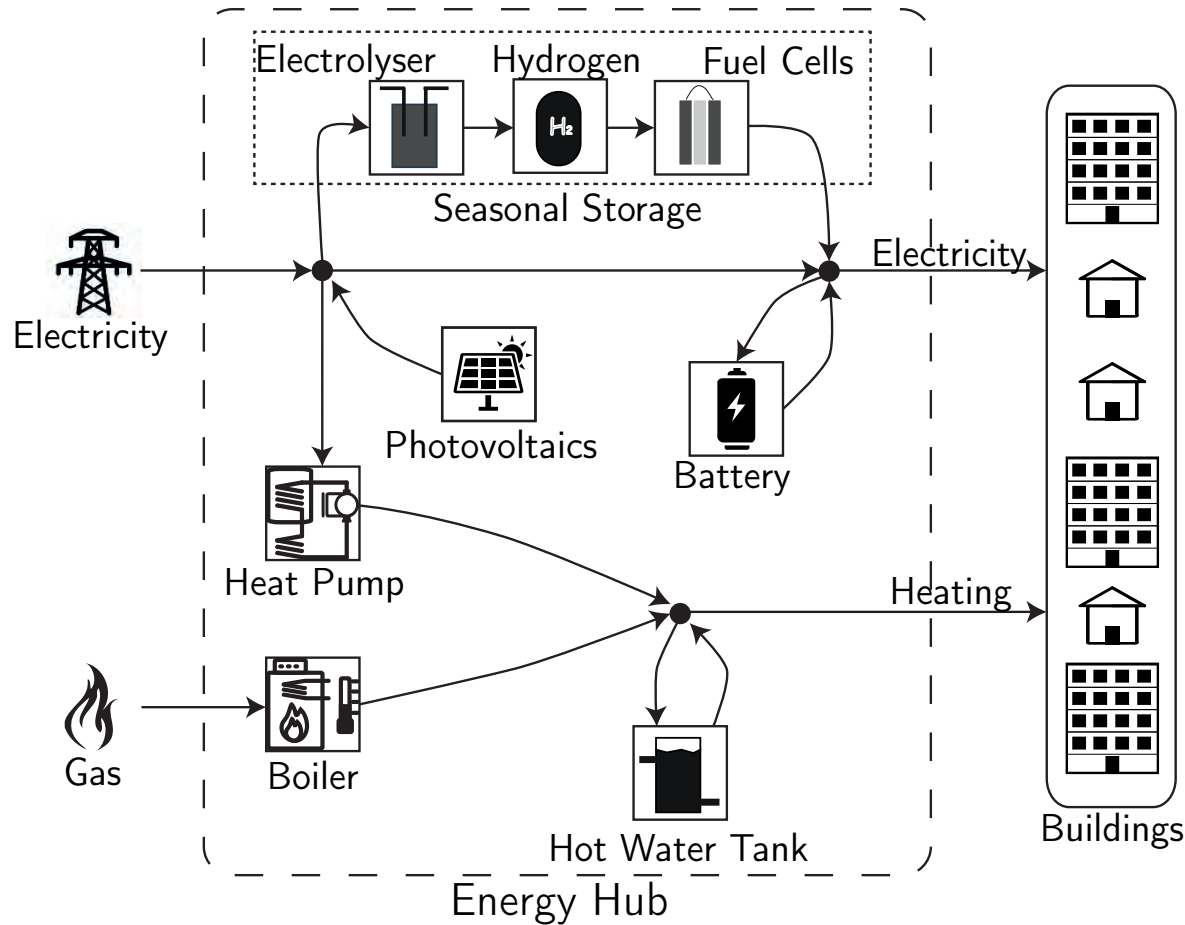
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1. Use model to predict car movement
  2. Select steering and acceleration for next 400ms
    - So that car stays inside the track and
    - Maximises progress/goes ahead of opponent
  3. Apply first 20ms of this selection to the car
  4. Measure what happened  Feedback
  5. Repeat
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- Infinite choices, cannot possibly check them all
- Real time optimisation to the rescue

**Receding Horizon or Model Predictive Control**

# Control of energy hubs

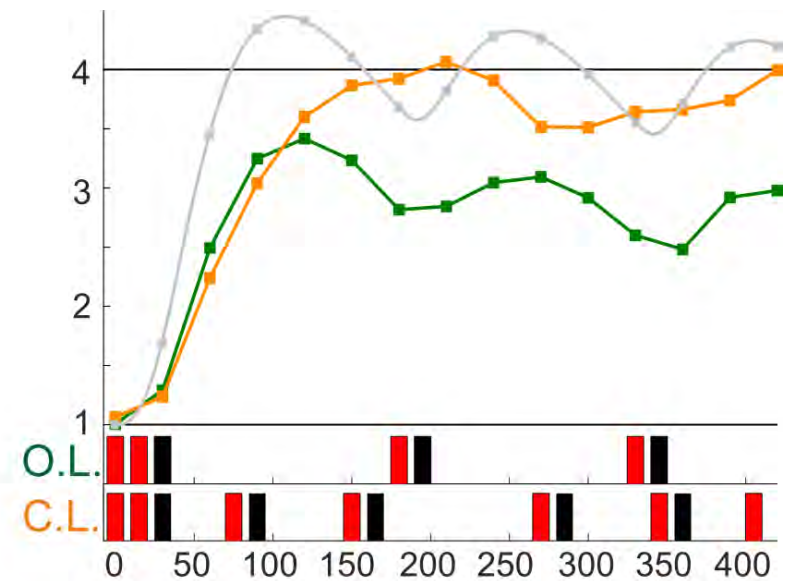
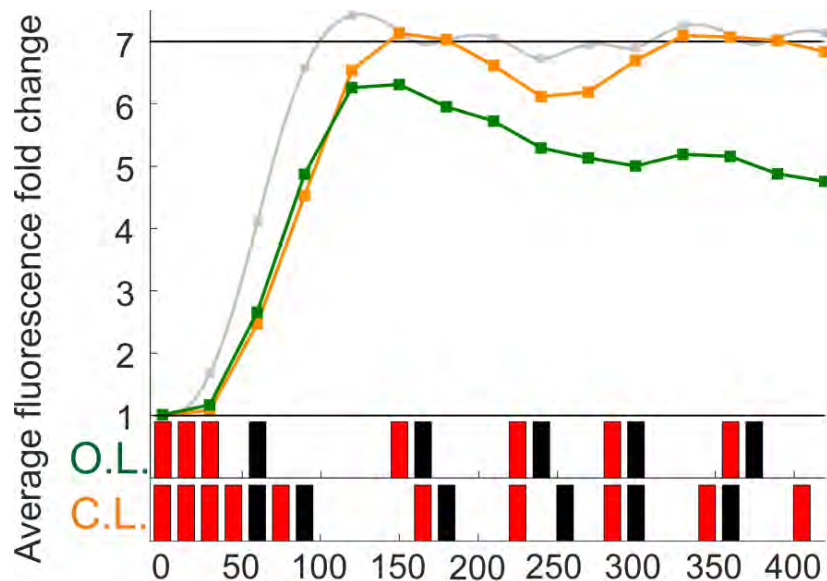
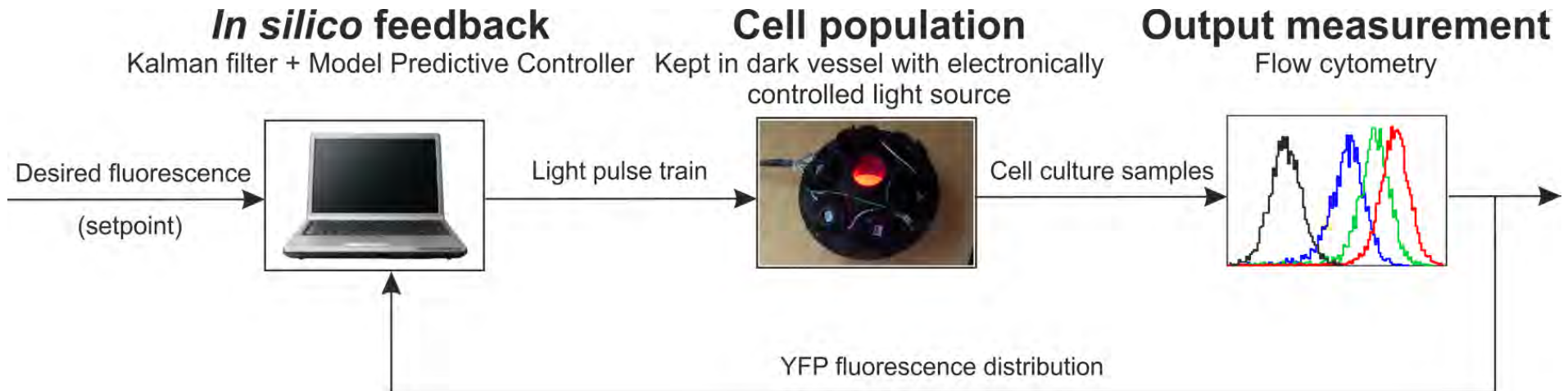


## Operational decisions

- Do I buy or sell energy?
- Do I store energy?
- Where?
- ...

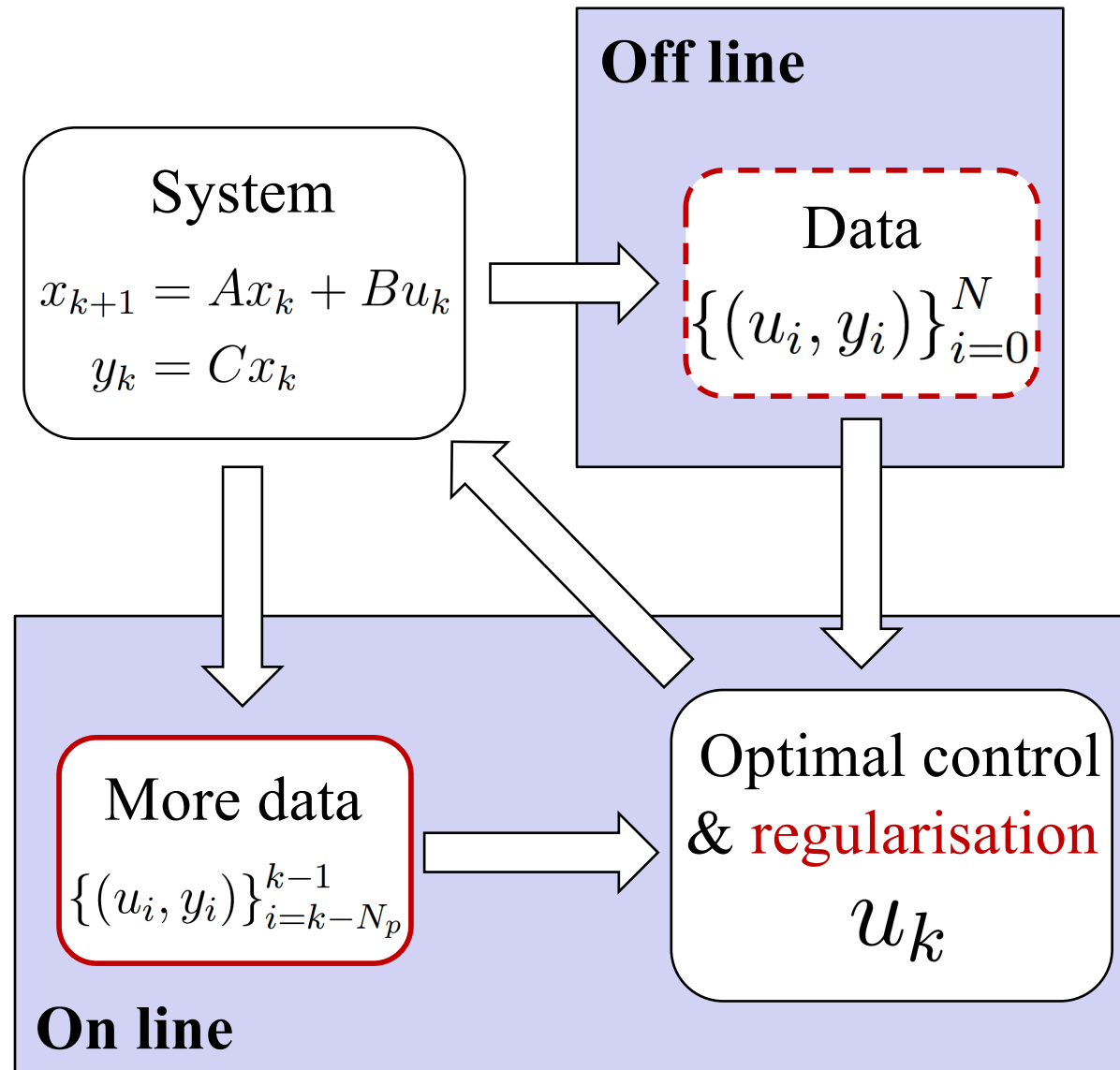
Require forecasting  
Complex feedback!

# In silico feedback in biology



Time (min)

# Data based optimal control



# Data based dynamic programming

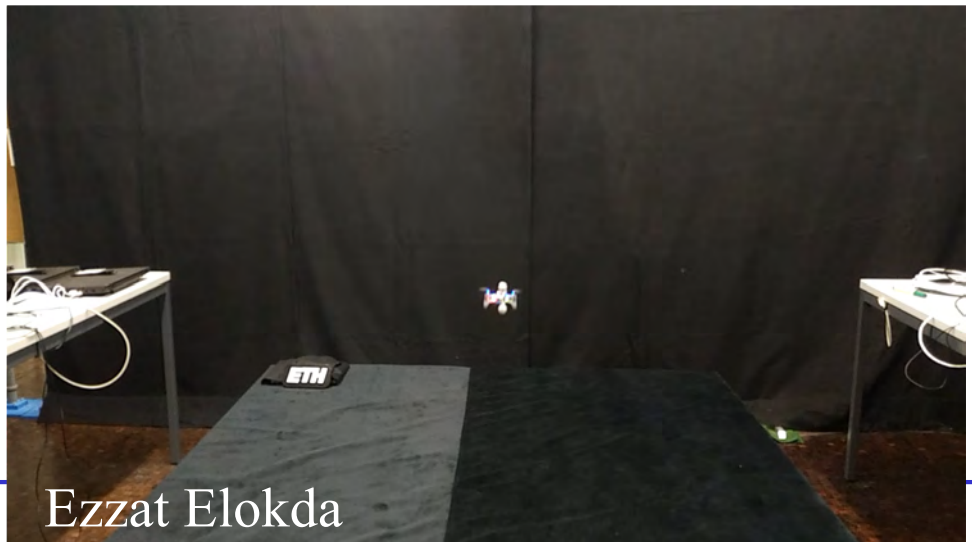
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- Value function or Q-function characterisation
  - Fixed point of nonlinear operator
- Through solution of linear program
  - Decision variables in space of functions
  - Robust constraint in state-action pairs
- Elegant and theoretically powerful, but
  - Infinite number of decision variables
  - Infinite number of constraints
- Try to use for computation
  - Approximation guarantees?
  - Basis for data driven approximation?

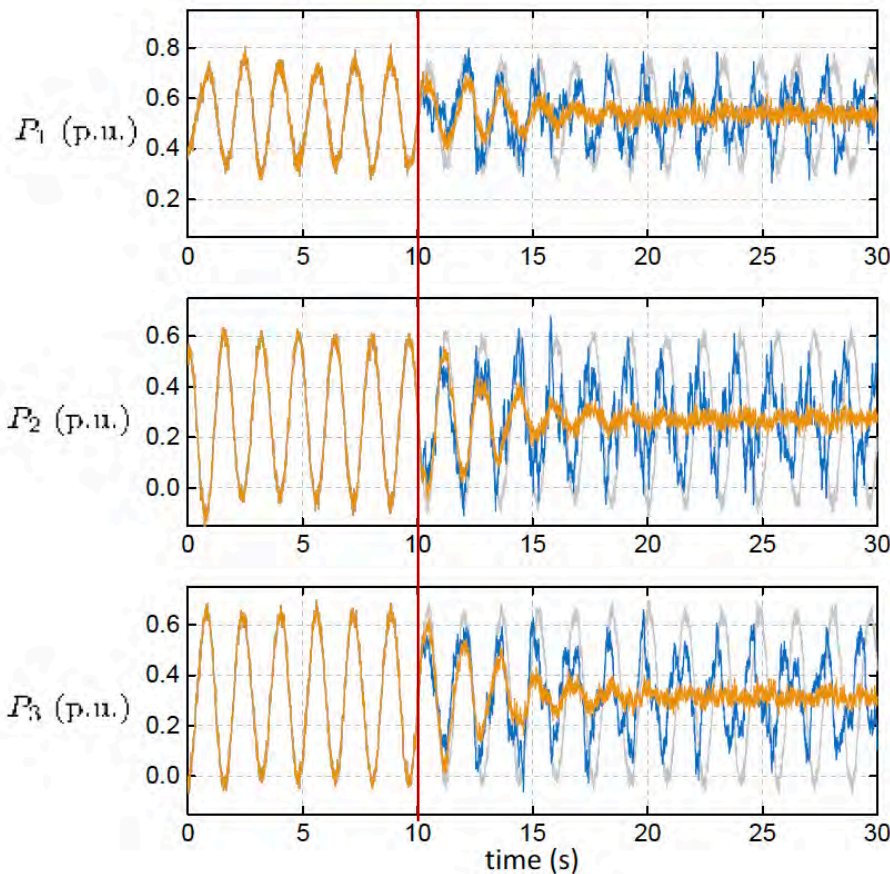
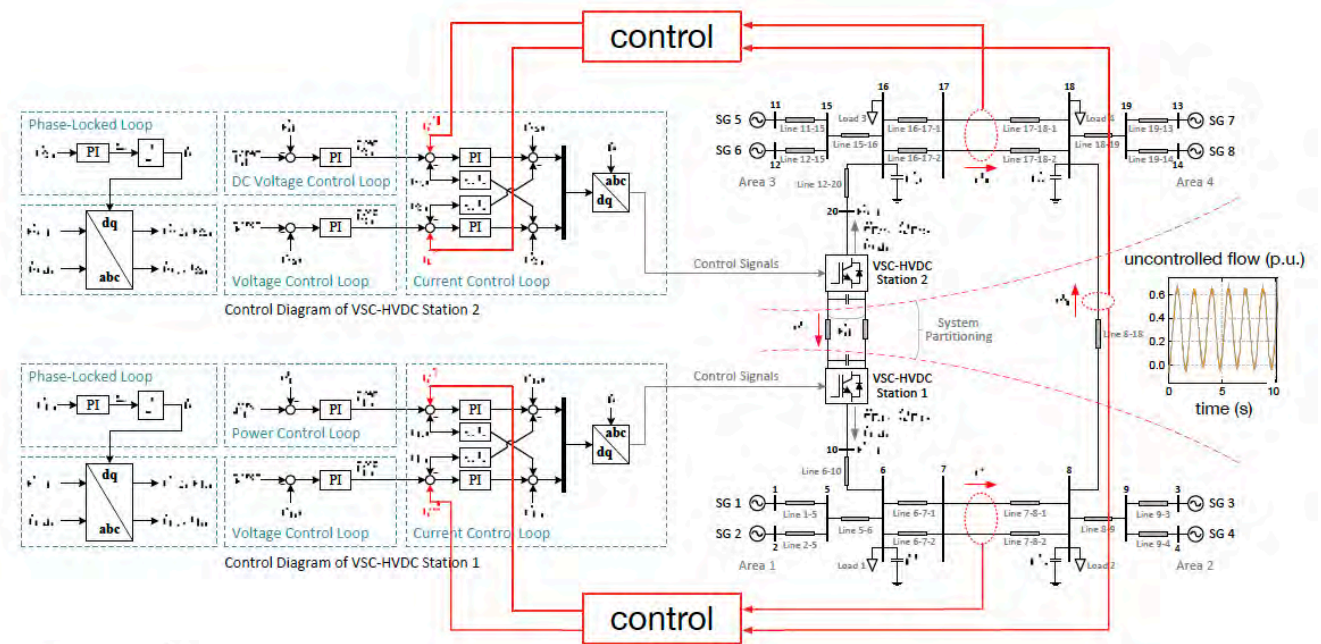
# Data Enabled Predictive Control

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- Data Enabled Predictive Control
  - Replace model constraint in MPC ...
  - ... with subspace constraint based on data matrix
- Behavioural system theory
  - Equivalent to MPC for ideal LTI systems
- With regularisation also works with noise, nonlinear systems ...
- Applications to
  - Quadrotors
  - Power systems
  - Building control



# Power system



- Power grid with HVDC
- Control set points of low level controllers
- Based on data from realistic nonlinear simulator
  - Grey uncontrolled
  - Orange: DeePC
  - Blue SysID+MPC