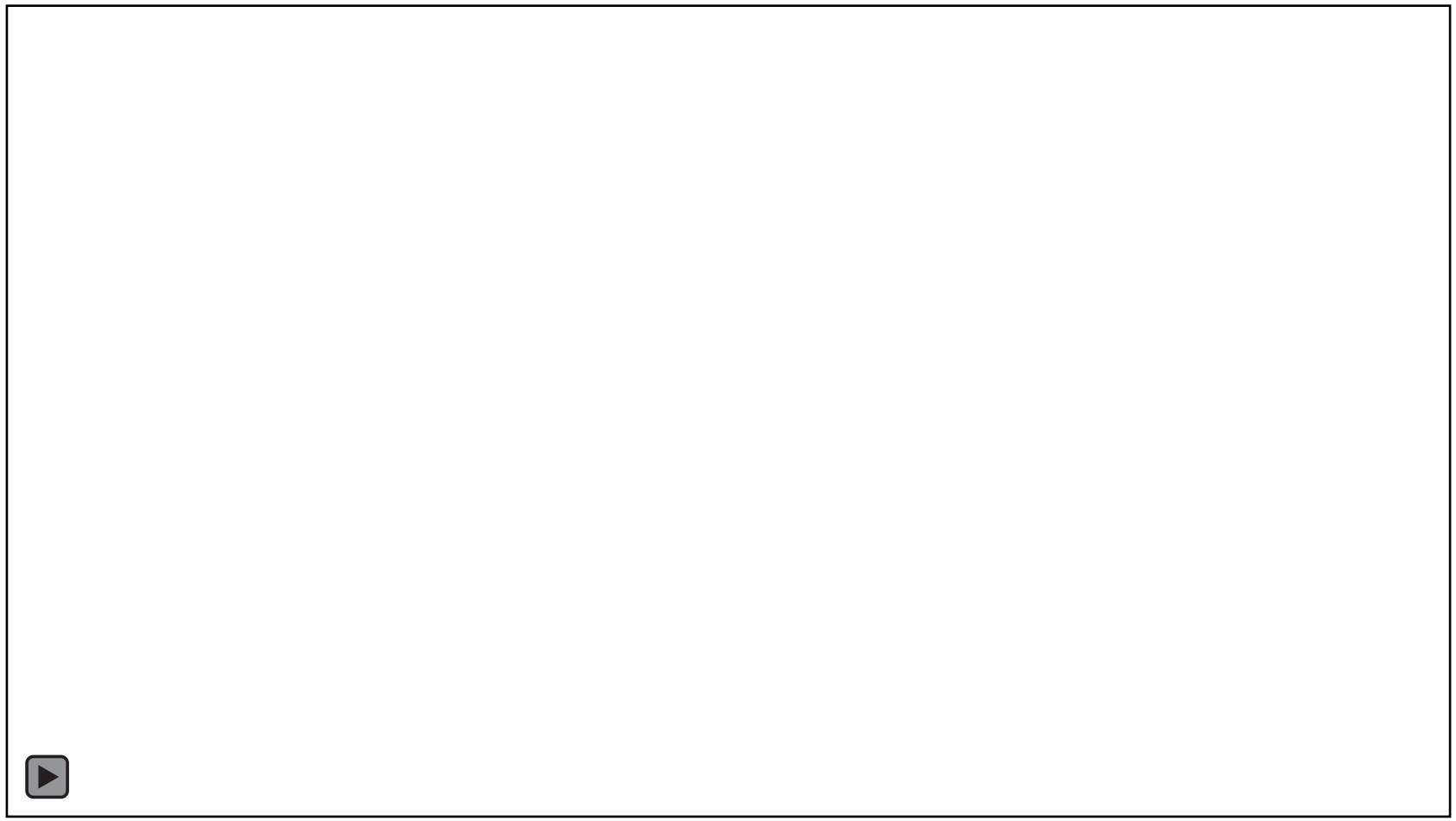
Everything under Control?

Prof. Paul M.J. Van den Hof

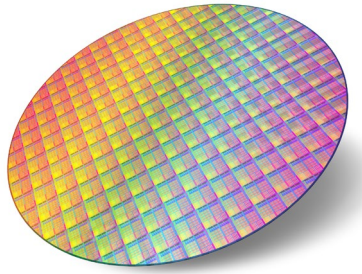
TU/e

ASML lithography machine



ASML lithography machine

BRAINPORT EINDHOVEN

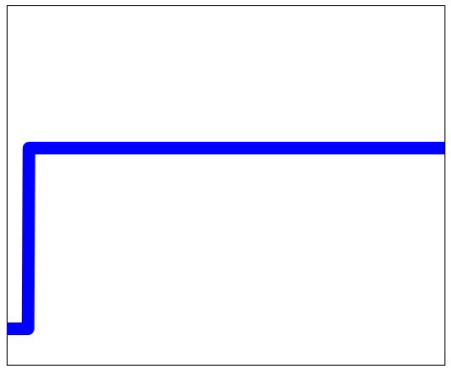


waferworld.com

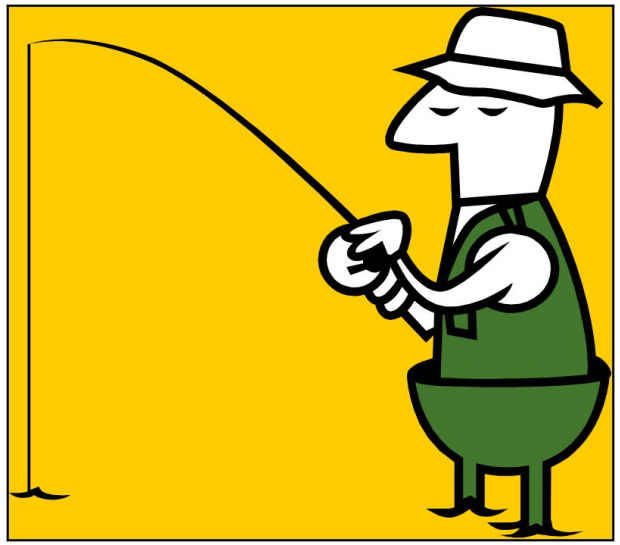
TU/e

What is control?

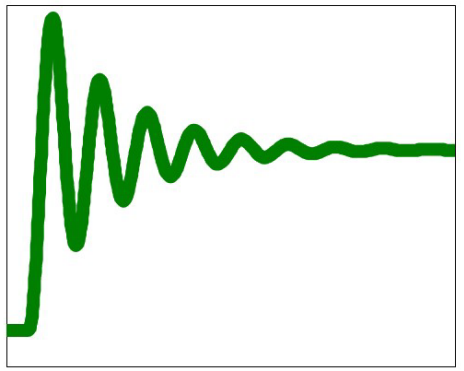
Hand position



time



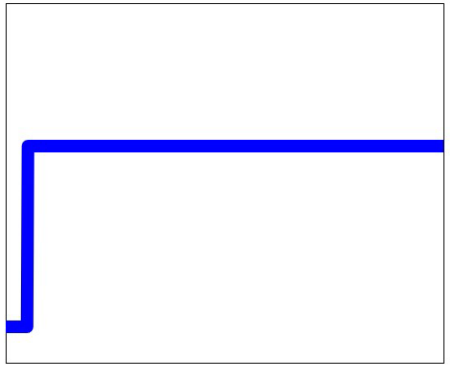
Tip position



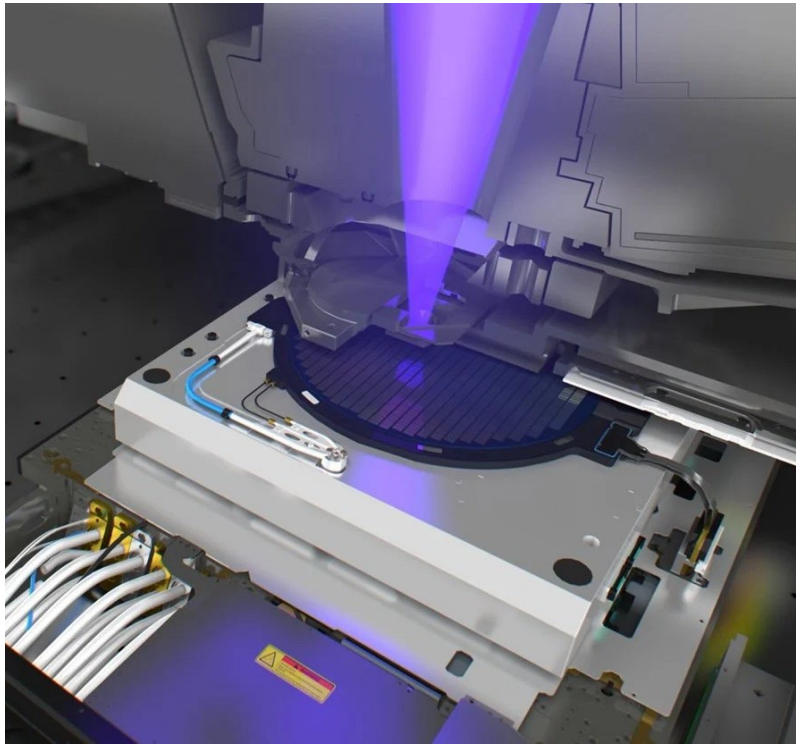
time

What is control?

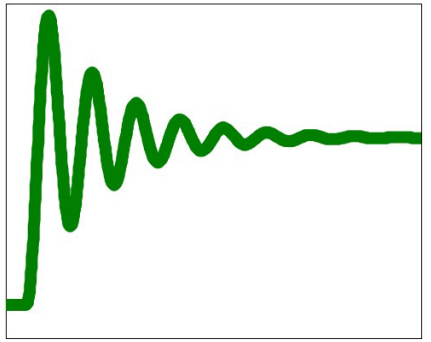
force



time

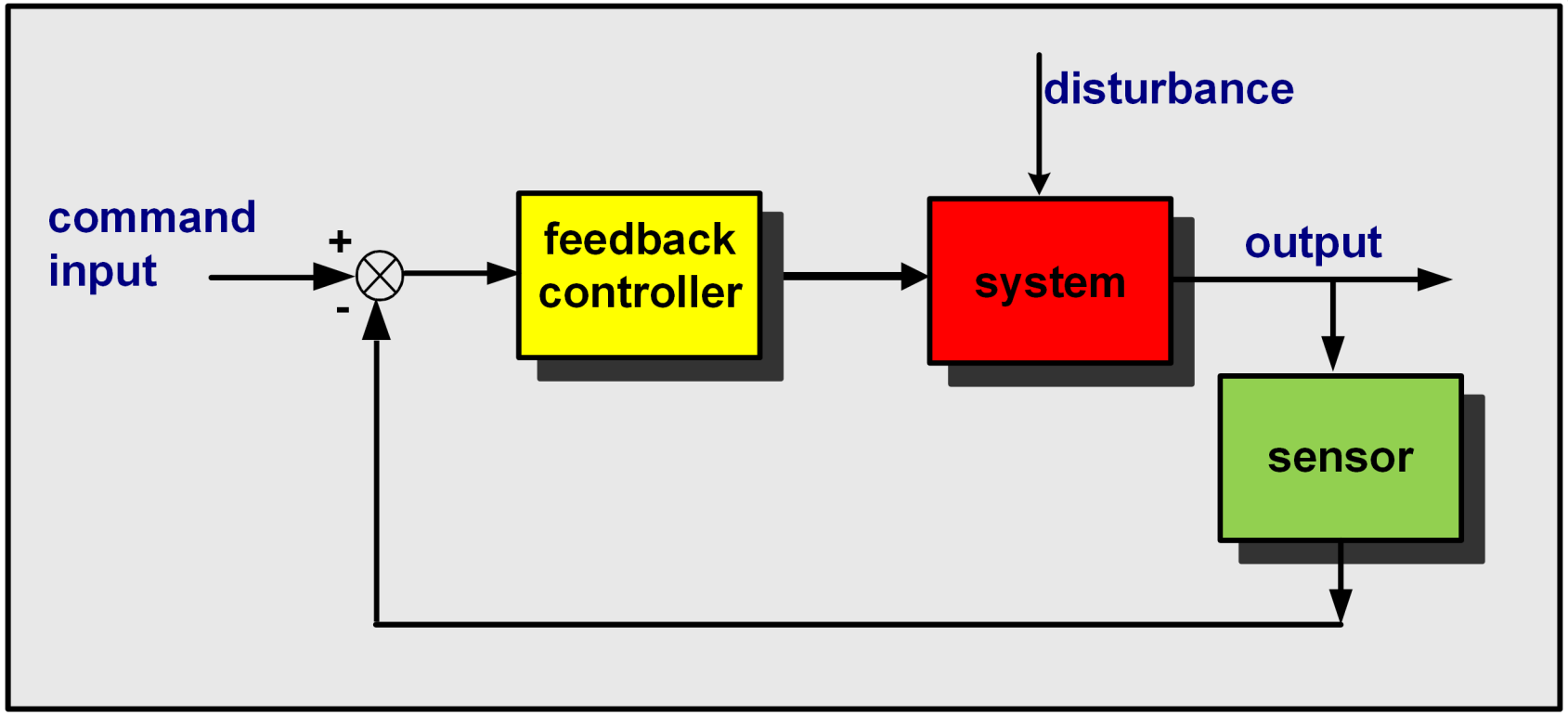


position



time

What is control?

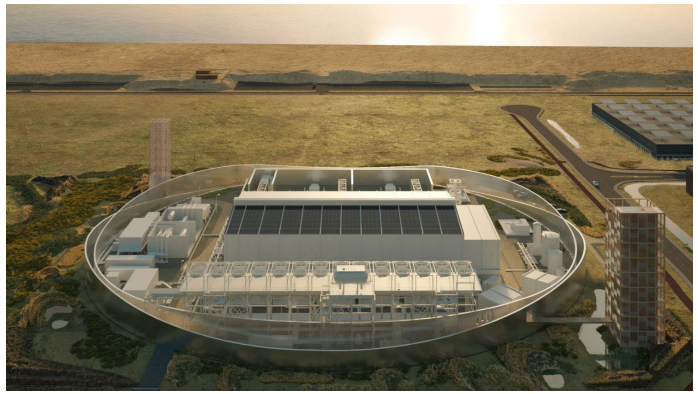


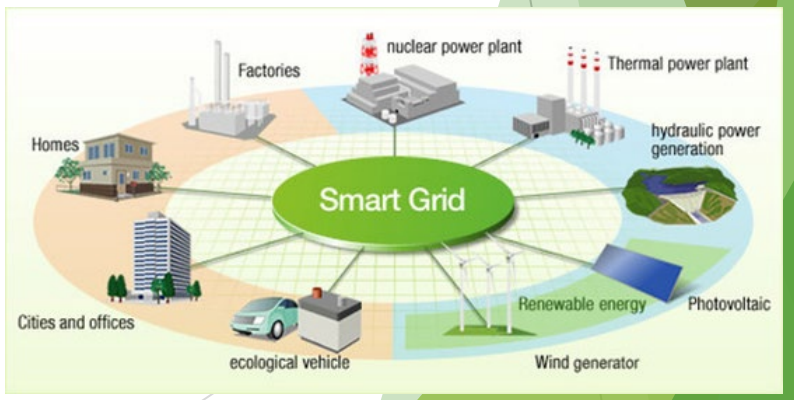
What is control?

Through feedback control, systems can be given a performance, beyond the accuracy specs of their physical components[1]

and become robust against disturbances

And this applies to systems in any domain of science and engineering:

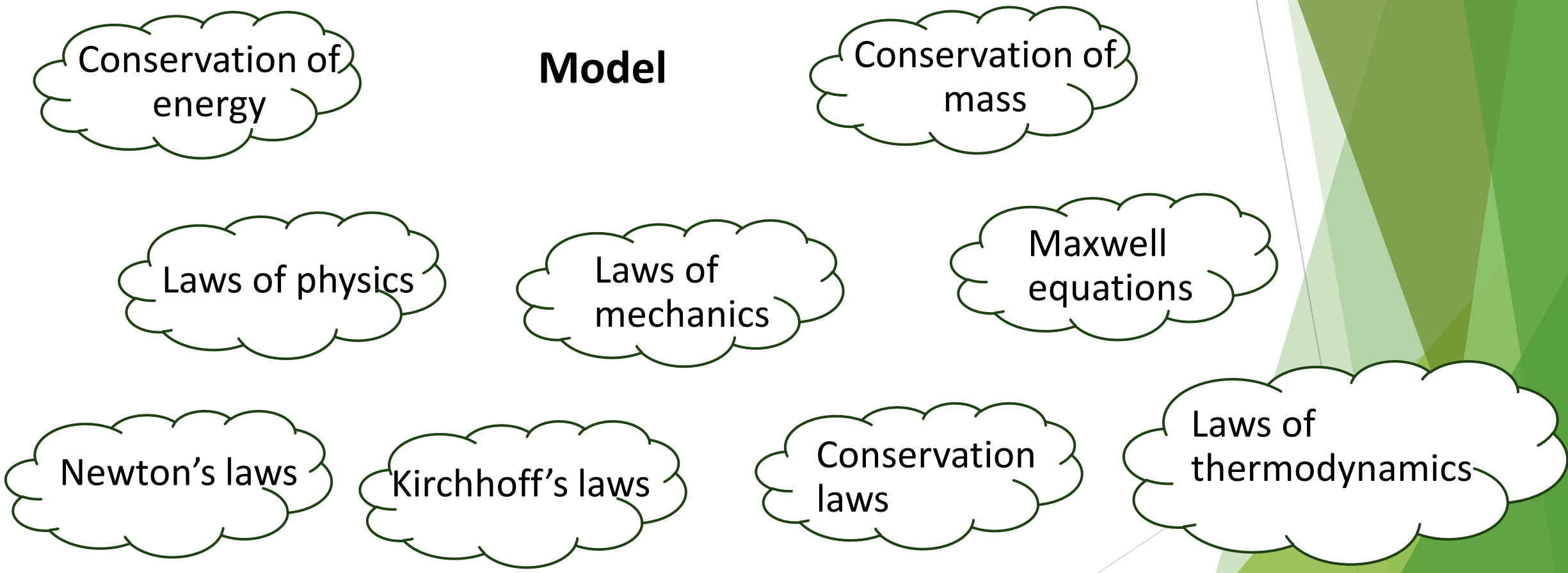




[1] R.M. Murray et al., 2003.

Models

How does the system respond to inputs?



Models

How does the system respond to inputs?

Model

Laws of mechanics

Conservation of mass

Kirchhoff's laws

Conservation laws

Conservation of energy

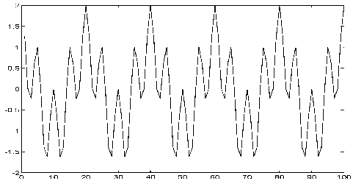
Maxwell equations

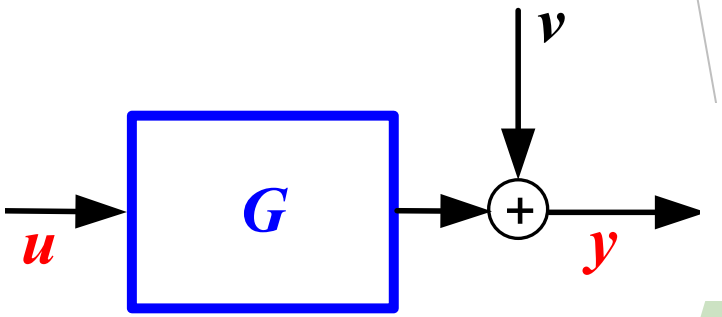
Laws of physics

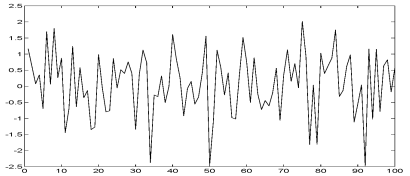
Laws of thermodynamics

Newton's laws

Data







System identification

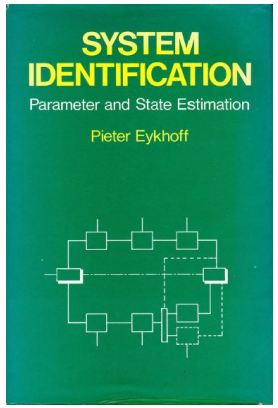
Mathematical model

TU/e

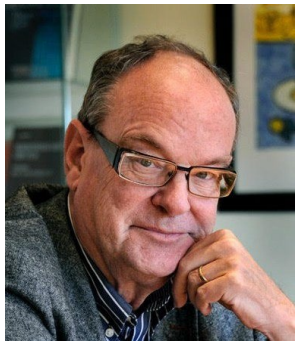
Models

How does the system respond to inputs?

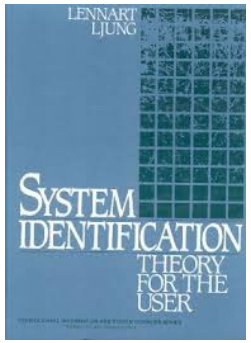
Pieter Eykhoff



1974



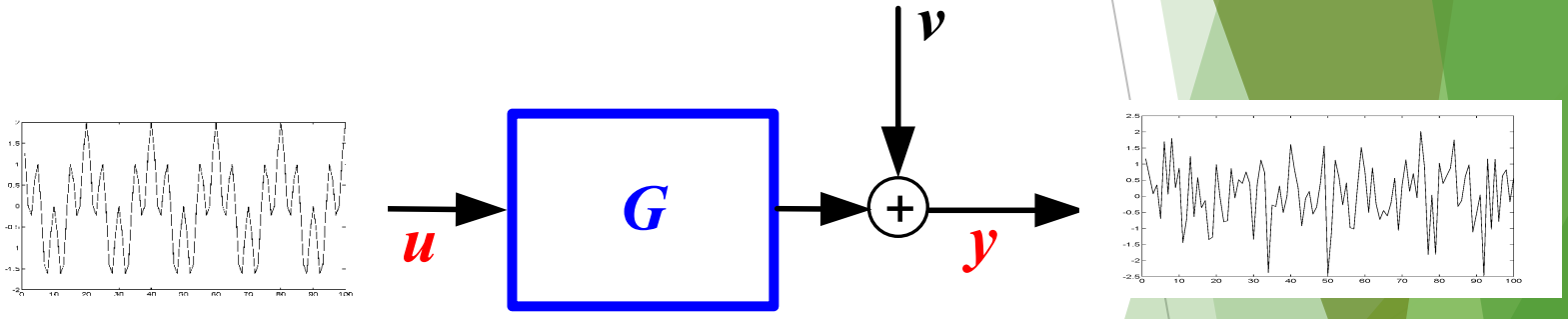
Lennart Ljung



1987

Model

Data



Machine learning

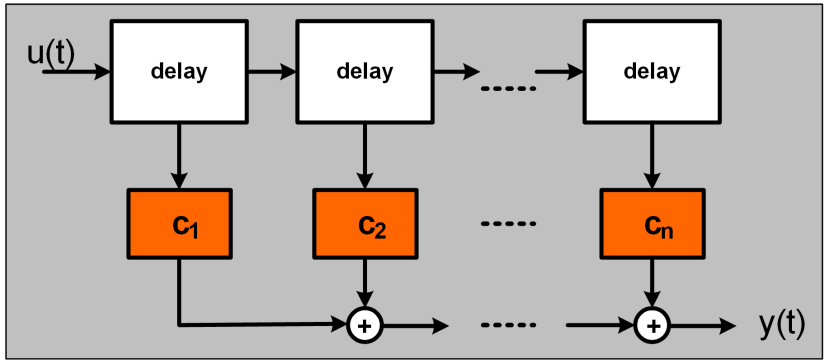
Mathematical model

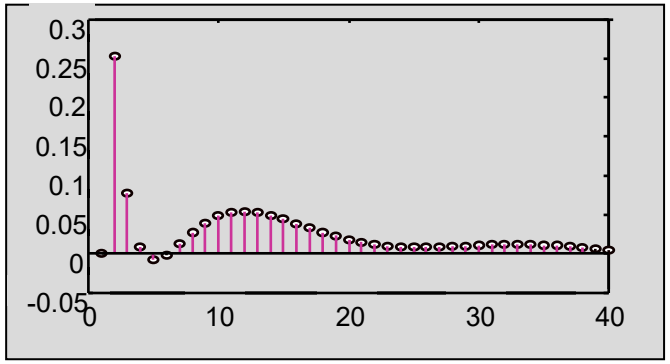
TU/e

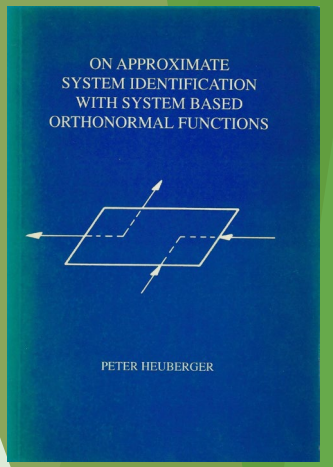
A selection of research programs

Orthogonal basis functions

Finding an attractive model structure, to represent systems with only a small number of unknowns (parameters)



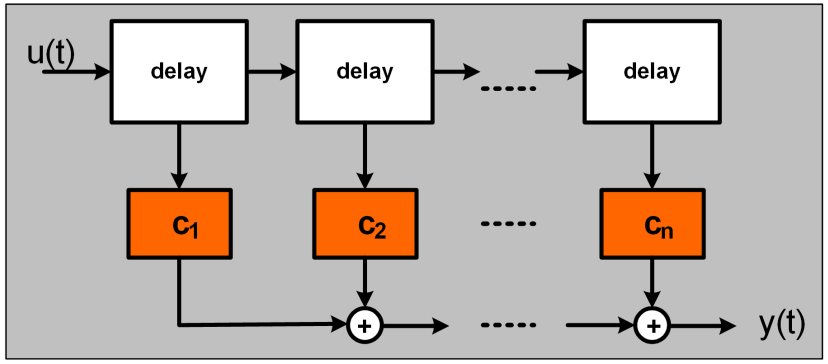


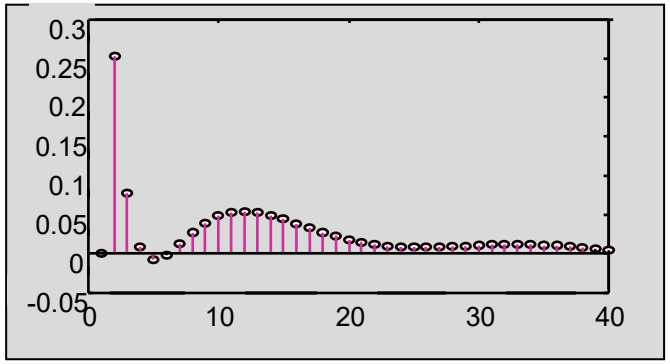


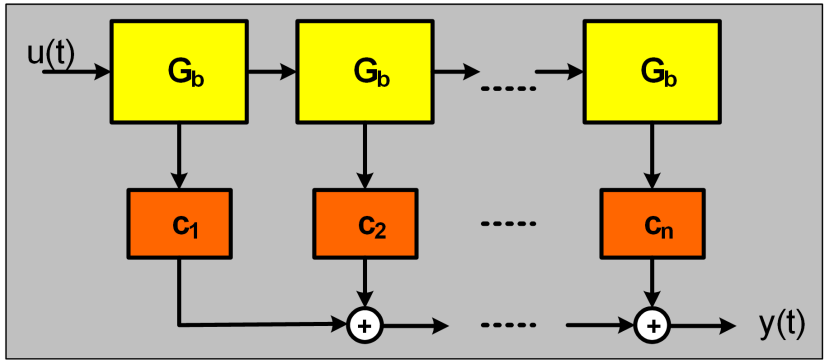
PhD Thesis
Peter Heuberger, 1991

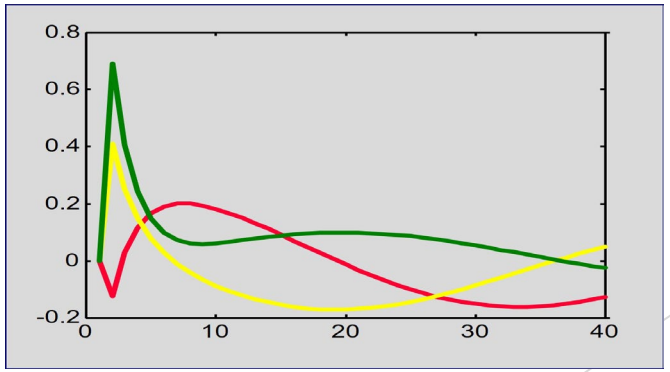
Orthogonal basis functions

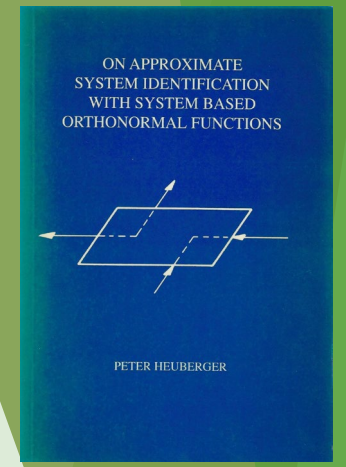
Finding an attractive model structure, to represent systems with only a small number of unknowns (parameters)



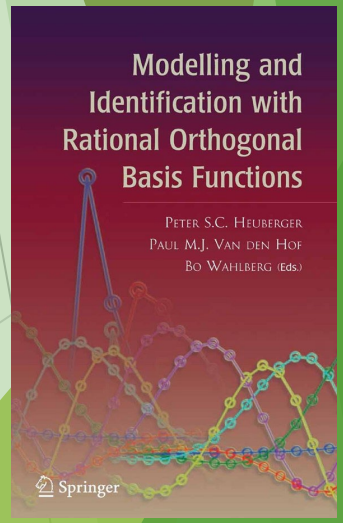






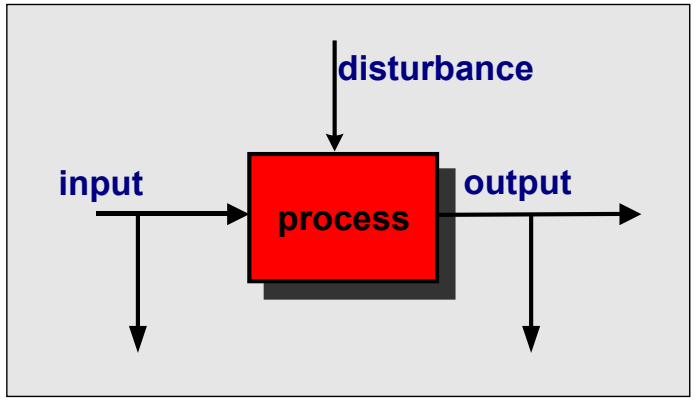


PhD Thesis
Peter Heuberger, 1991



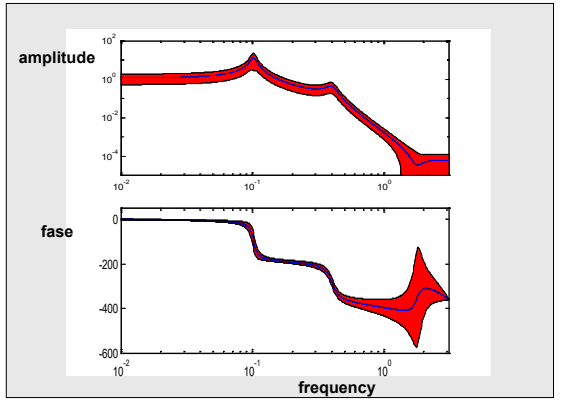
Springer, 2005

Identification for control (1990 - …)



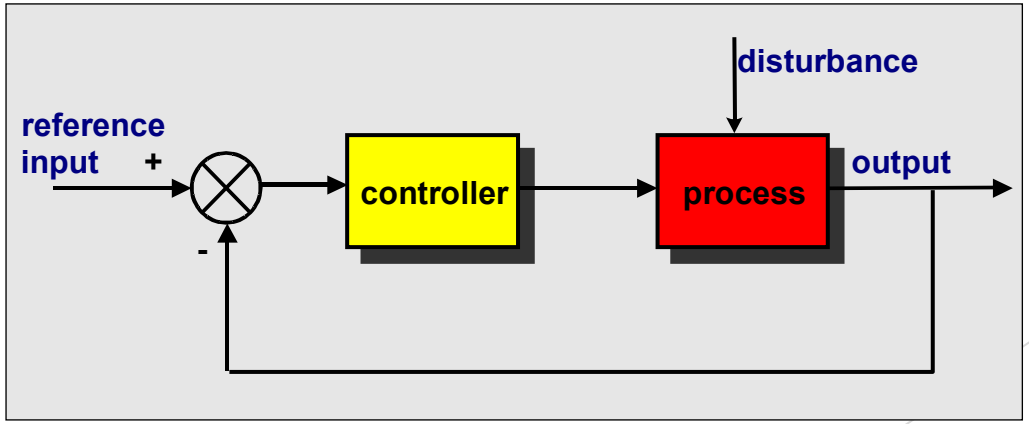
Identification

Data ⟶ Model



Model ⟶ Controller

Feedback control system

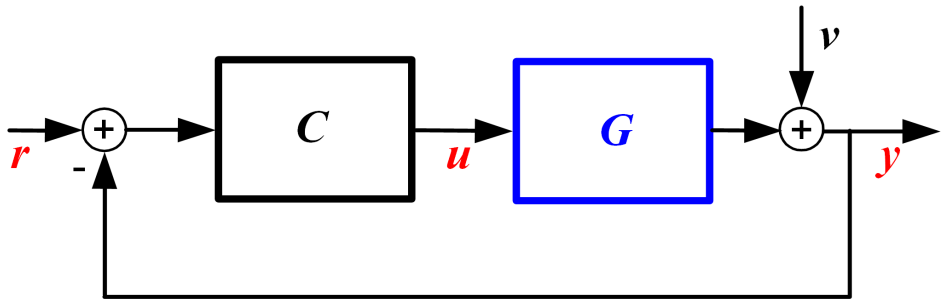


Identification for control

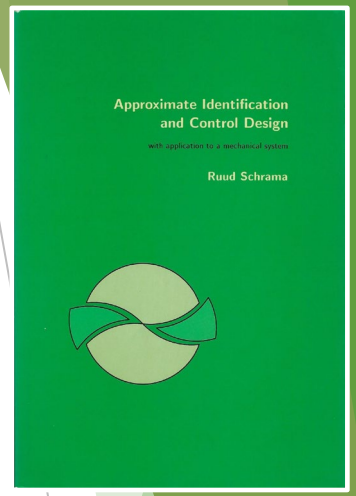
- Question:

How to identify models that are best suited for model-based control ?

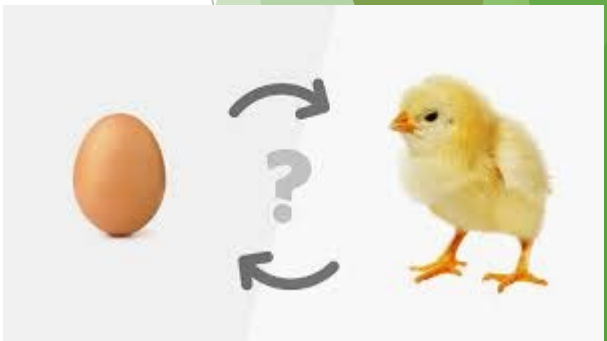
- Prime result:



Under closed-loop control of the to-be-designed controller



Ruud Schrama
1992



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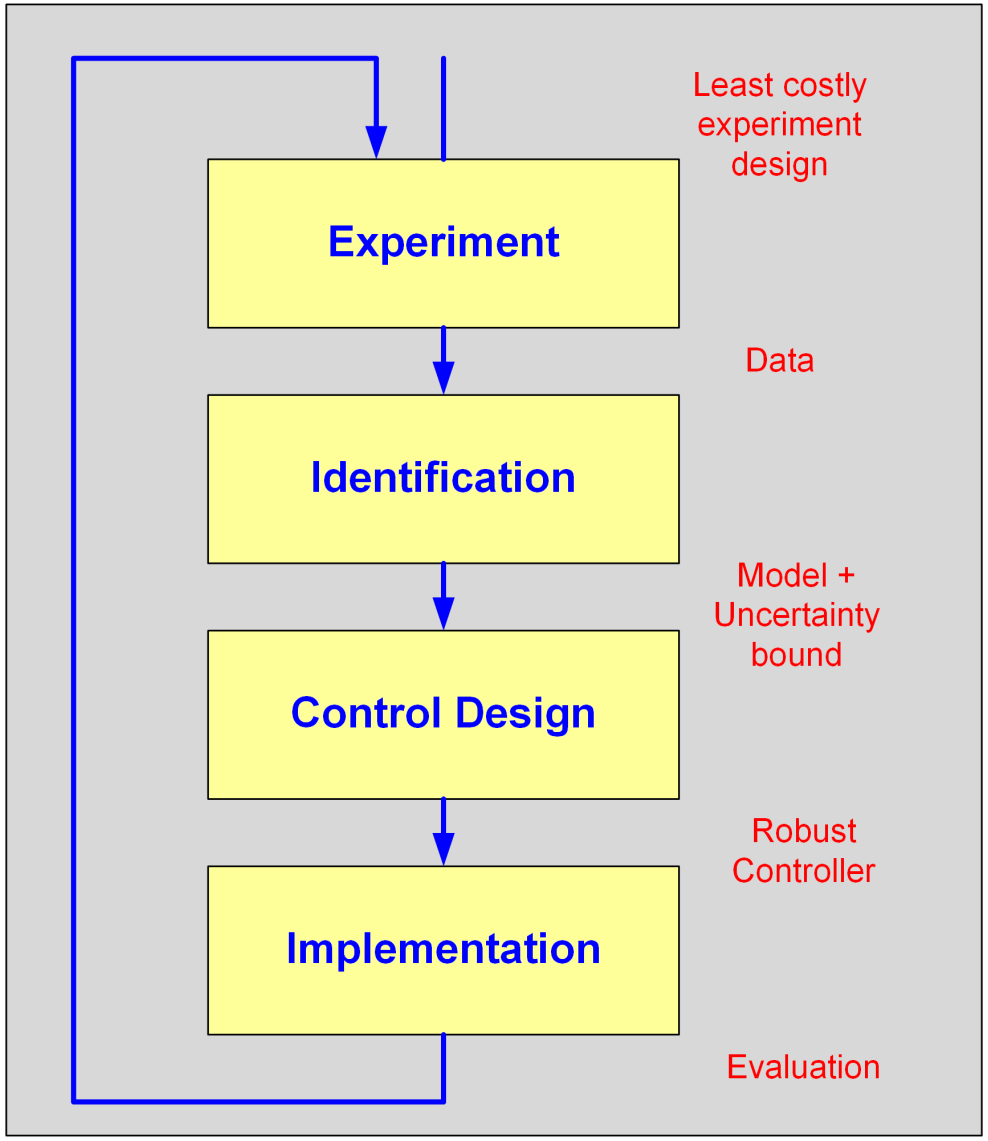
Identification for control



Solution through iterative procedure

Modelling for control is learning

Modern version of adaptive control

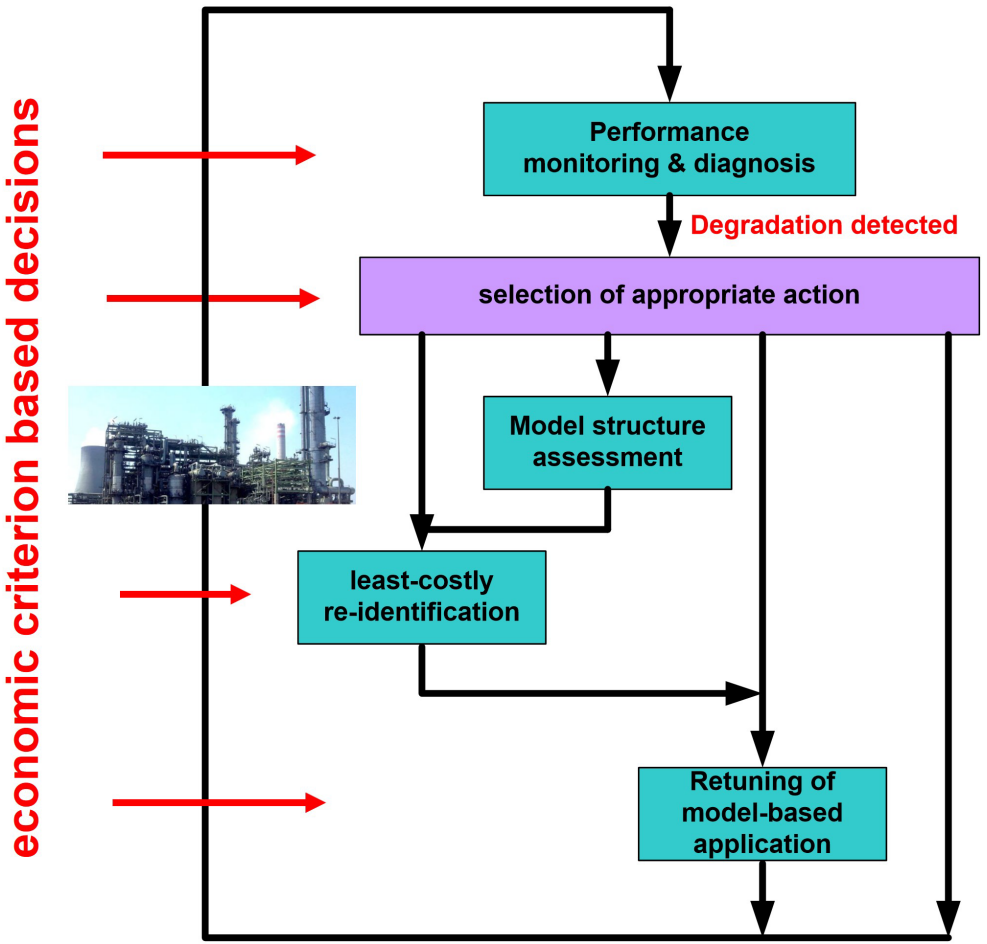
Identification for control

Challenge:

Bring industrial process controllers to a higher level of autonomy, through effective use of online data and model / controller updating

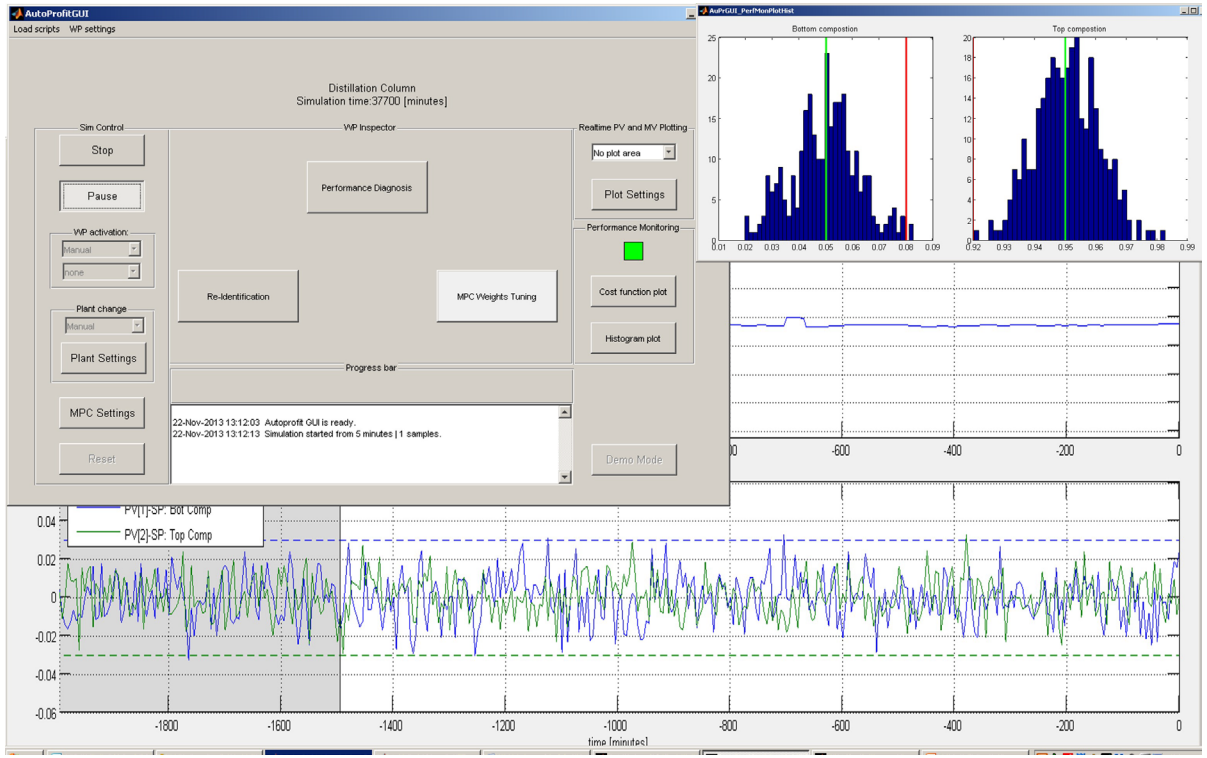
EU FP7 STREP 2010-2013

Identification for control



Autonomous maintenance loop for linear model-based operation

Identification for control



Sasol site Secunda,
South Africa

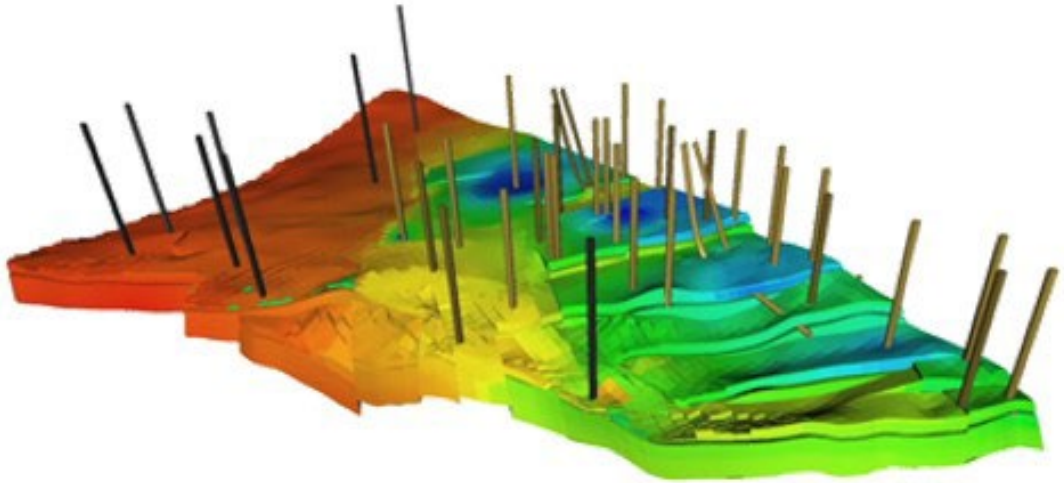
Identification for control

No continuation after 2014

Reservoir Engineering (2002-2018)

Joint effort:

- TUD Systems & Control
- TUD Applied Earth Sciences
- Shell



THE VALUE OF SMARTNESS

ISAPP

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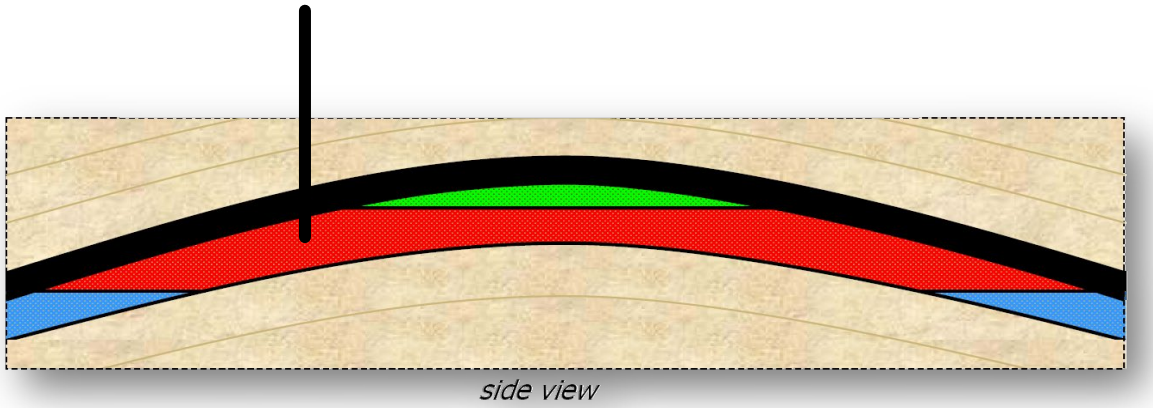
Oil Production

- Porous rock with oil in pores
- 1 – 10 km underground



side view

cap rock
water bearing reservoir rock
non- reservoir rock
oil bearing reservoir rock
gas bearing reservoir rock

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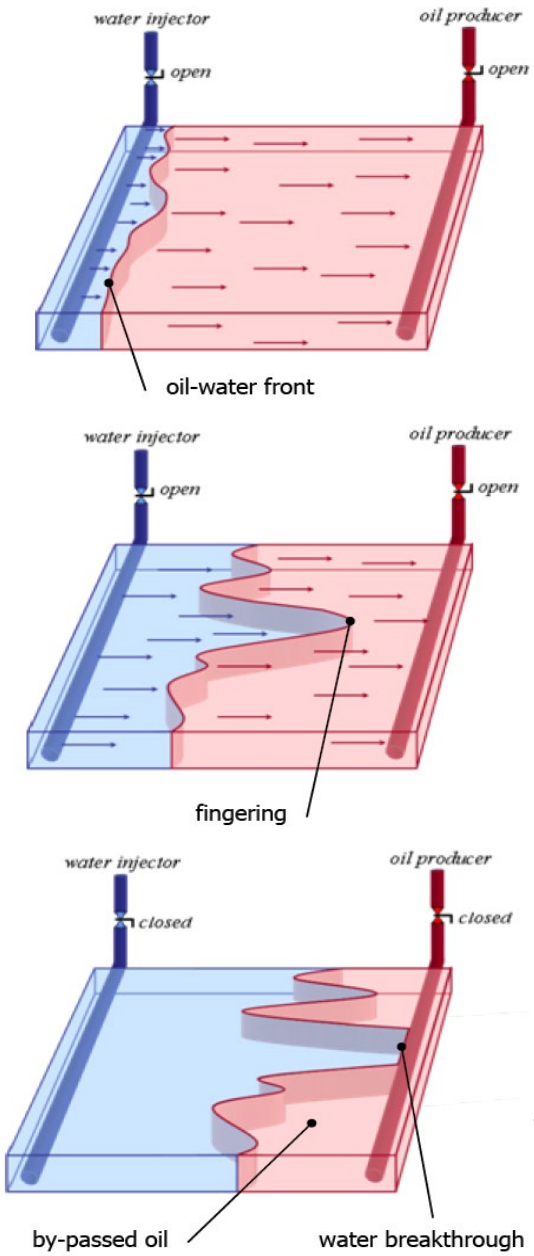
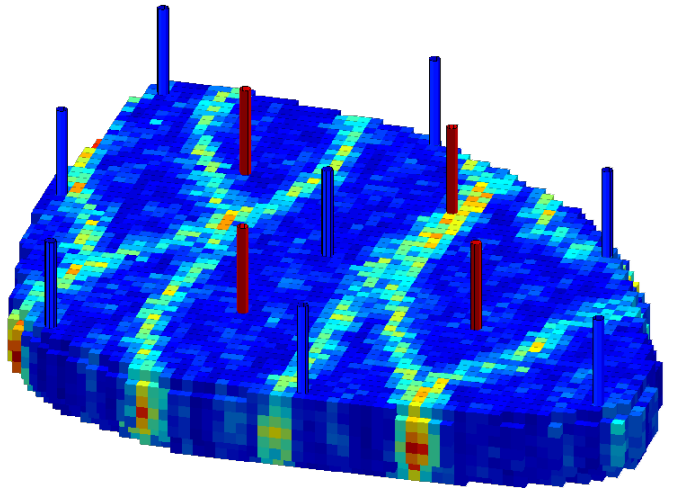
Oil Production

- Waterflooding (WF) popular secondary recovery process
- Smart wells have sensors and control valves
- Life time of reservoir in the order of decades
- Lack of smart operational strategy



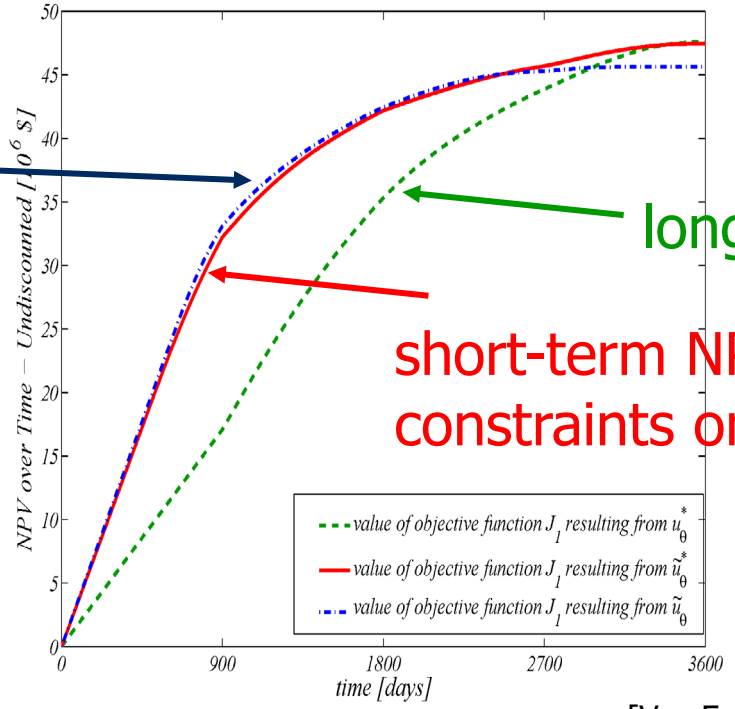
Reservoir characteristics

- heterogenity of reservoir
- flow dynamics determined by geological structure (permeability)



(Gijs van Essen et al., CAA 2006)

reactive



long term NPV

short-term NPV under constraints on long-term NPV

[Van Essen et al, SPE J, 2011]
IFAC 2012

- Decision making under geological and economic uncertainty
- Online improvement of geological models

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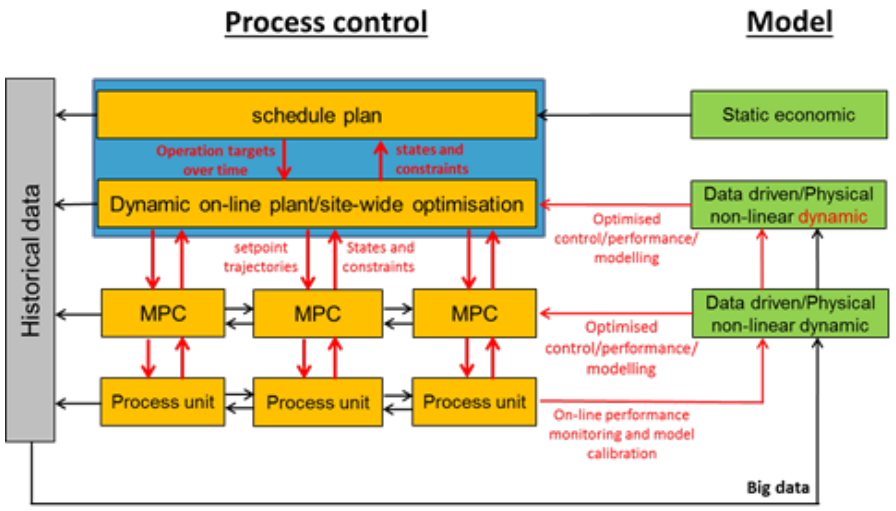
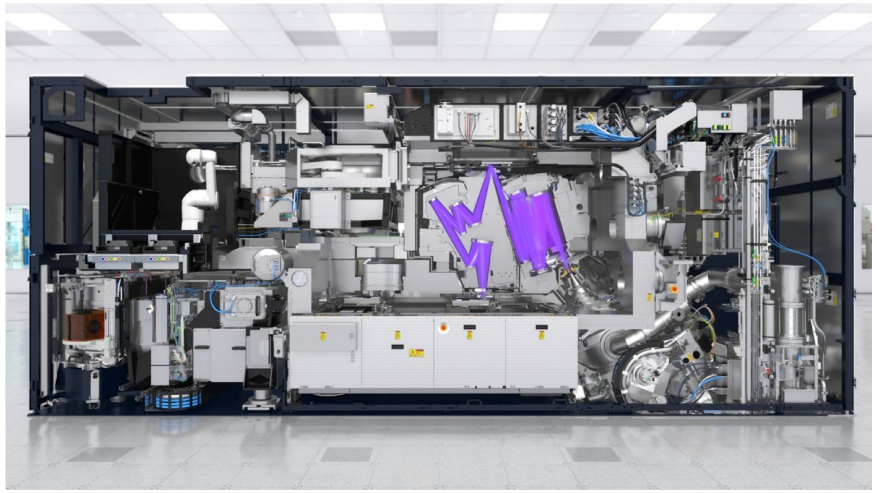
Identification in dynamic networks

Decentralized process control



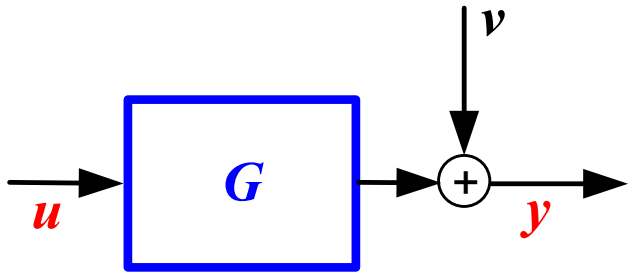
Complex machines



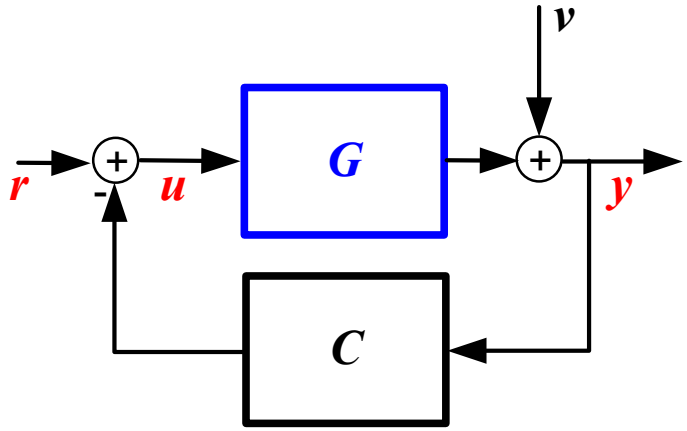
- (Large-scale) interconnected dynamic systems
- Data is “everywhere”, AI/machine learning tools
- **Learning models from data**

Identification in dynamic networks

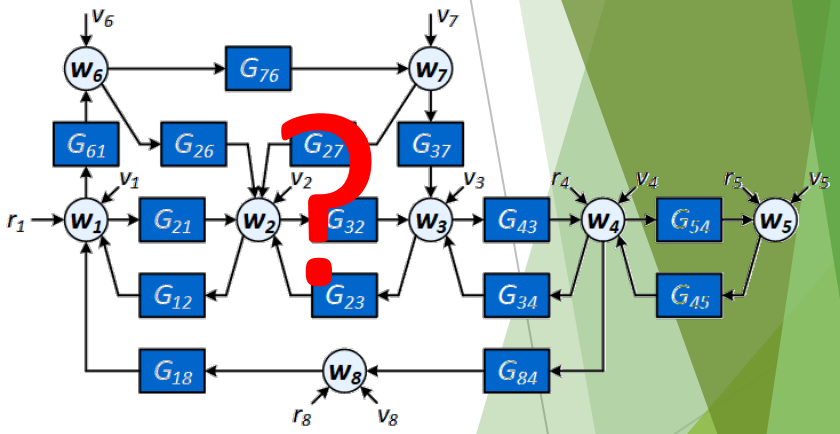
Open-loop



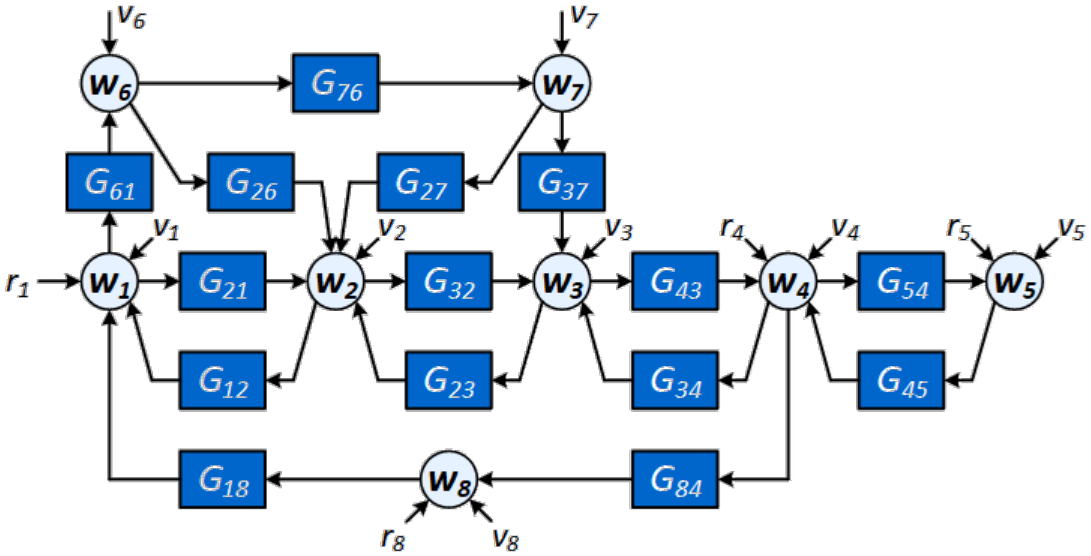
Closed-loop



Networks



Identification in dynamic networks



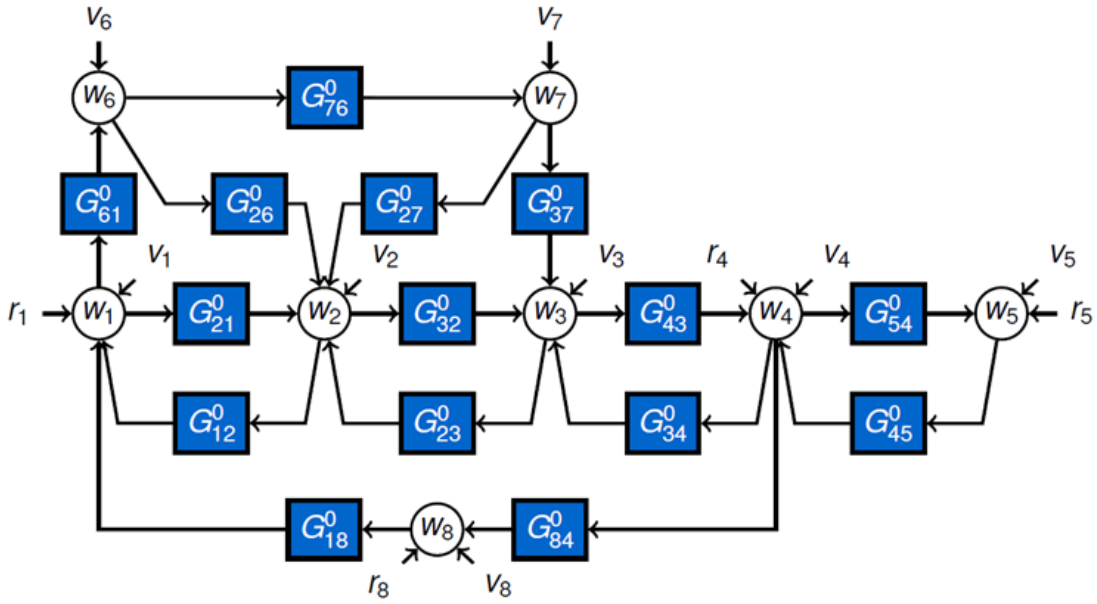
- Introducing structure/topology
- Developing the fundamental theory

SYSTEM IDENTIFICATION IN DYNAMIC NETWORKS ARNE DANKERS

(2014)

TU/e

Identification in dynamic networks

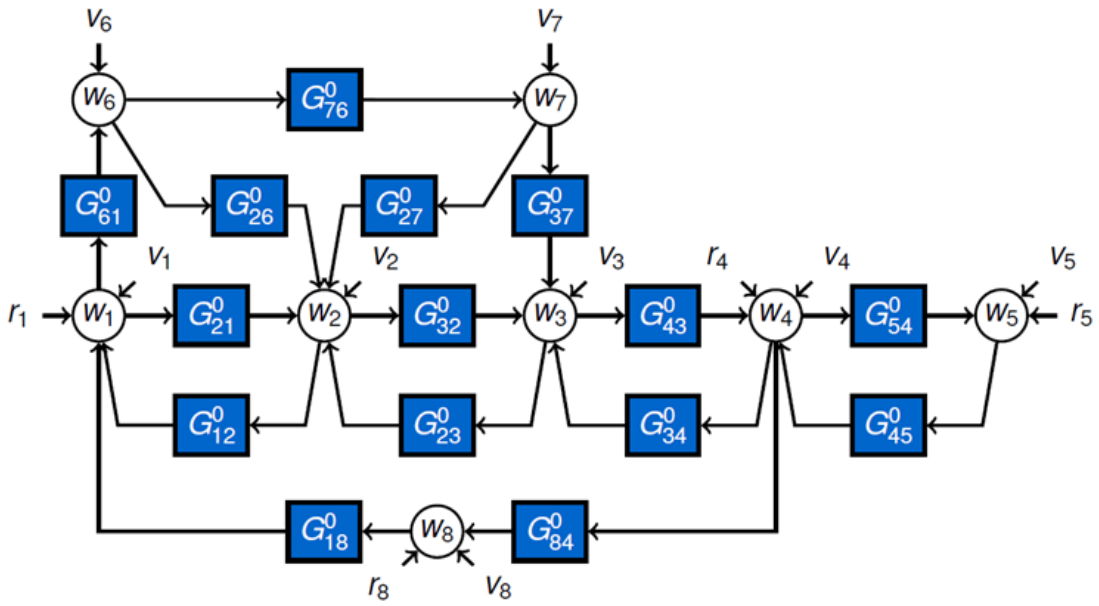


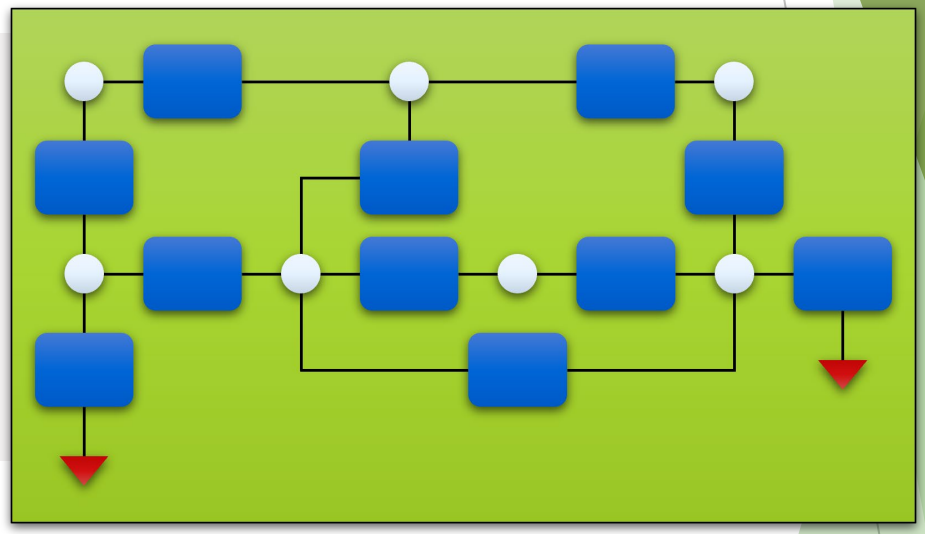
Many open problems

European Research Council

TU/e

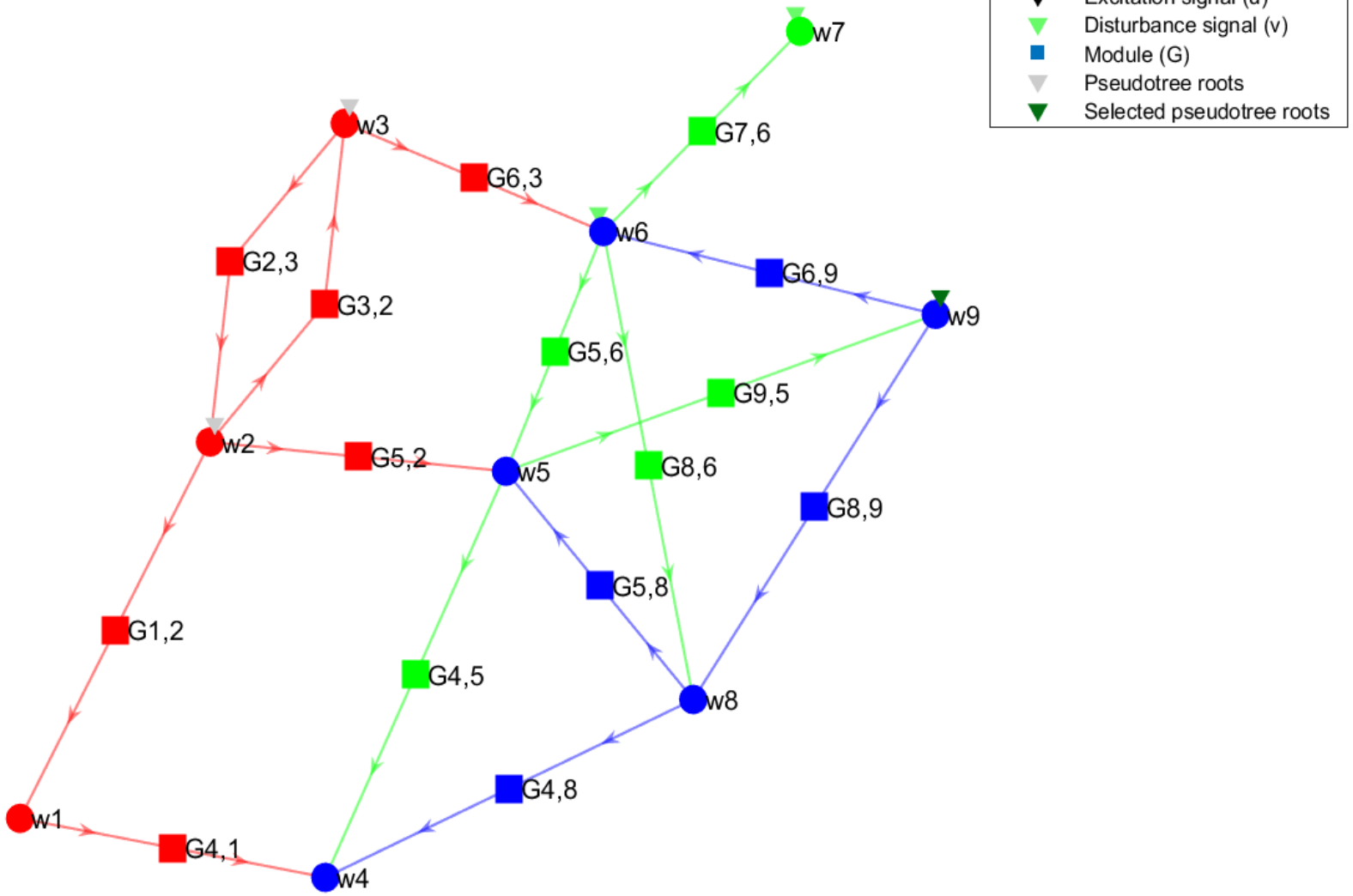
Identification in dynamic networks





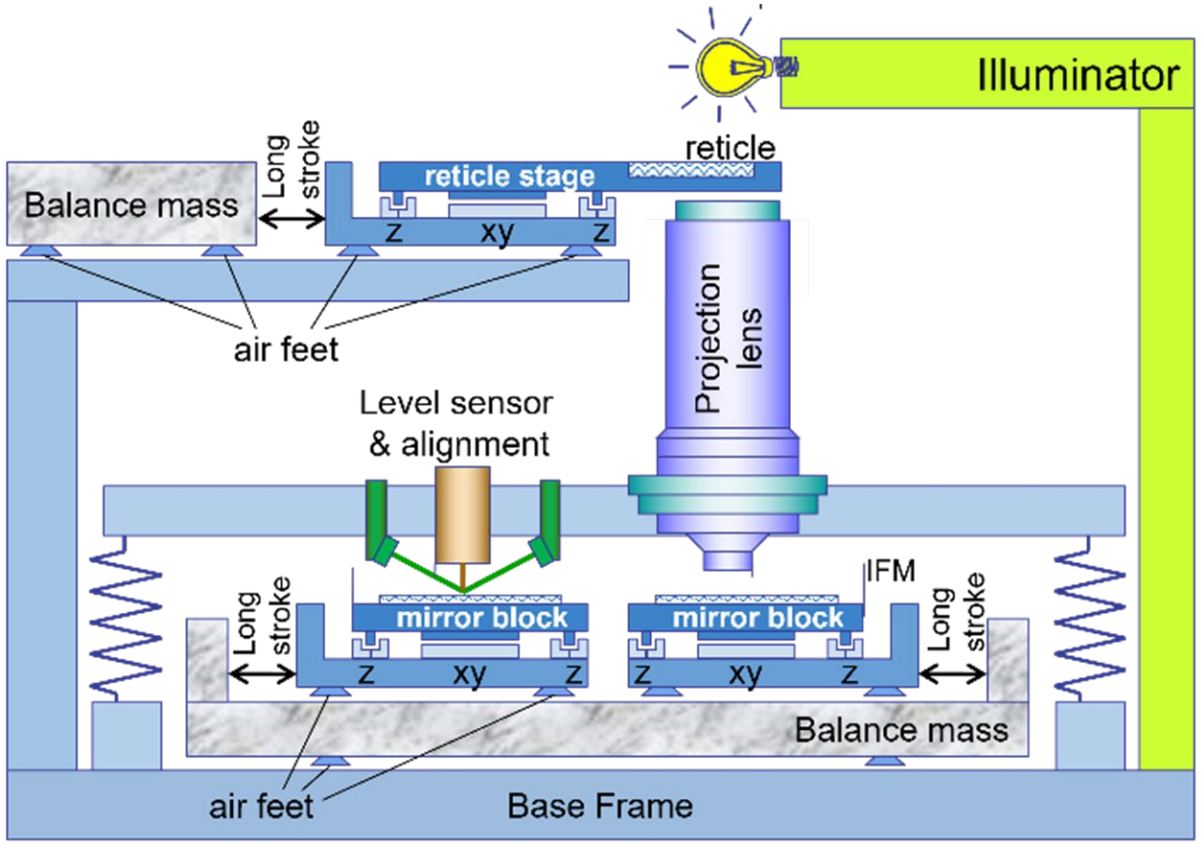
Kivits, 2024

Identification in dynamic networks



X.Cheng et al. 2022

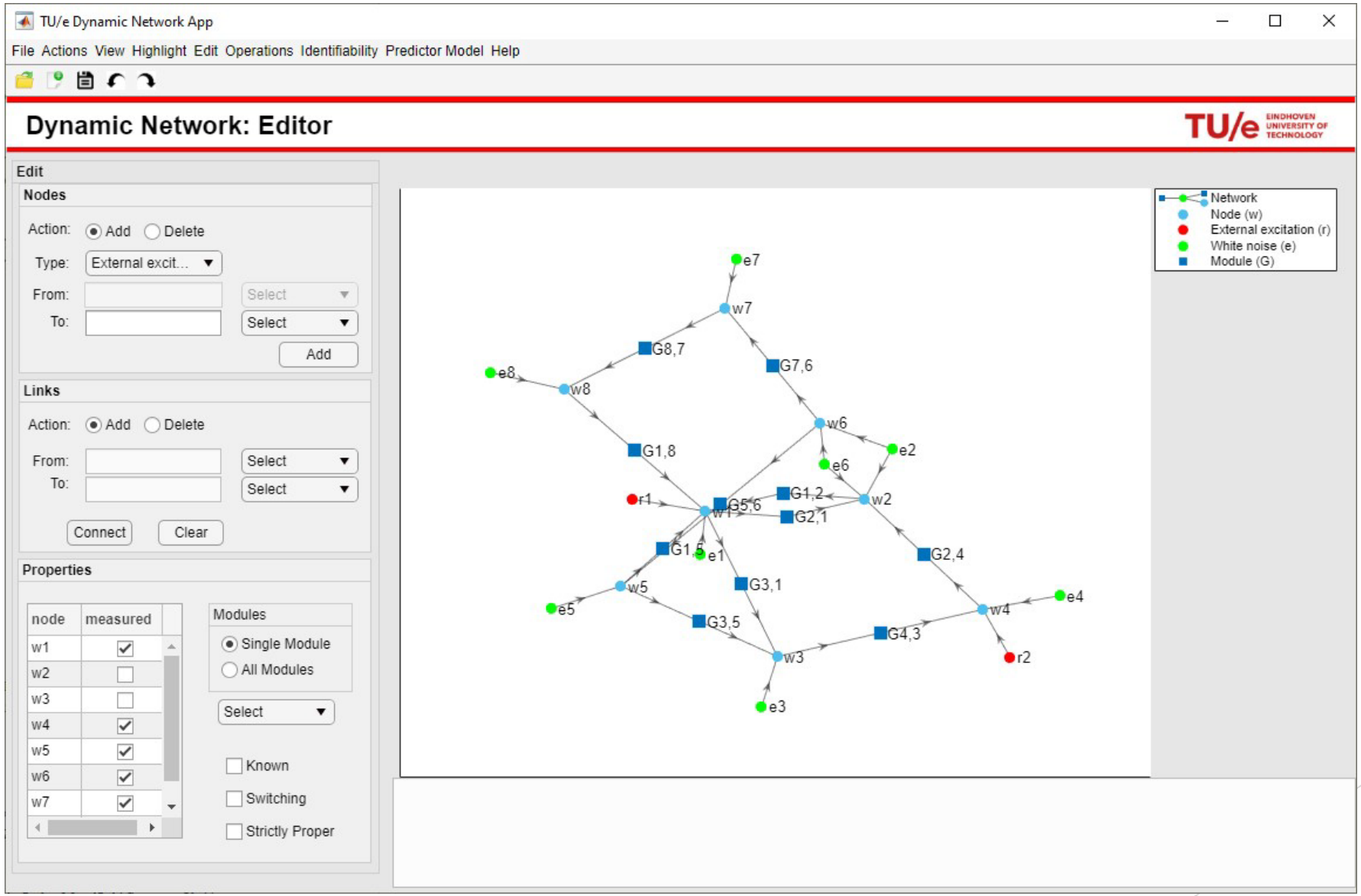
Diagnostics in lithography systems



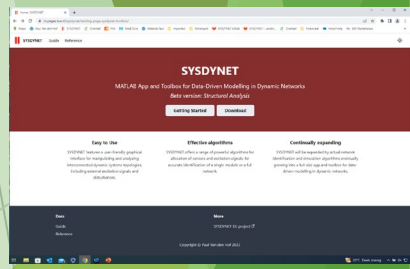
- Many interconnected subsystems
- Need for very fast recovery from faults
- Tools for automated diagnostics

Figure from Hans Butler (2011).

SYSDYNET MATLAB App and Toolbox



European Research Council



www.sysdynet.net

Researcher, supervisor, teacher and manager

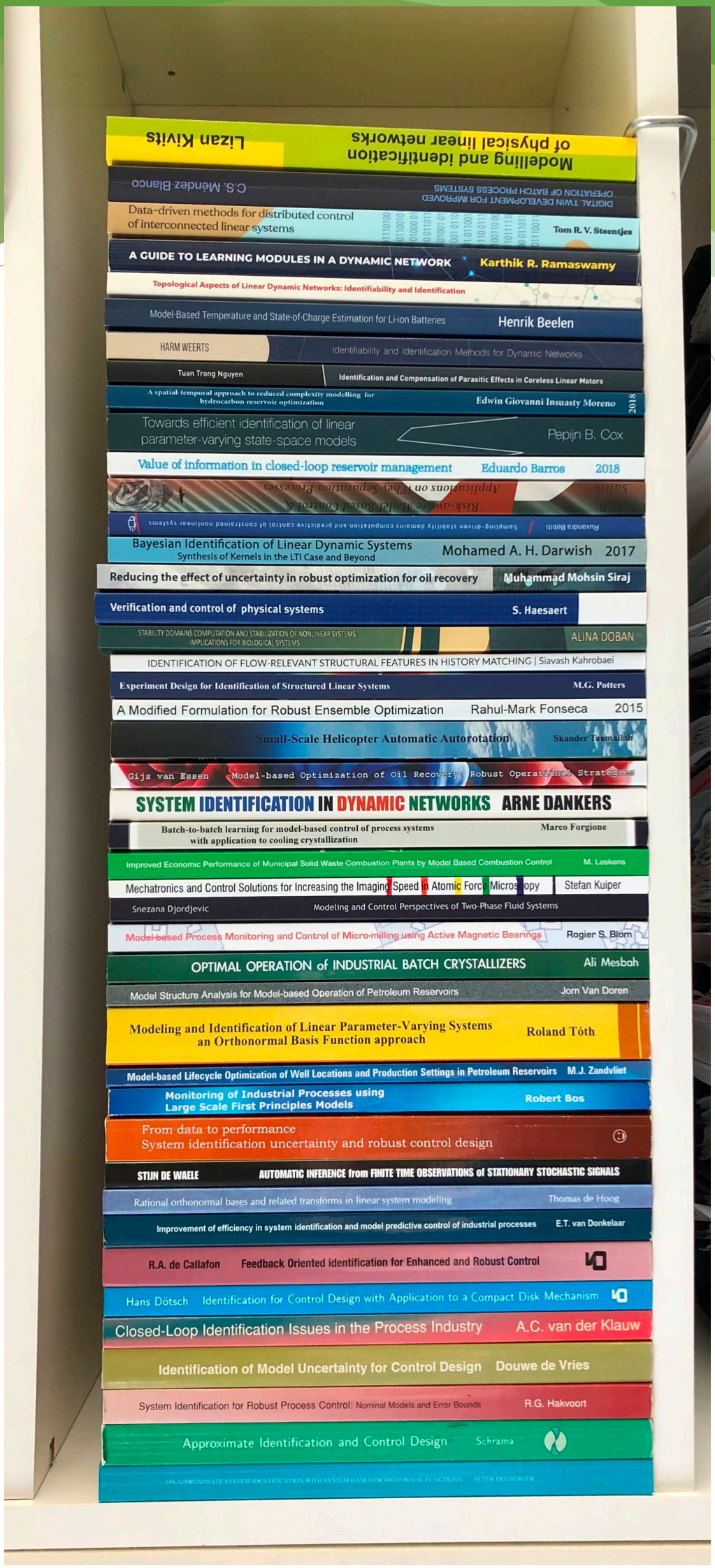
A fantastic job in an international setting

International setting

It’s all about people

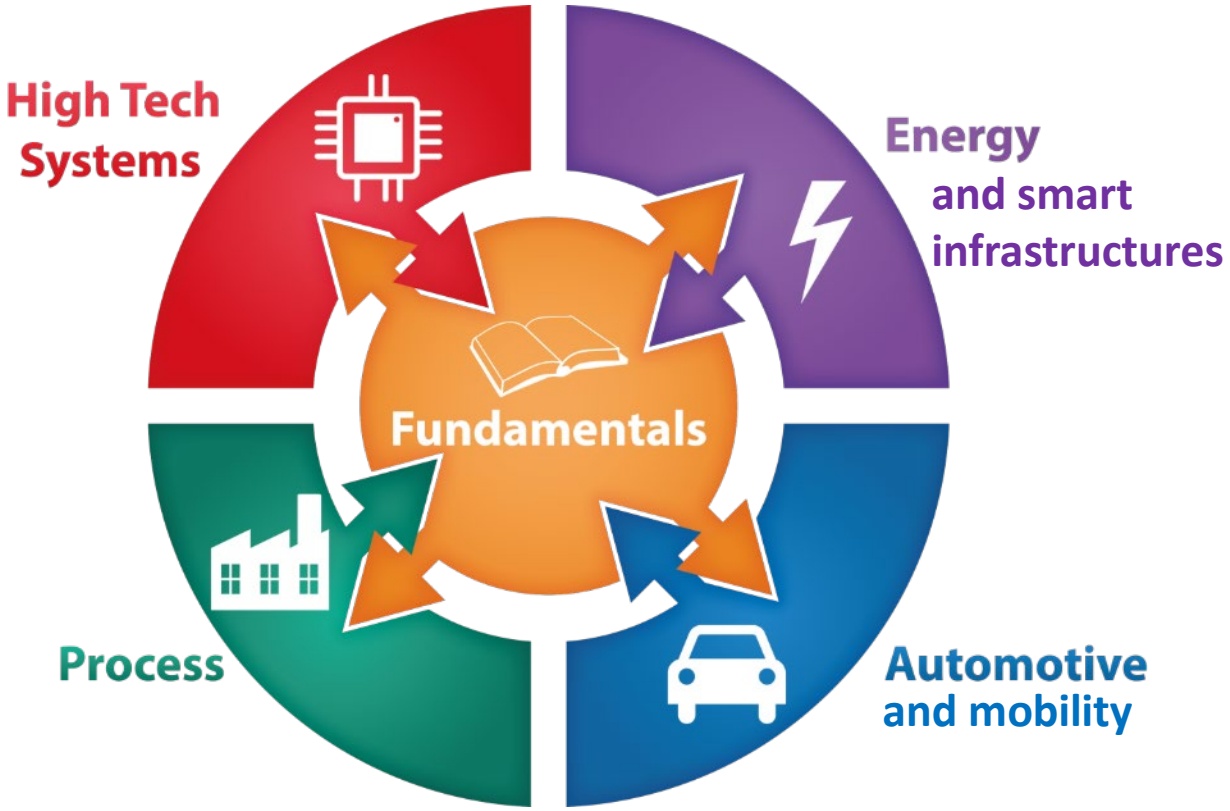
PhD students

The PhD students

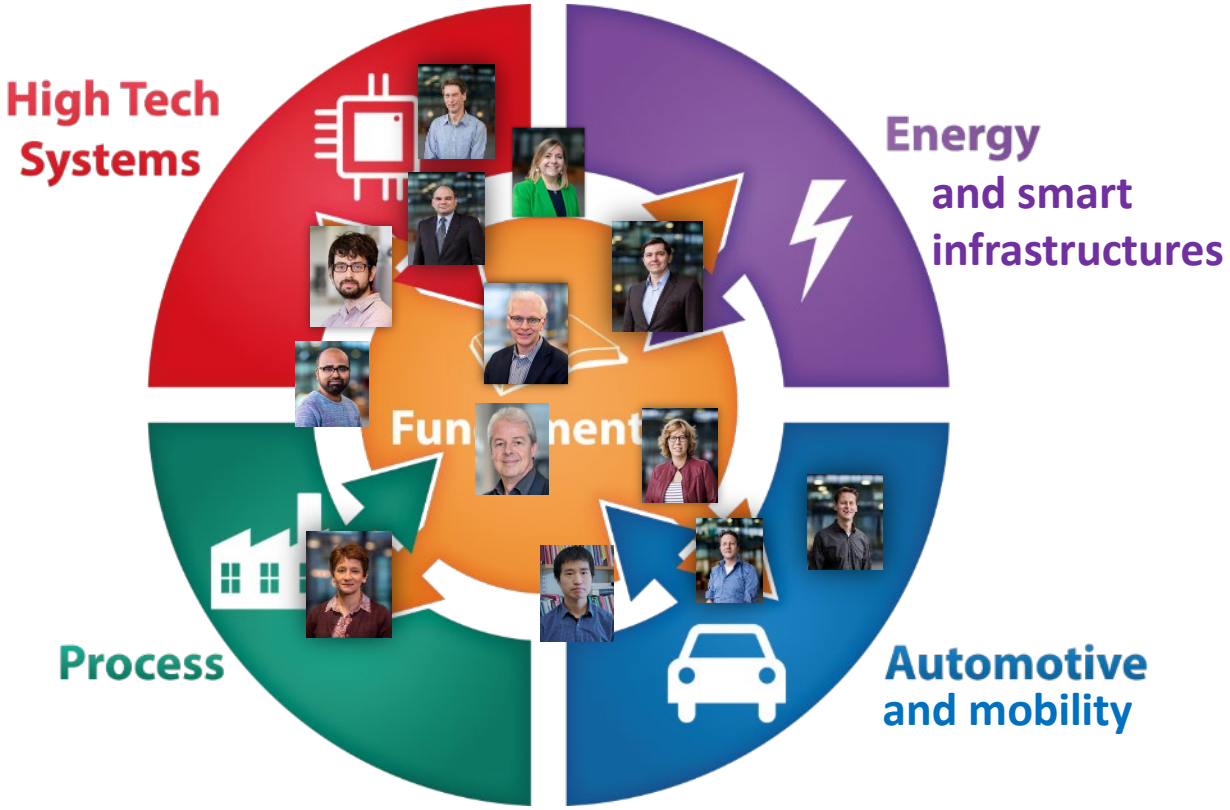


Building a team

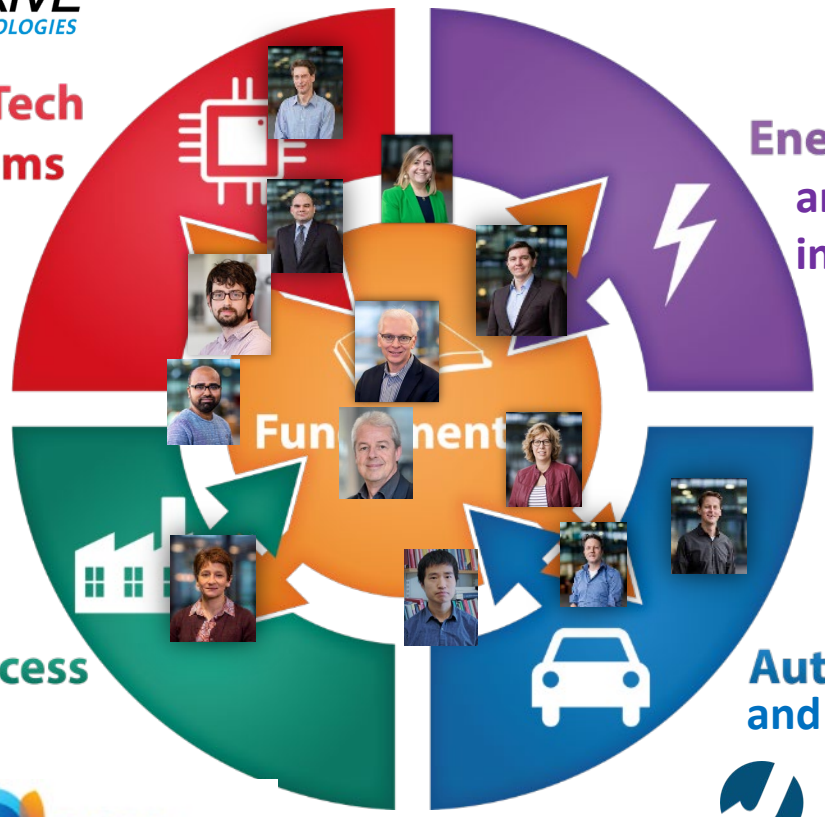
Research domains – Control Systems Group



Research domains – Control Systems Group



Research domains – Control Systems Group



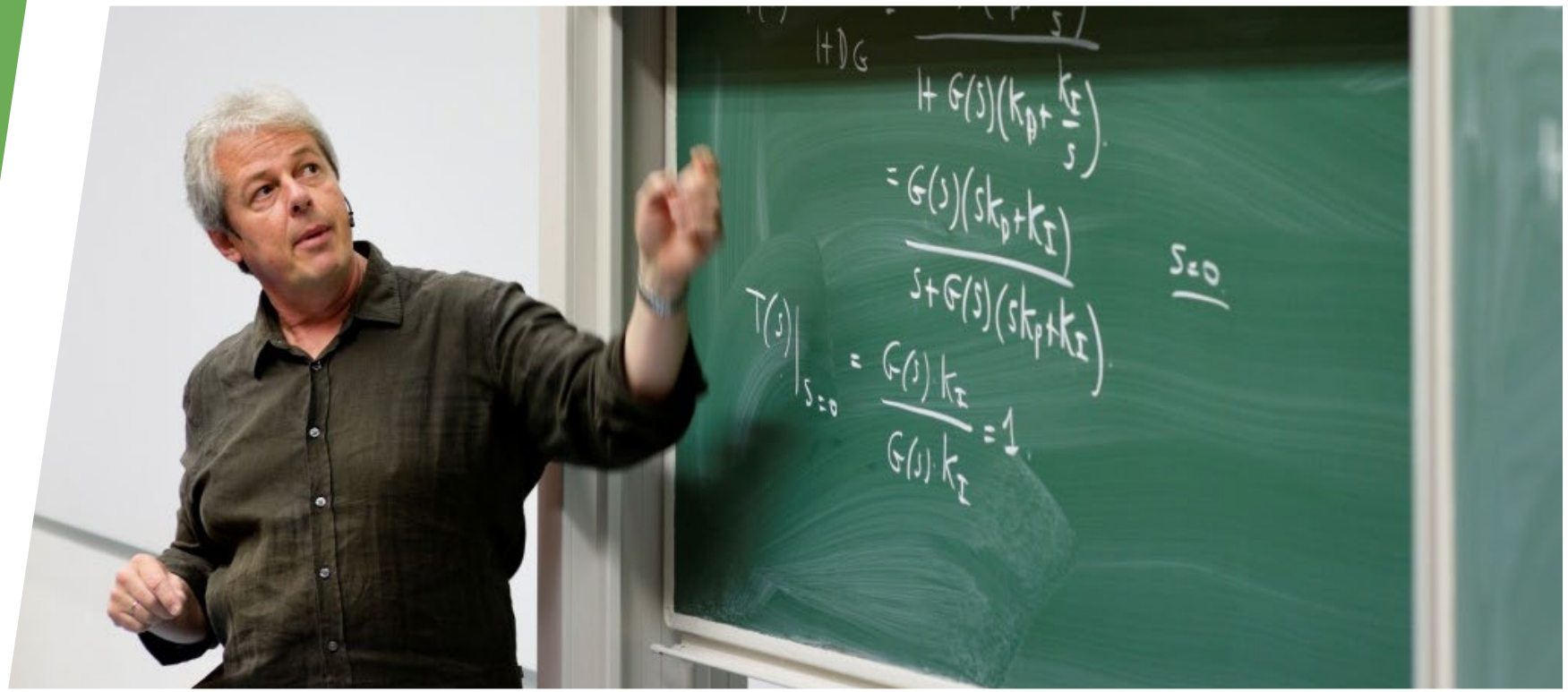
National setting

National setting

disc dutch institute of systems and control

IFAC 2029 amsterdam

TU/e

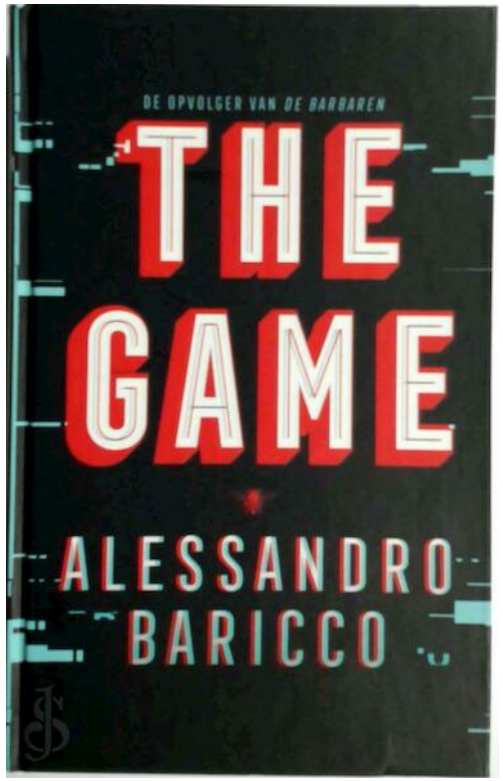


Education

Highly rewarding

48

Education



2019

Why the cyber world is so much more attractive than the physical world…

Education – Challenge-based learning

- How to develop analytical skills?

- Which skills are required for engineers in the next decades?

Some university initiatives

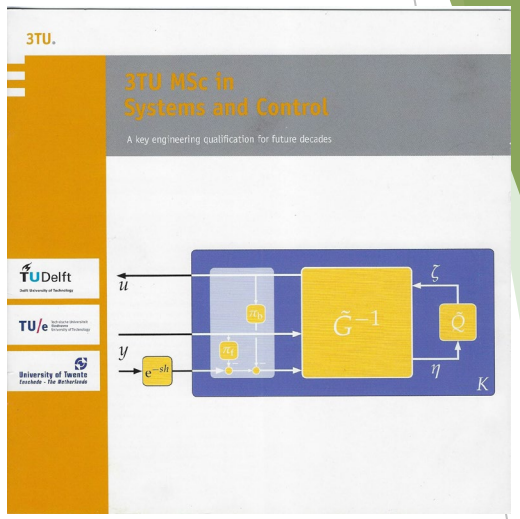
- Delft Center for Systems and Control (2003)

Some university initiatives

- Delft Center for Systems and Control (2003)

- MSc Systems and Control (2004-)

  National recognitions, 2010, 2019



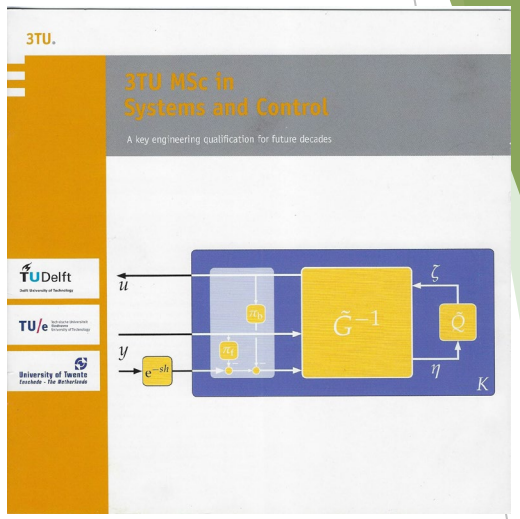
Some university initiatives

- Delft Center for Systems and Control (2003)

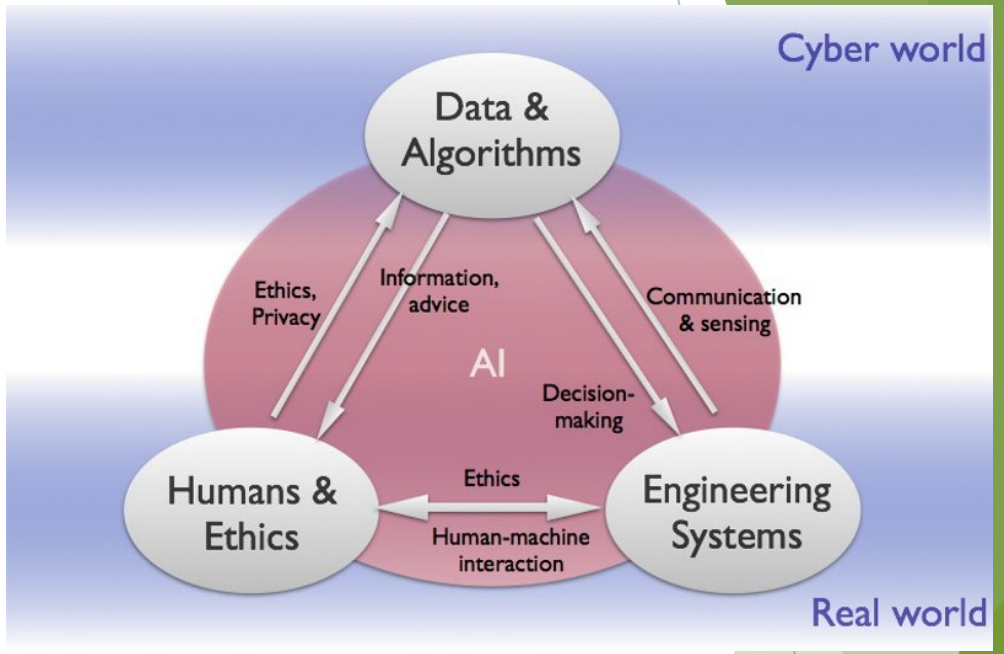
- MSc Systems and Control (2004-)

  National recognitions, 2010, 2019

- TU/e High-Tech Systems Center (2013)



Some university initiatives



New MSc program

Artificial Intelligence and Engineering Systems (2022 -)

TU/e

Prospects of the field

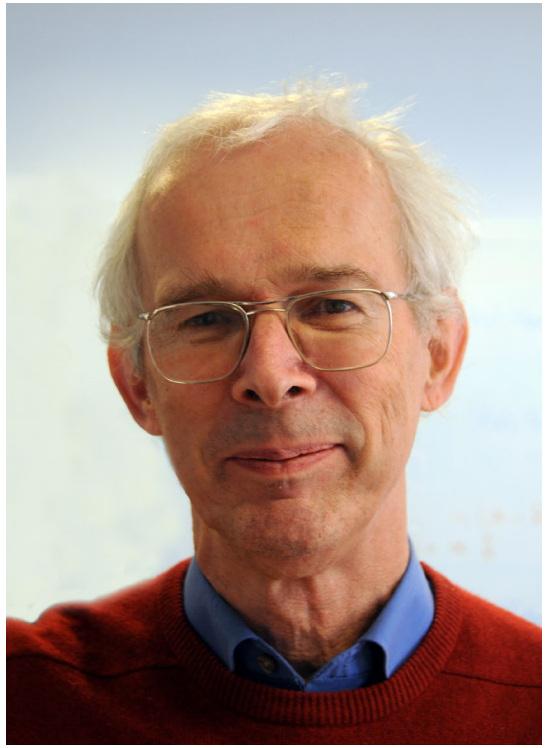
- In Eindhoven: > 100 PhD students in control
- Smart production systems, energy transition, robotics, mobility

Prospects of the field

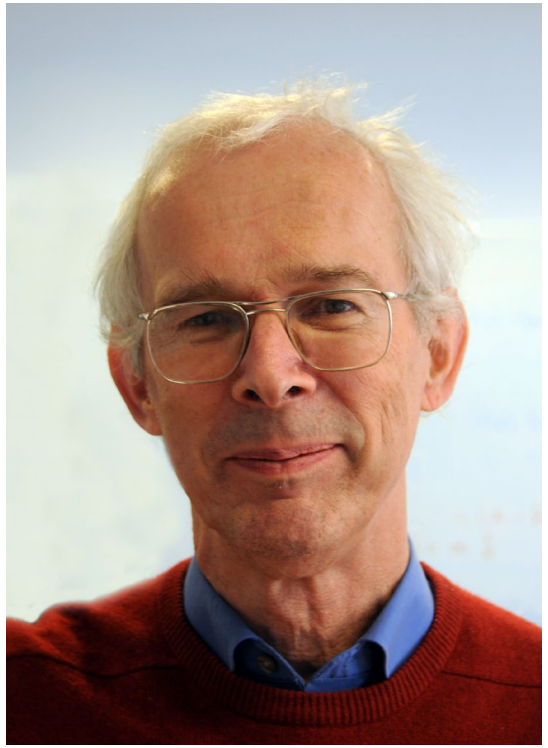
- In Eindhoven: > 100 PhD students in control
- Smart production systems, energy transition, robotics, mobility
- Model-based or data-driven ?
- Complex dynamics and large-scale interconnections

Everything under ~~control~~
AI

Final words and thanks



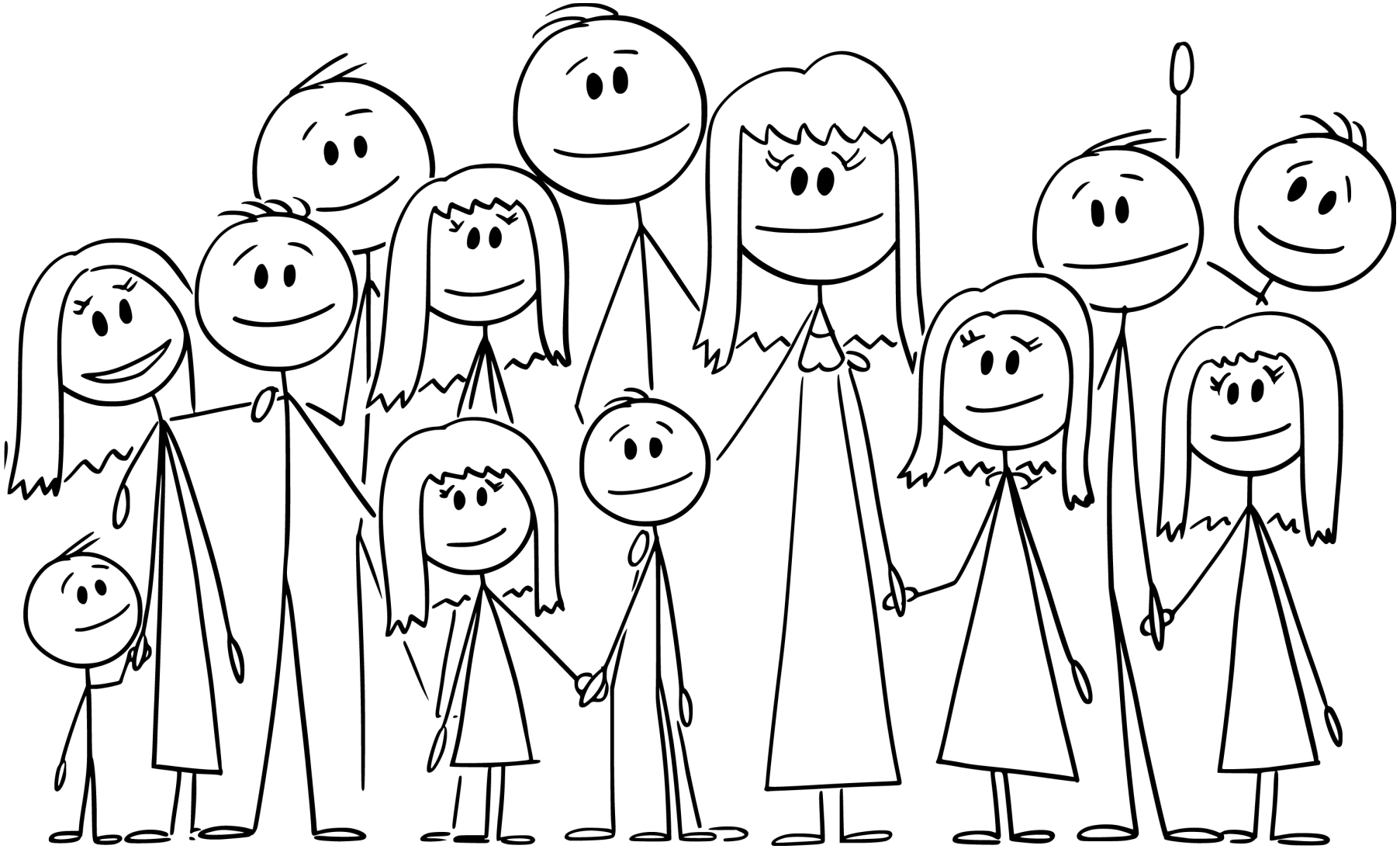
Okko Bosgra



Okko Bosgra

Jan Willems

Thank you



- Ik heb gezegd

Prof. Paul M.J. Van den Hof