Robot Brains

Prof.dr. R. Babuška

Intelligent Control & Robotics

14 January 2011

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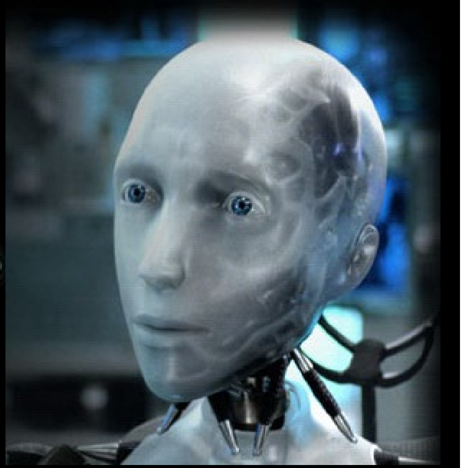
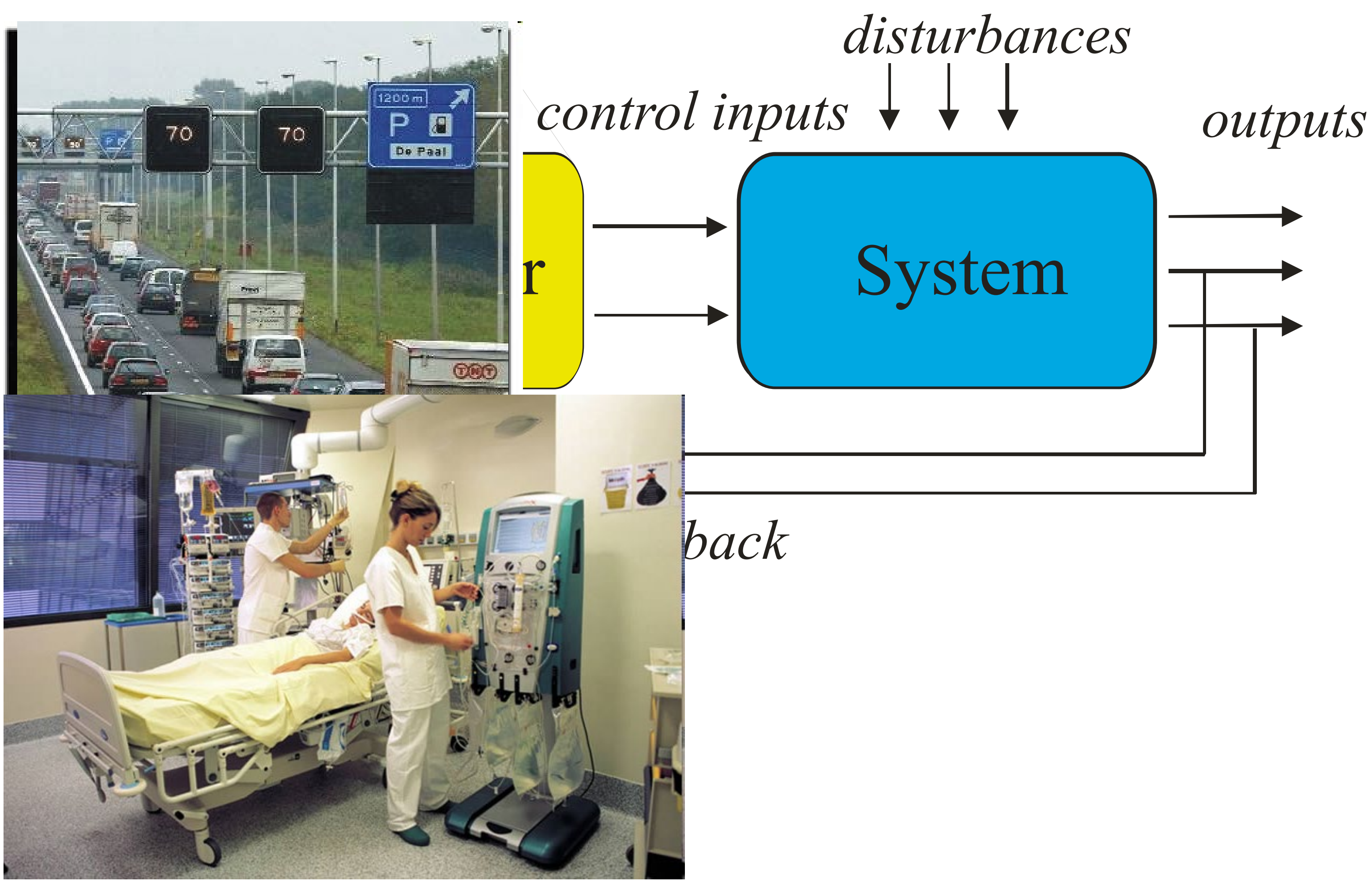
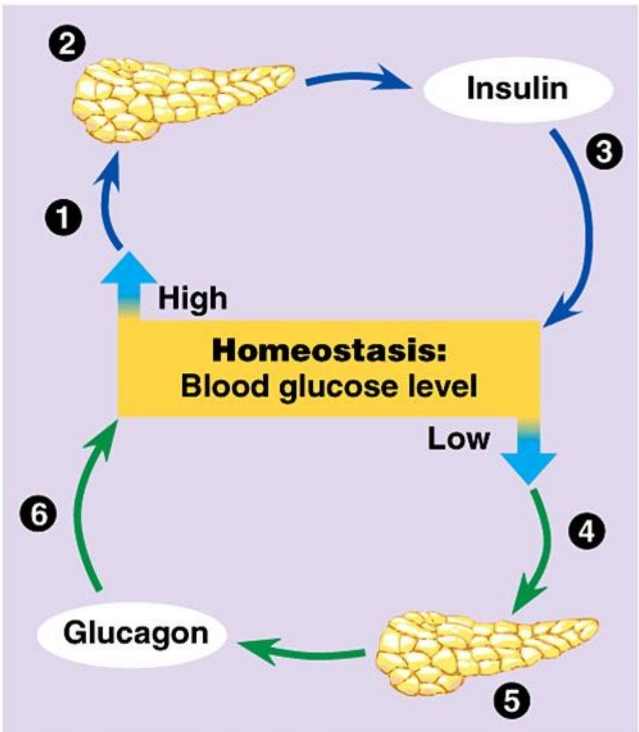


- Systems and control
- Challenges in robotics
- Intelligent control

Automatic Control



Feedback in Nature



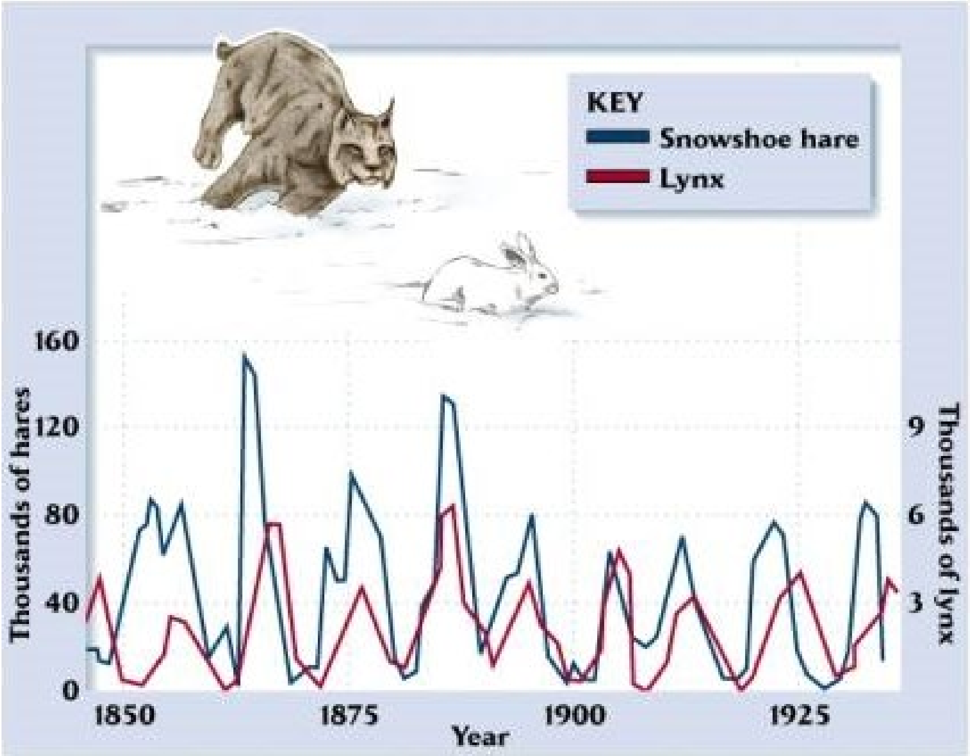
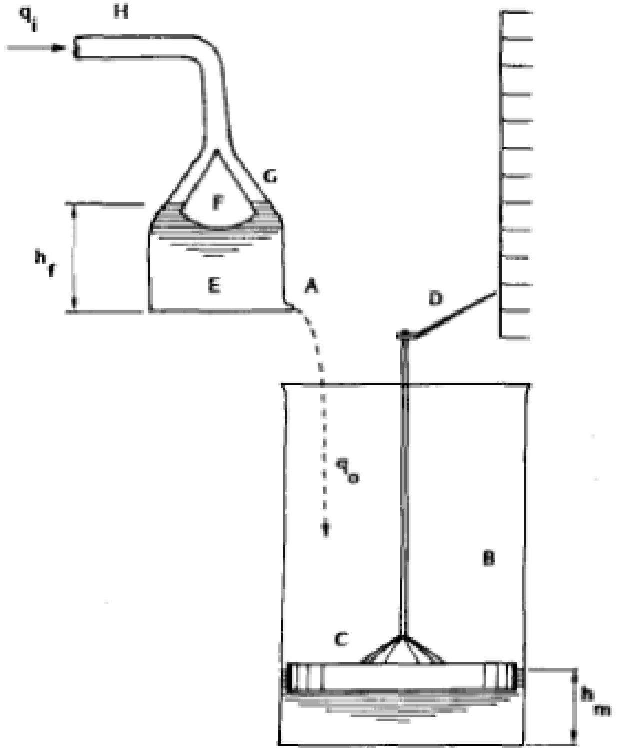
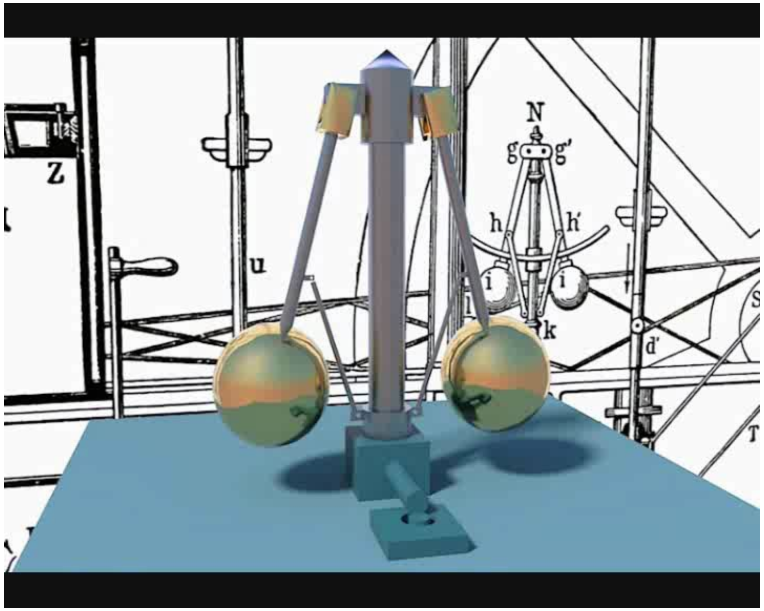


Image source: mathnathan.com

First Man-Made Control Systems

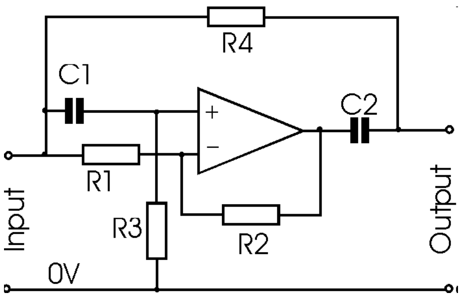


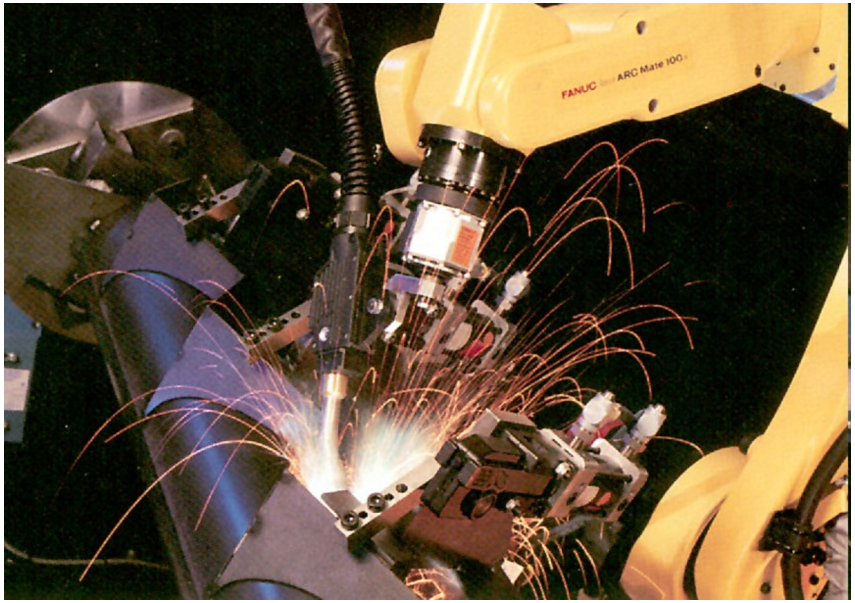


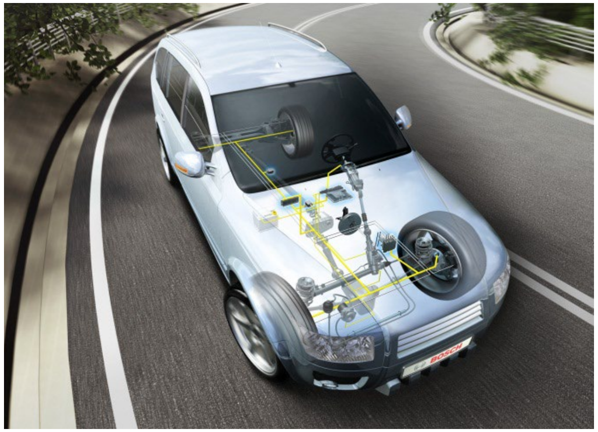
Ancient water clock by Ktesibios
Alexandria 3rd century BC

Steam engine speed regulator
James Watt, Scotland 1788

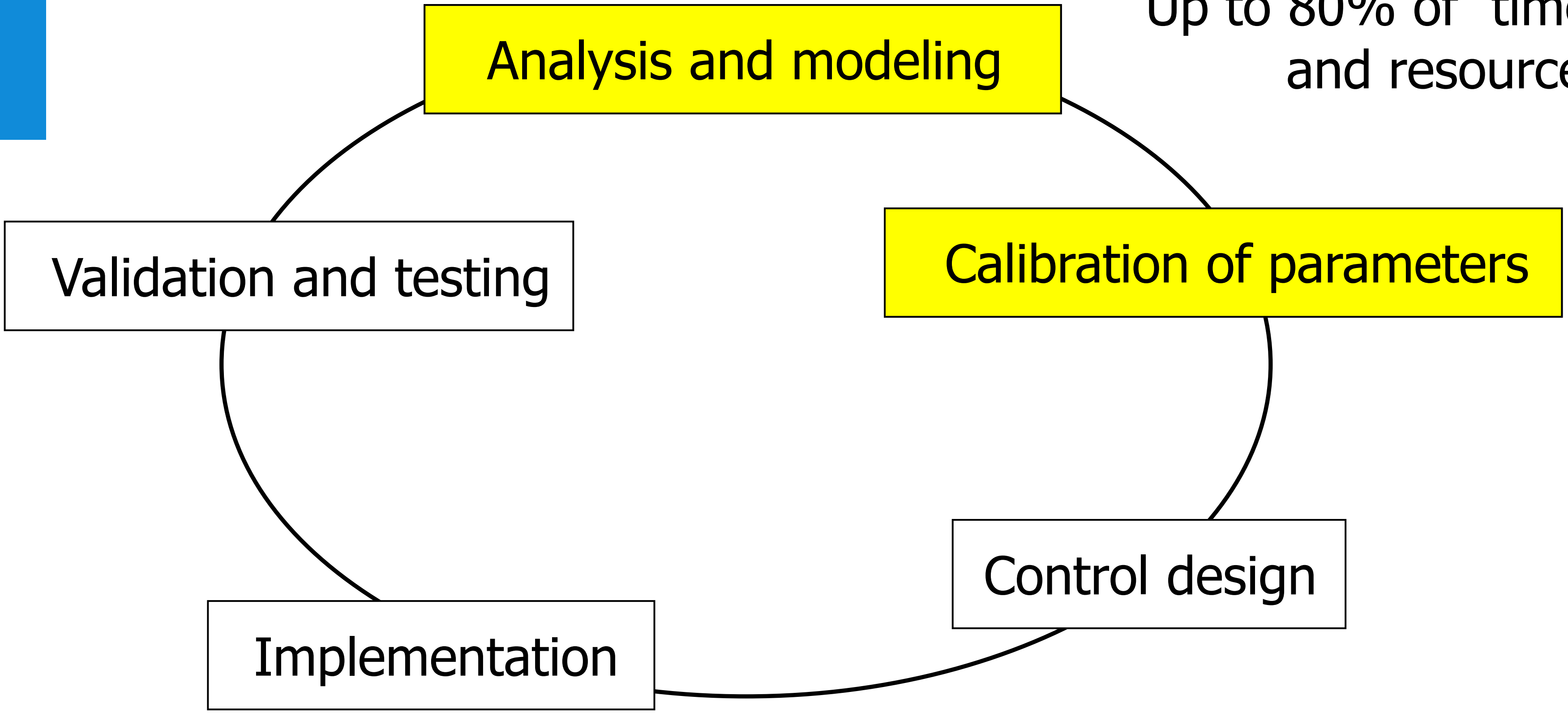
Huge Impact of Invisible Technology





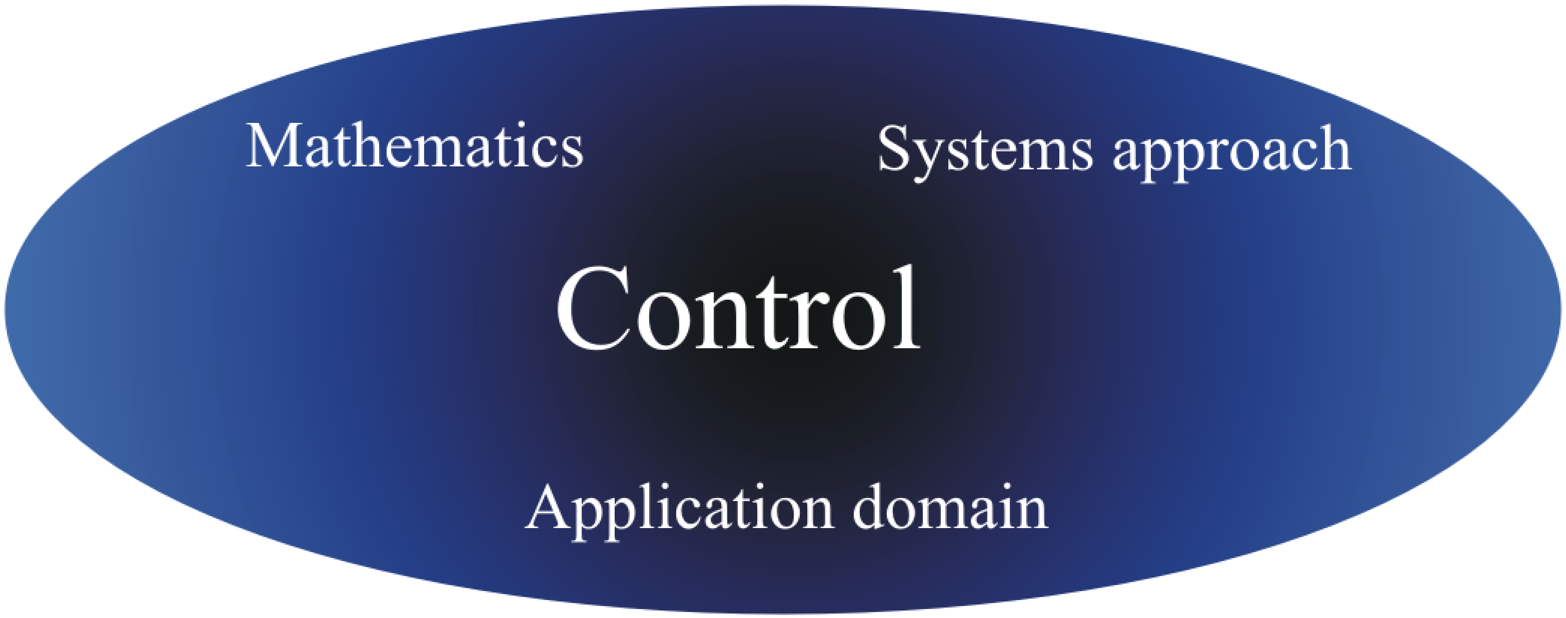


Model-Based Design



Up to 80% of time and resources

Cornerstones of Control Research



Emphasis on provably correct design

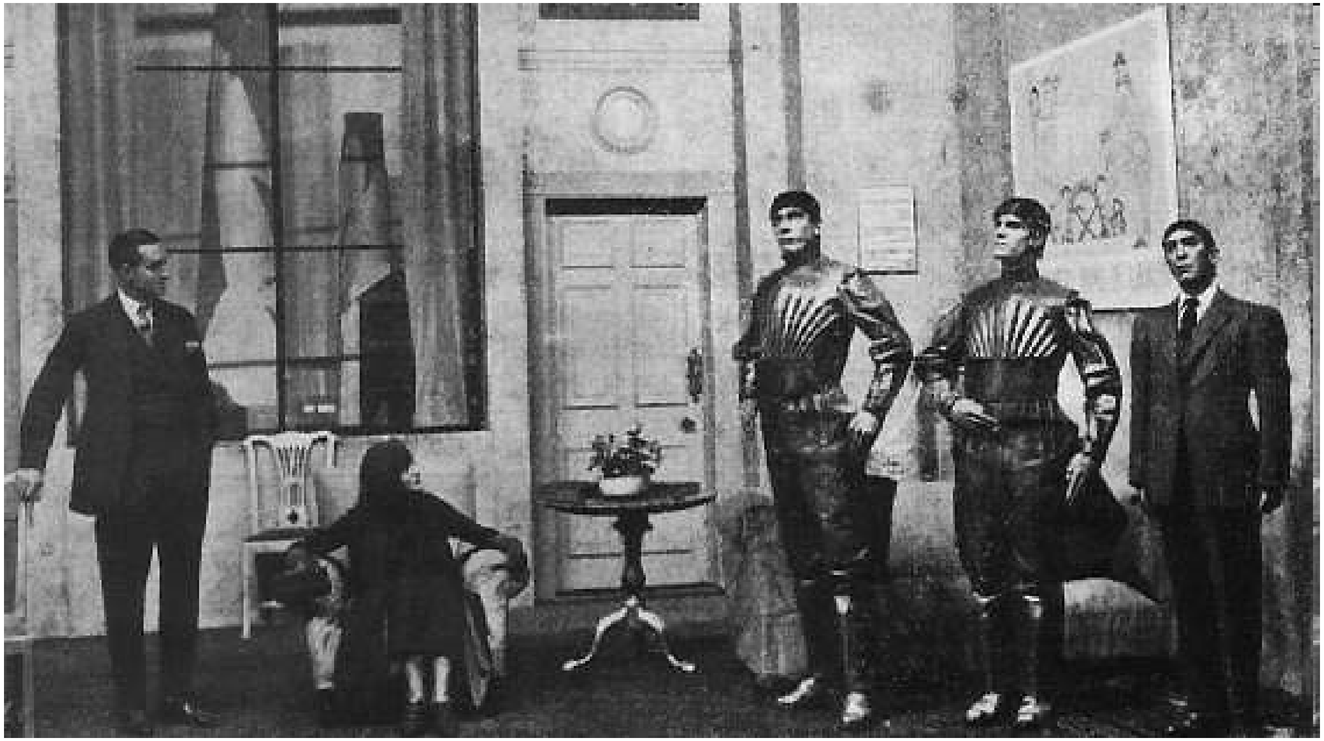
- stability and performance guarantees

Robotics

Robot

– a mechanical system which performs tasks under human control, in collaboration with humans or autonomously

from Czech "robota" – forced labor (Karel Čapek's play R.U.R., 1921)



Robotics

Great impact in **well structured, engineered environments**

- speed, accuracy, repeatability, automatic operation

- *preprogrammed* tasks, *no interaction* with humans

Robotics

Some success in **telemanipulation** and **teleoperation**

- *robots operated by* humans

Robotics

Challenges ahead in **domestic, service and care applications**

-operate autonomously and interact with humans

Robotics

Challenges ahead in **domestic, service and care applications**

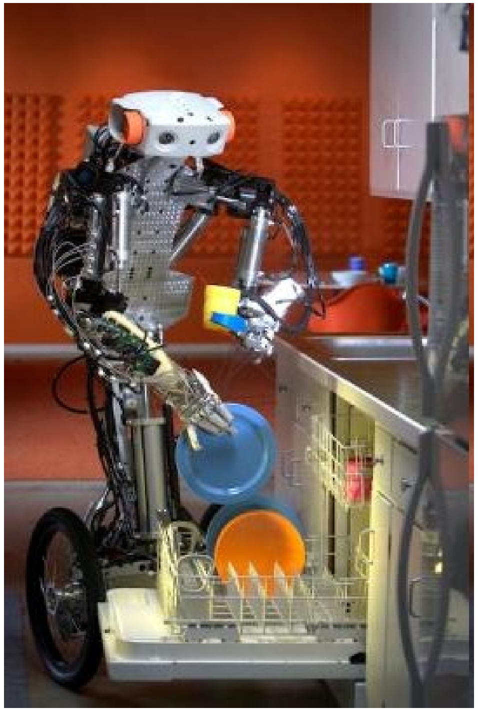
-operate autonomously and interact with humans

video source: youtube

Robotics

Challenges ahead in **domestic, service and care applications**

-*operate semi-autonomously and interact with humans*



Robotics

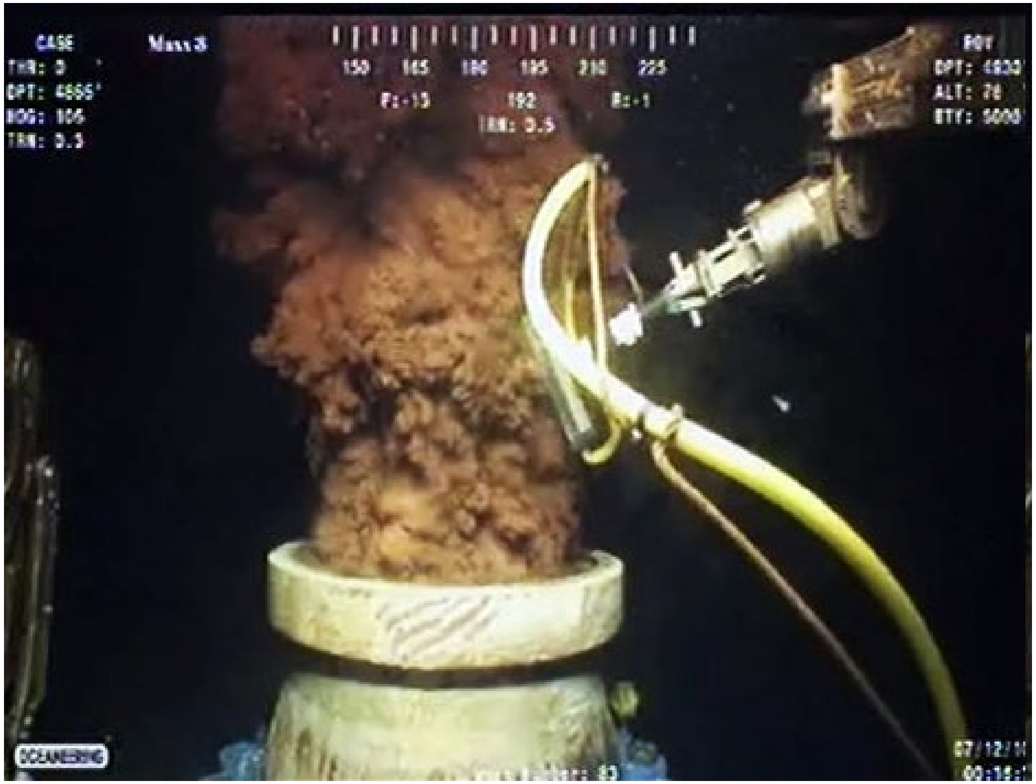
Challenges ahead in **domestic, service and care applications**

-*operate semi-autonomously and interact with humans*

Freek Liefhebber (TNO & TU Delft)

Robotics

more challenges: **agriculture, deep sea, construction, …**



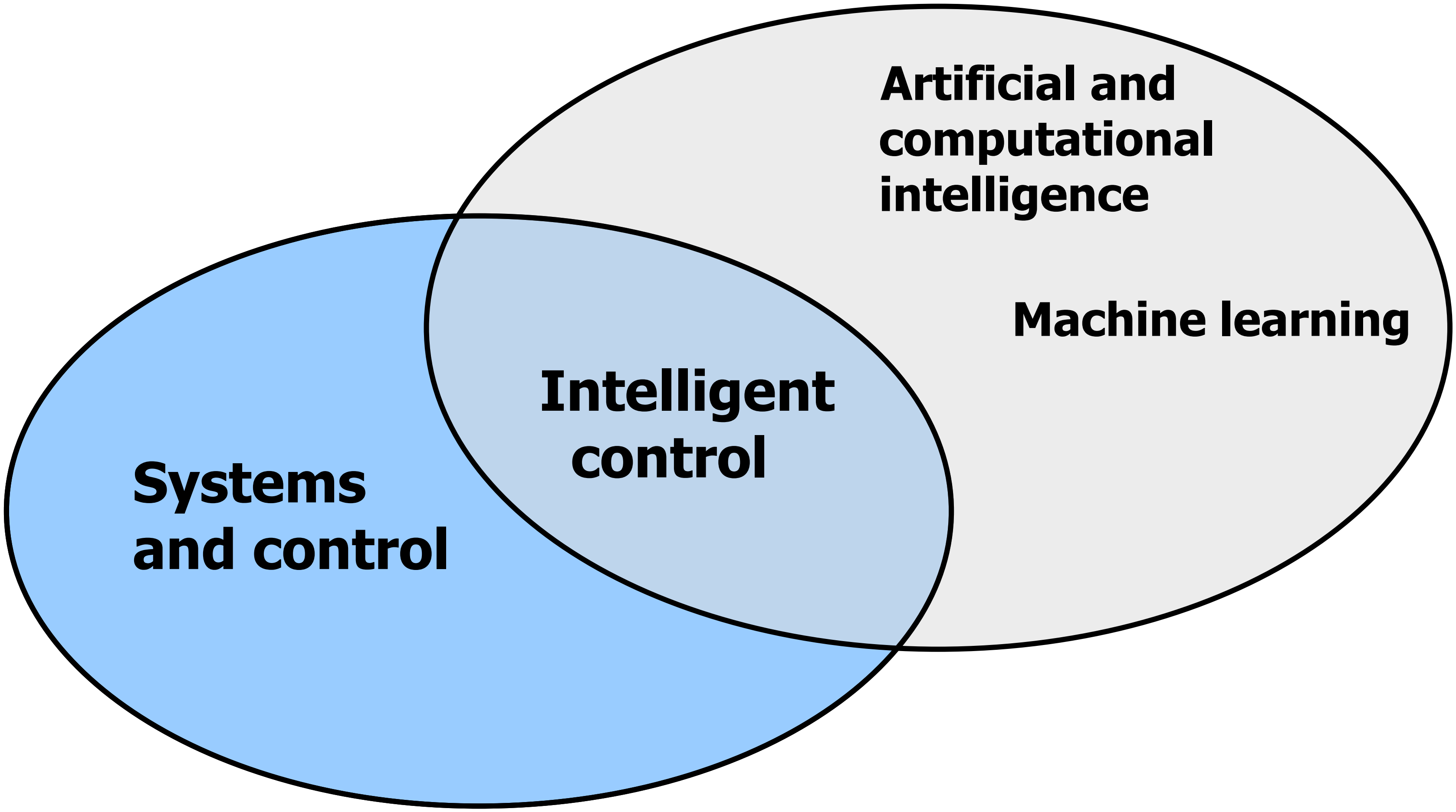
Challenges in Robotics

- safety in human-machine interaction
- autonomy and shared autonomy (collaborate with humans)
- coping with unstructured environments

versus

Intelligent Control

Intelligent Control

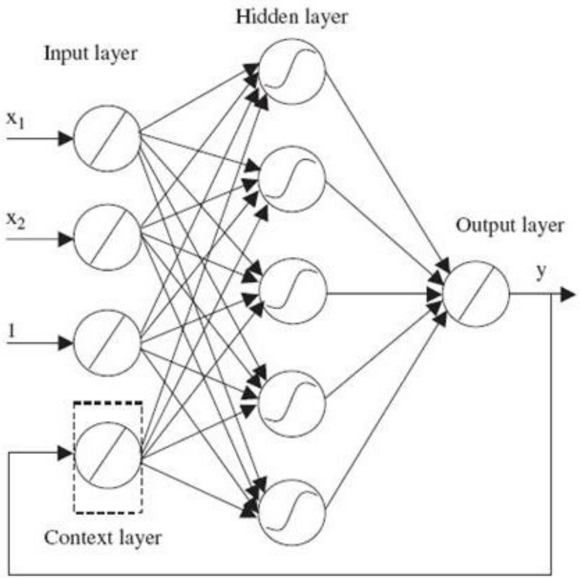


Alternative Representation Schemes

Traditional control

Inspiration in nature

$$y(k+1) = A(q)y(k) + B(q)u(k)$$



artificial neural networks

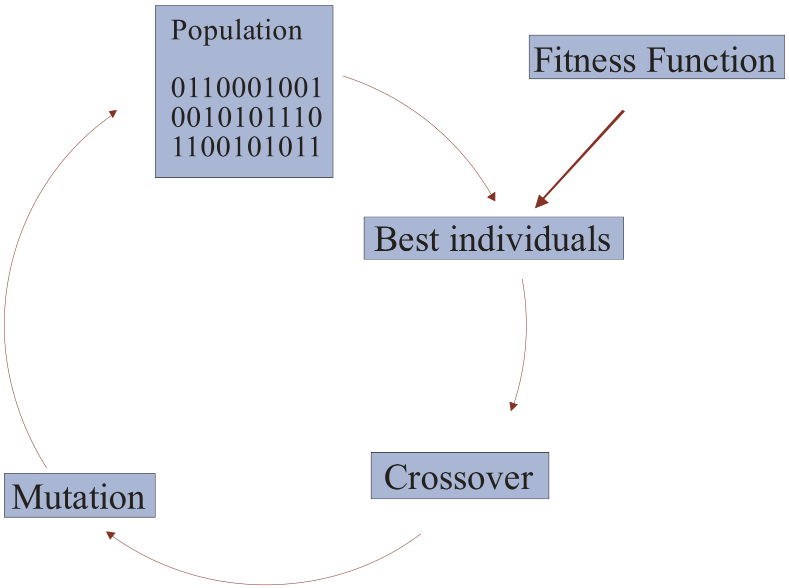
rule-based models

if <condition> then <conclusion>

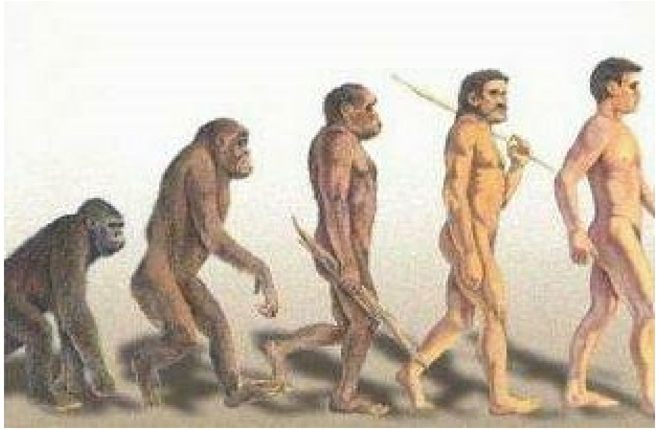
Optimization in Control

Roots in maths

$$x_{opt} = \arg\max_{x} F(x)$$



Inspiration in nature



Genetic and evolutionary algorithms

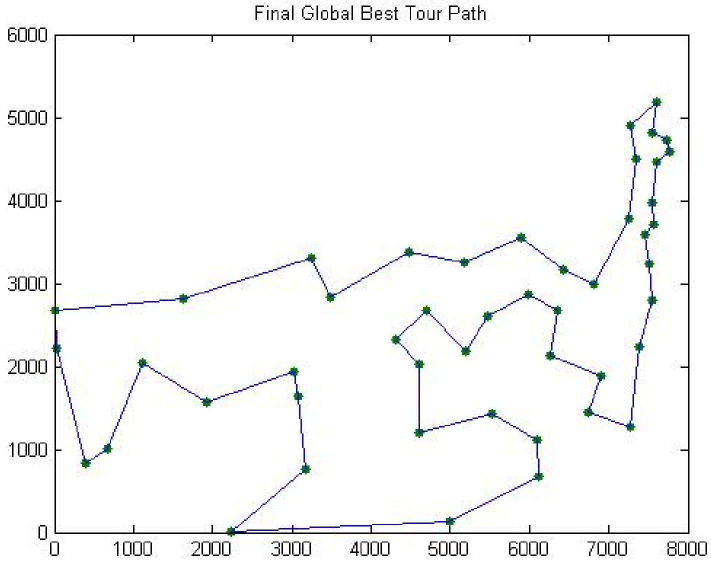
Optimization in Control

Roots in maths

$$x_{opt} = \underset{x}{\operatorname{argmax}}\, F(x)$$

Inspiration in nature

Swarm intelligence



Machine Learning

ability to learn a *specific task* from experience, without being specifically programmed for that task

- adapt to changes in environment
- find new, better solutions
- teach by demonstration or imitation

Spectrum of Learning Techniques

Reinforcement learning

(learn directly to control)

Supervised learning

(with ‘teacher’)

Unsupervised learning

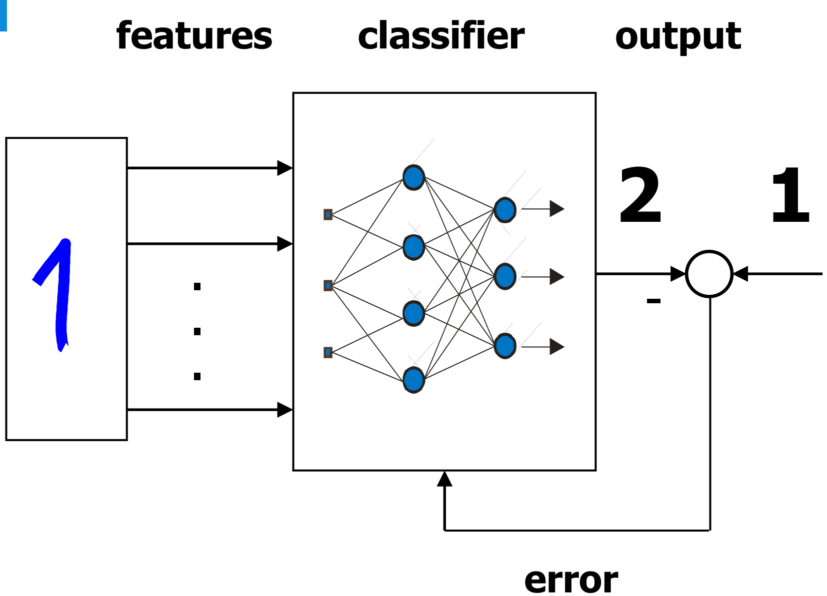
(without ‘teacher’)

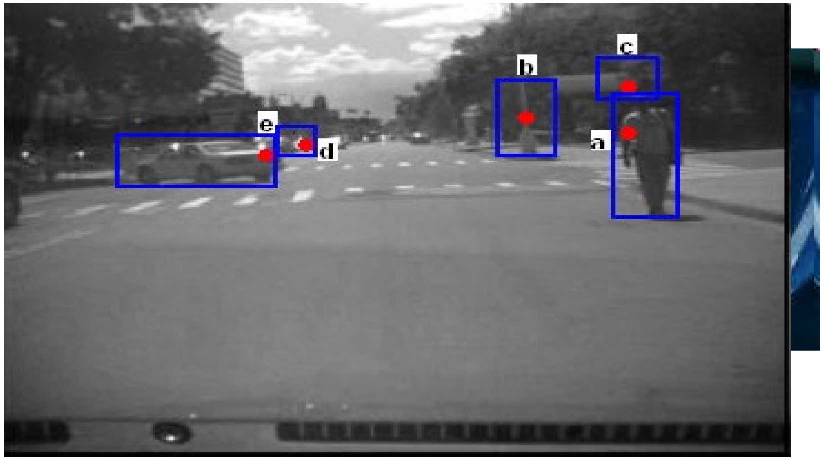
Supervised Learning: Classification

Input pattern		Class
	→	1
	→	2
	→	3
…		…

1. **Collect a training set**

Supervised Learning: Classification





1. Collect a training set
2. Train the classifier
3. Use to classify new patterns

Construct a Robot Model from Data

actuate motors and observe the response

Two ways to model the system:

1. **Physical modeling**
2. **System identification**

Maarten Vaandrager

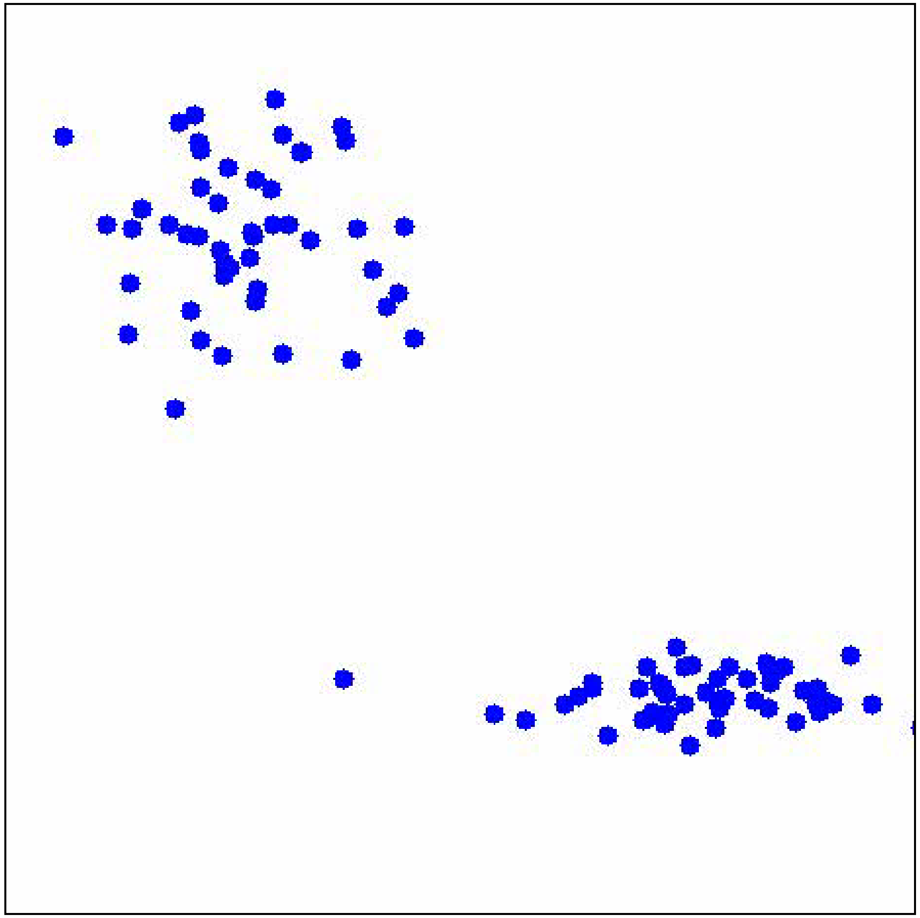
Spectrum of Learning Techniques

Reinforcement learning
(learn directly to control)

Supervised learning
(with 'teacher')

Unsupervised learning
(without 'teacher')

Unsupervised Learning - Clustering

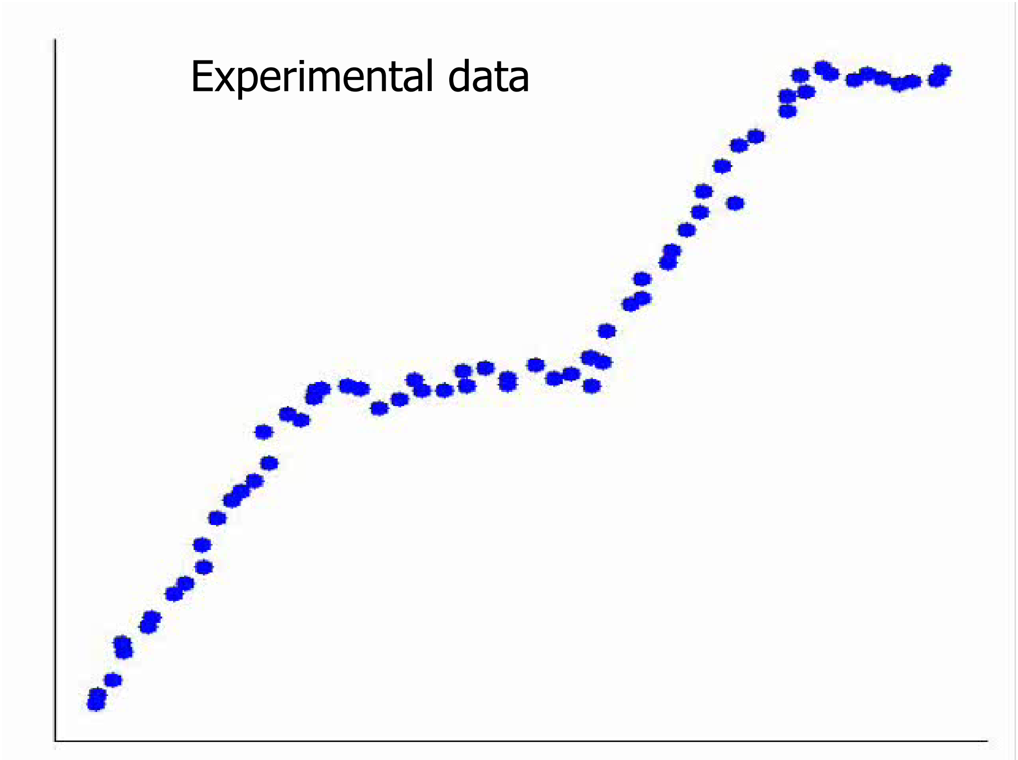


- *Discover automatically groups and structures in data*

Applications:

- Pattern recognition
- Robot perception, vision
- Data-driven construction of dynamic models

Construction of Nonlinear Models



Nonlinear and uncertain behavior

Spectrum of Learning Techniques

Reinforcement learning

(learn directly to control)

Supervised learning

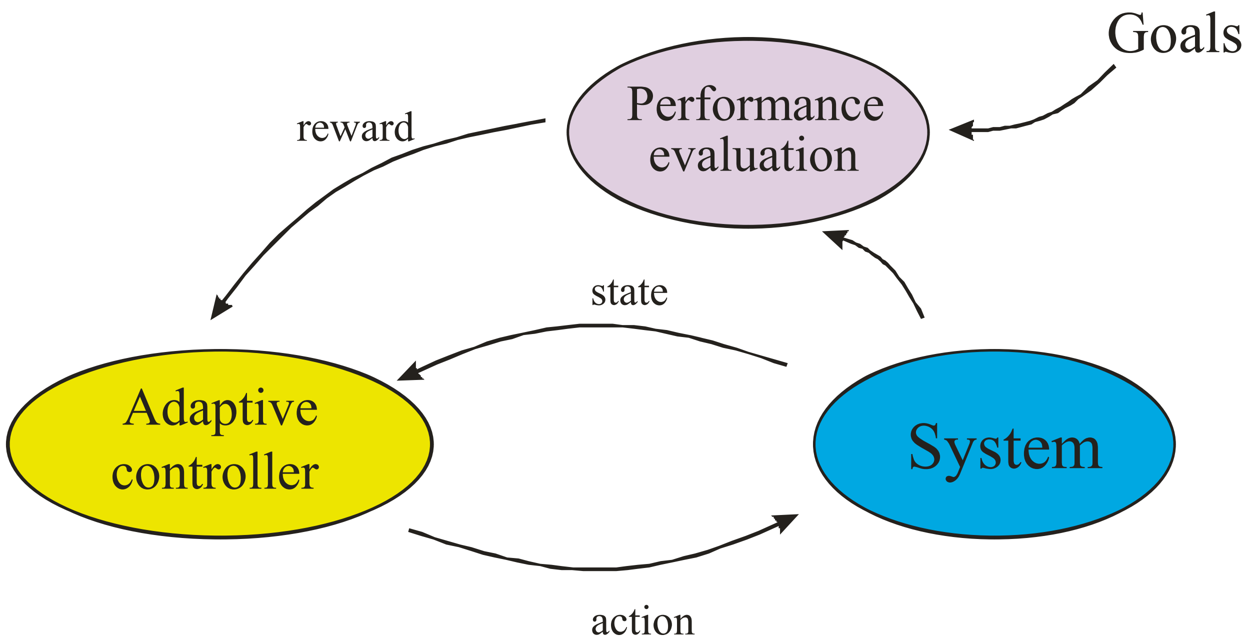
(with ‘teacher’)

Unsupervised learning

(without ‘teacher’)

Reinforcement Learning

Inspiration - animal learning (reward desired behavior)



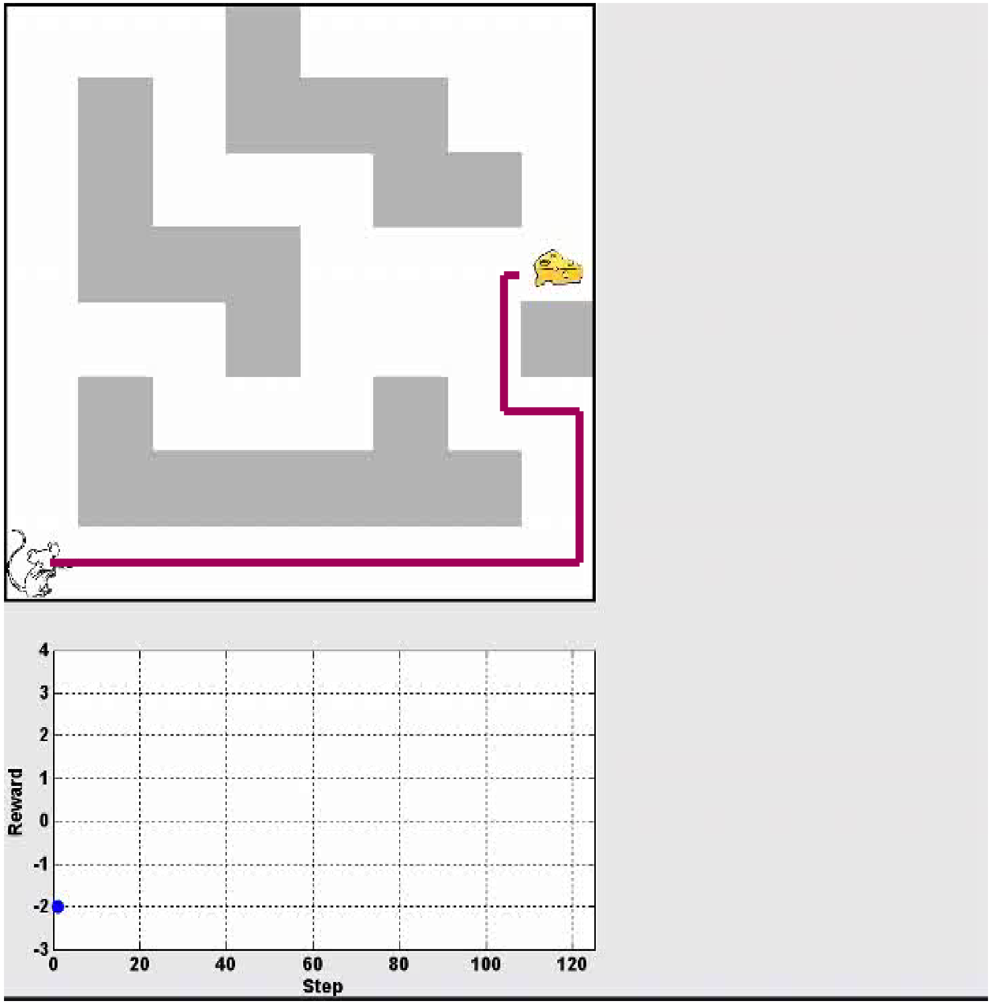
Goal:

Adapt the control strategy so that the sum of rewards over time is maximal.

Reinforcement Learning

Inspiration - animal learning (reward desired behavior)

Example - Learning Optimal Path



Initial position

Reward = -1
(goal not yet reached, energy consumed)

Reward = 3
(goal reached)

Learning in Real World, in Real Time

Long-term Research Goal

Physical models
(*a priori* design)

Constraints
- Performance
- Ethical norms, …

Environment

Learning from
experience

Precocial

Altricial

Robot Control: Traditional View

Task control

Perception, situation awareness

Motion control

Integrated Robot Control

Task control

Perception, situation awareness

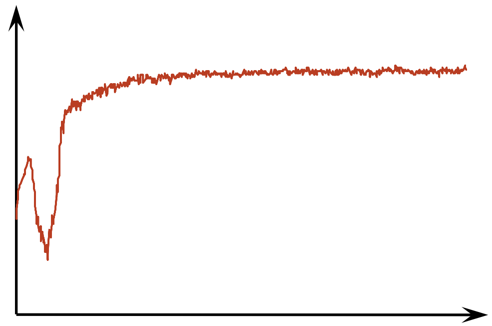
Motion control

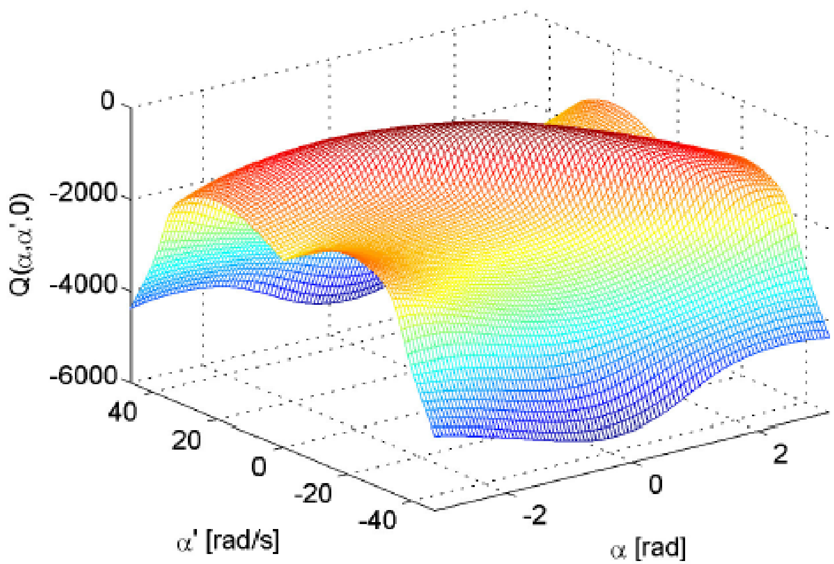
- Interaction
- Learning at all levels
- Robot teams

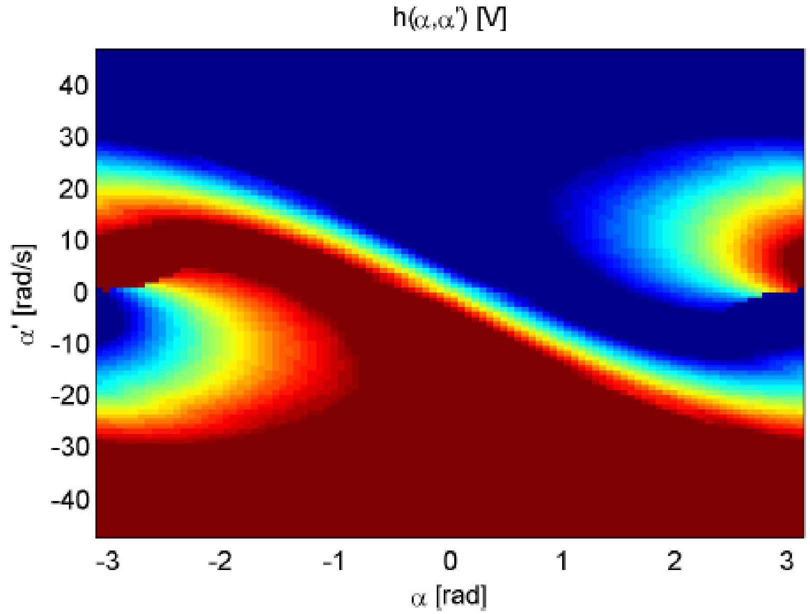
Research Themes

Reinforcement Learning for Control and Planning

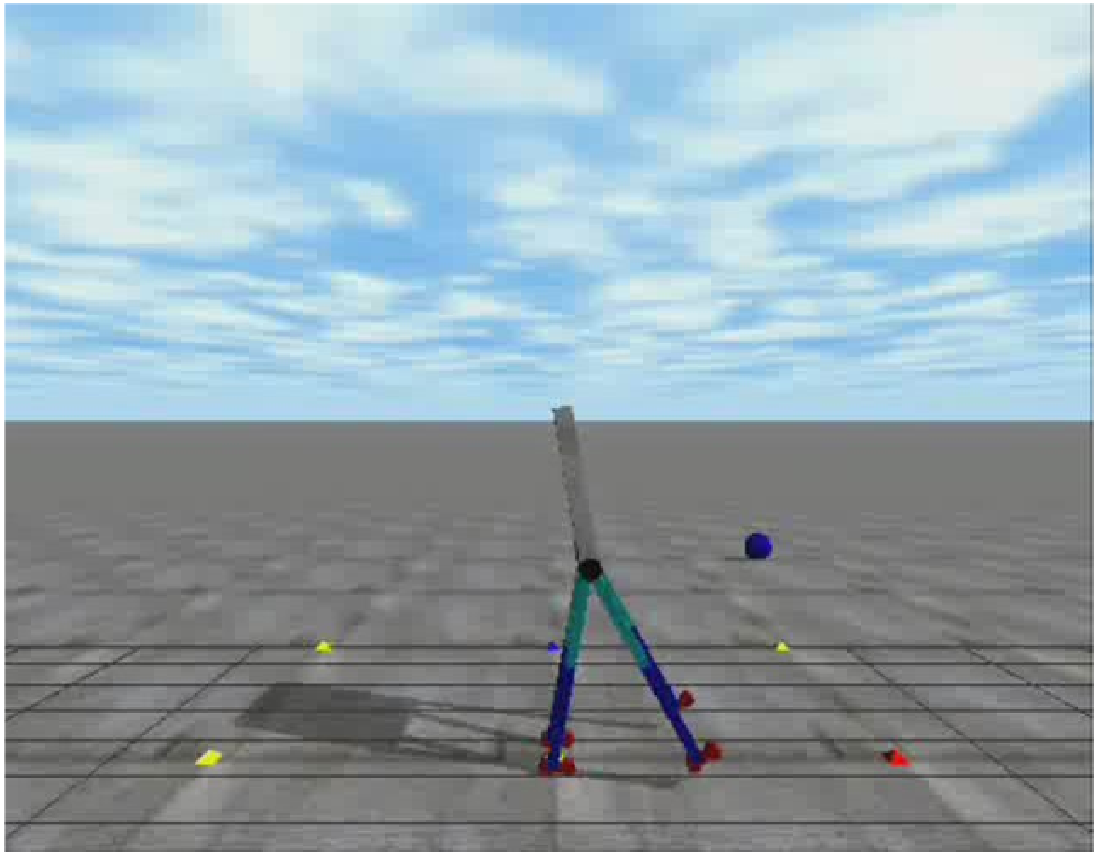
- Approximation in high-dimensional continuous spaces
- Computationally effective methods
- Constrained learning and convergence

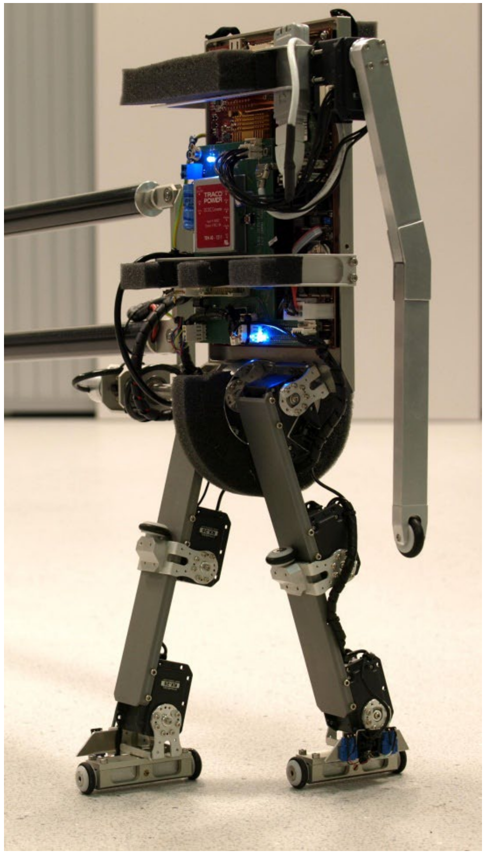






Reinforcement Learning for Bipedal Locomotion





E. Schuitema (collaboration with the Biorobotics Lab, TU Delft - M. Wisse and P. Jonker).

Research Themes

Filtering, estimation and adaptive control

- Distributed filtering and localization
- Nonlinear adaptive methods
- Stochastic estimation

Andrea Simonetto and Tamas Keviczky

Research Themes

Legged locomotion

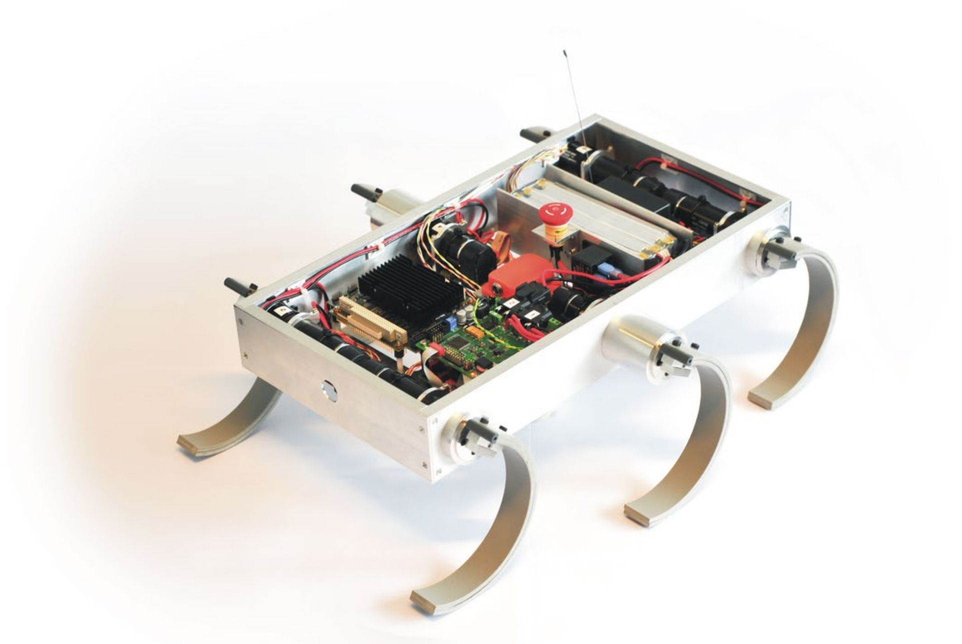
- Gait generation
- Learning and optimization

Robotic manipulators

- Task-oriented control
- Adaptive payload estimation

Software and hardware

- Automatic code generation
- Development of infrastructure



Gabriel Lopes & DCSC engineering team

Integrated Robot Control

Task control

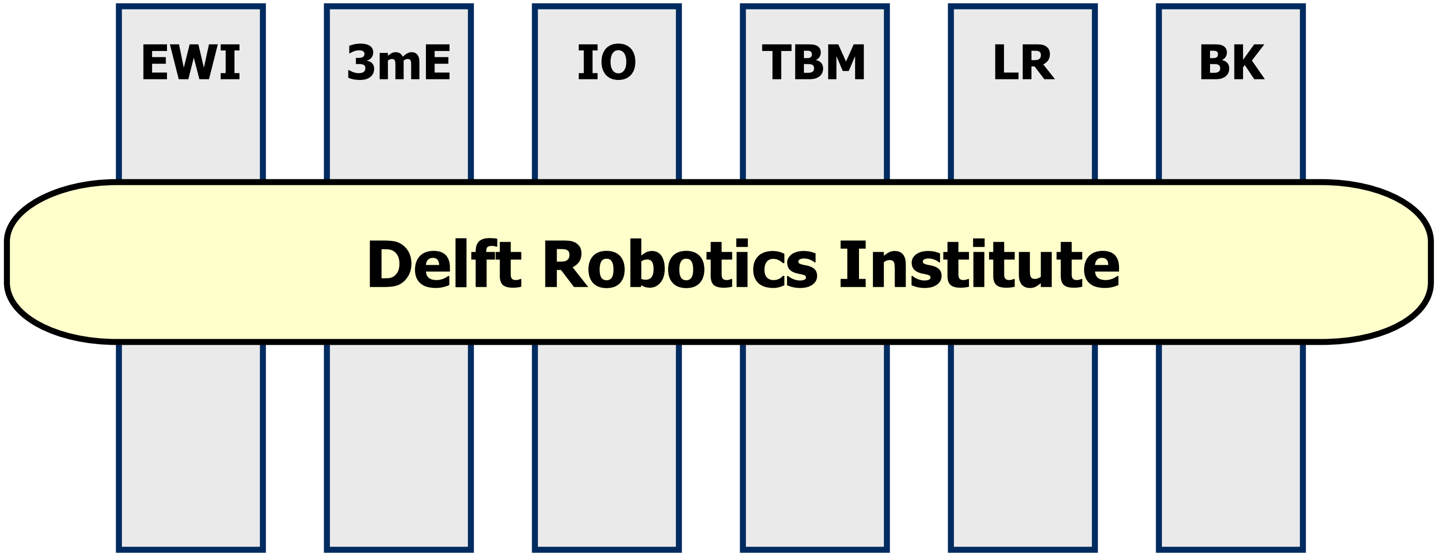
Perception, situation awareness

- Interaction
- Learning at all levels
- Robot teams

Motion control

Coordinated multi-disciplinary research!

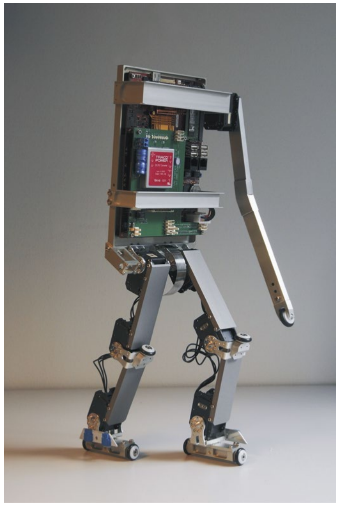
Robotics @ TU Delft

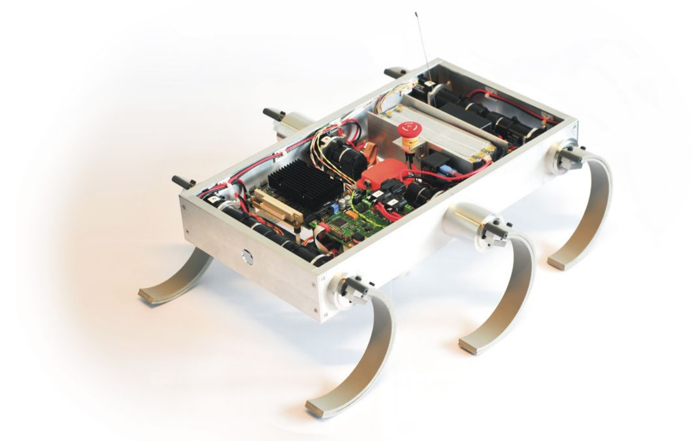


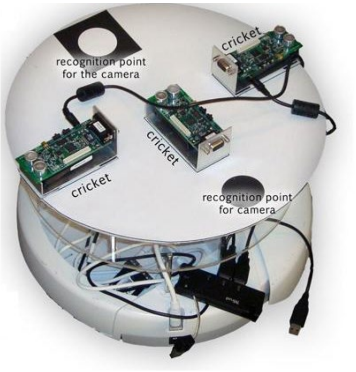
Goal: advance robotics research, education and valorization in a coordinated fashion.

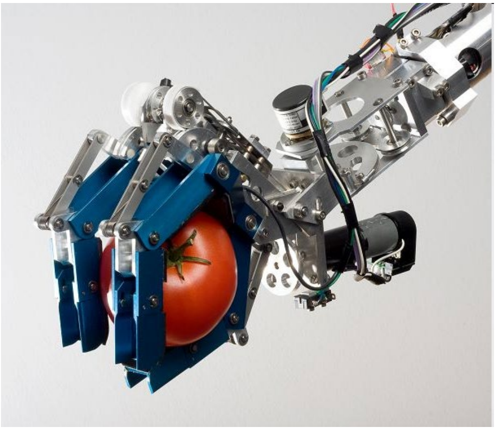
Mechanics, electronics, design, control, sensing, vision, human-robot interaction, …

Research Platforms

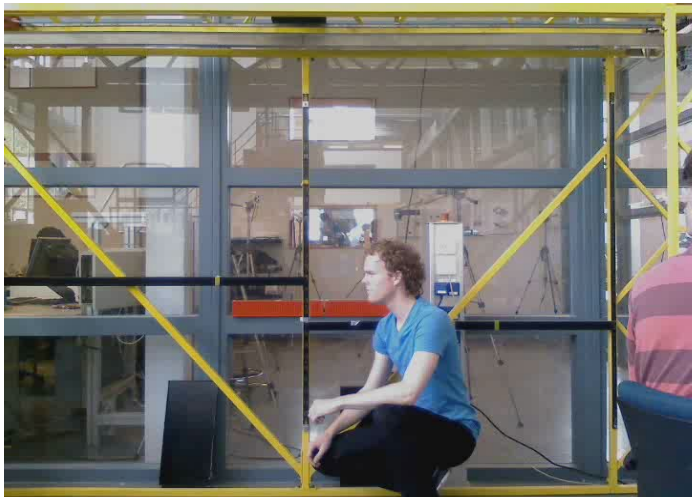








Educational Platforms



Robotics in the Dutch Context

disc dutch institute of systems and control

Acknowledgements

- University board
- Dean of 3mE, Prof. Marco Waas
- Rector Magnificus, Prof. Karel Luyben
- My teachers, mentors, colleagues and students

Special Thanks to

Henk Verbuggen (emeritus professor)

Biggest Thanks to

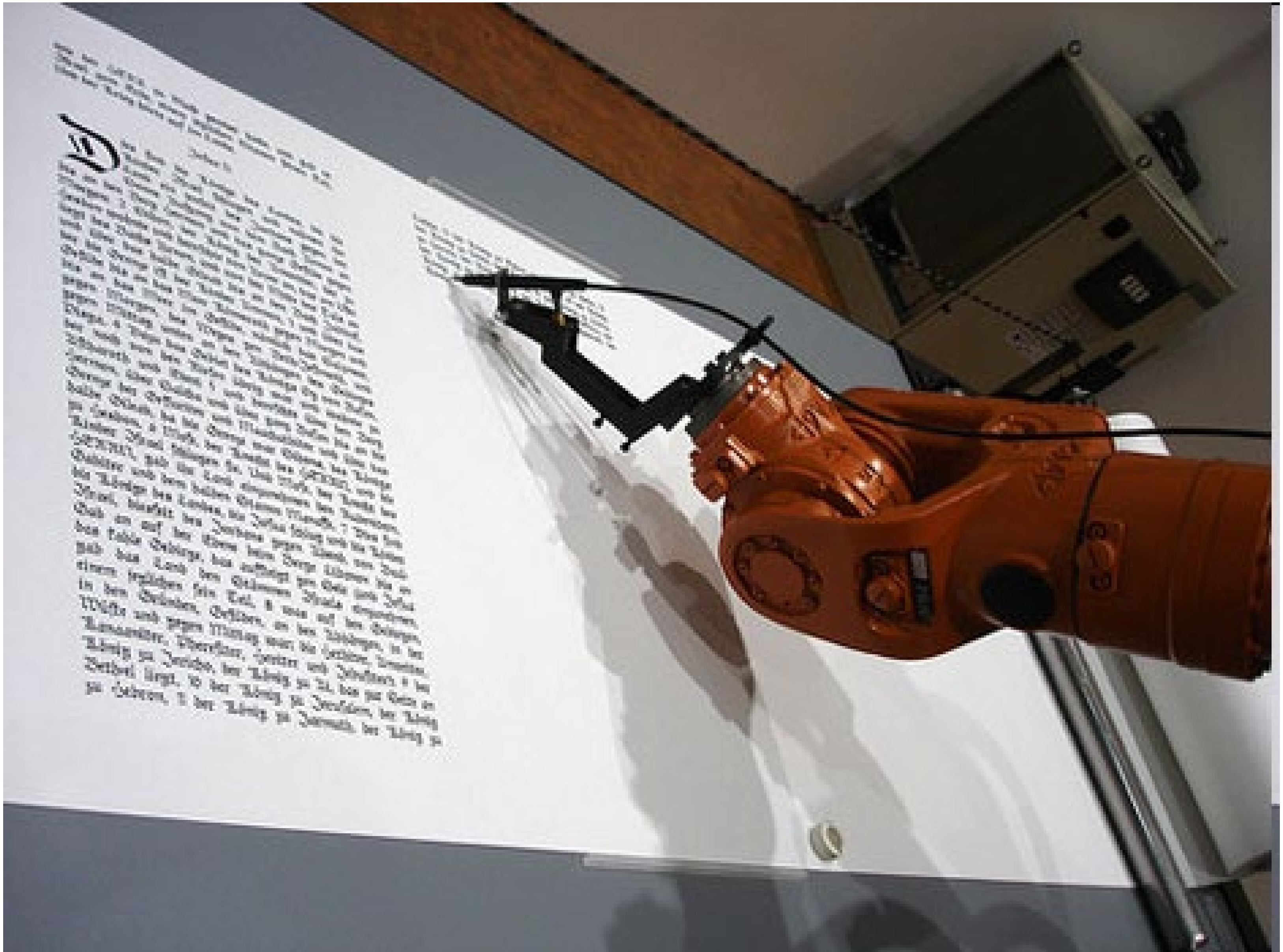
Dana, Markéta and Míša

TECHNISCHE UNIVERSITEIT DELFT

MDCCCXLII

Hard Disk Read/Write Head Control

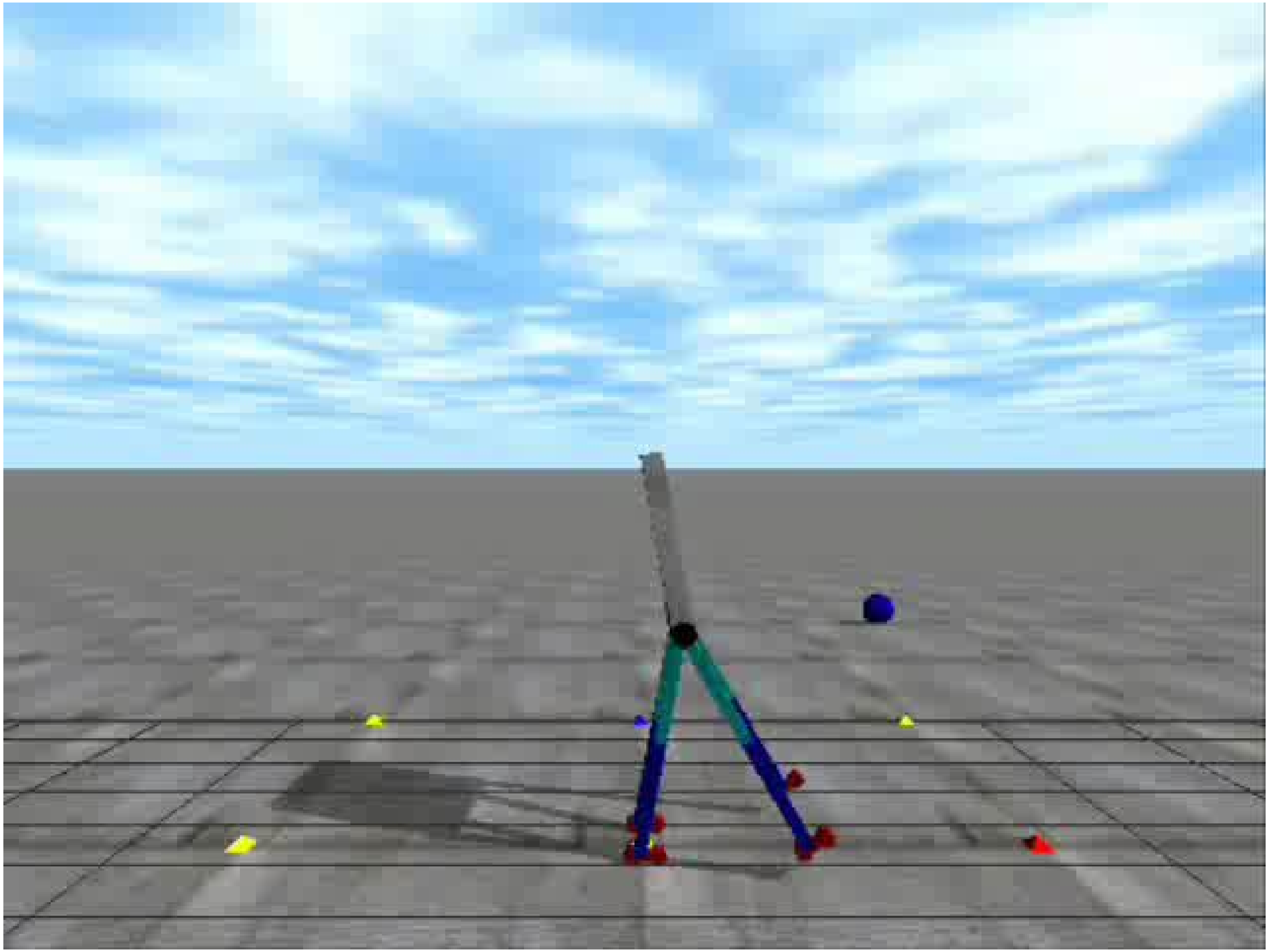
- high-speed, high-precision positioning of the arm
- closed system, little interaction with environment



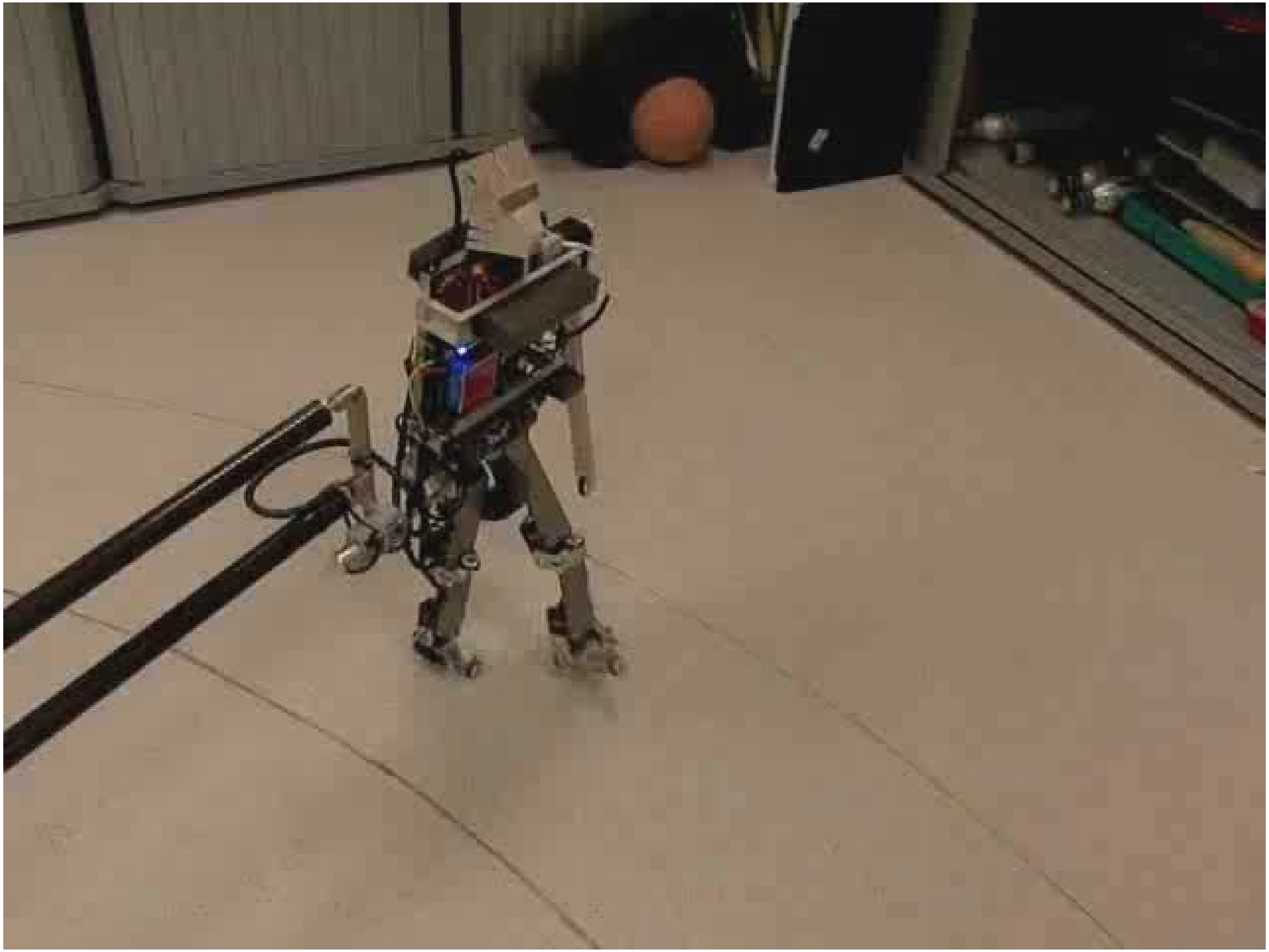

STAPLES

Harvesting Robot

- high-speed, high-precision, gentle handling
- open system, interaction with environment is crucial



E. Schuitema, M. Wisse and P. Jonker



E. Schuitema

RHex project, USA

Possible Convergence Curve