Technische Universität Kaiserslautern

Chapter 1

Principle, structure and application of feedback control

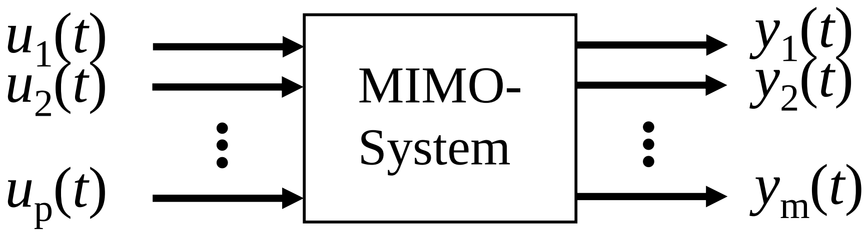
Prof. Dr.-Ing. Steven Liu
Lehrstuhl für Regelungssysteme
Technische Universität Kaiserslautern

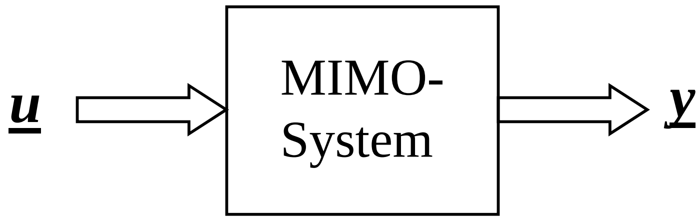
Dynamic systems

A dynamic system is a functional unit containing time-varying *inputs*, *outputs* (and intern *state* variables), which influence each other in a cause-effect relationship. A dynamic system is often mathematically described by differential equations and represented by a functional *block* with signals (input, output).

SISO = single-input single-output

A *SISO system*





A *MIMO system*

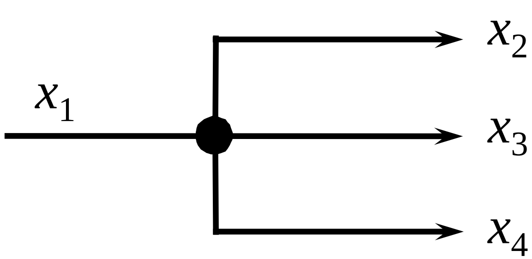
MIMO = multi-input multi-output

Block diagram

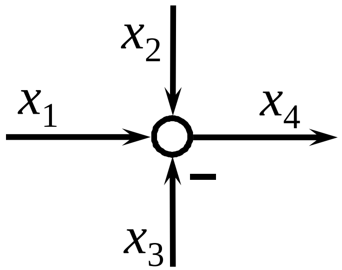
The block diagram shows functional relationship between signals and system components

Basic elements

Signal connections

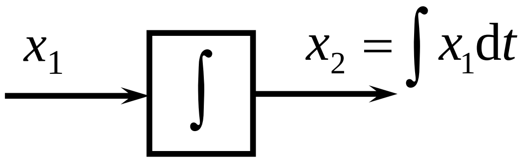


Pickoff point ($x_1 = x_2 = x_3 = x_4$)

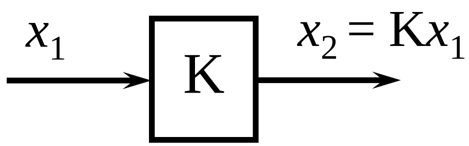


Summing point ($x_4 = x_1 + x_2 - x_3$)

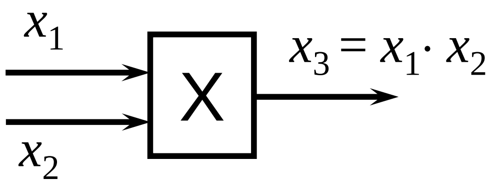
Signal processing (examples)



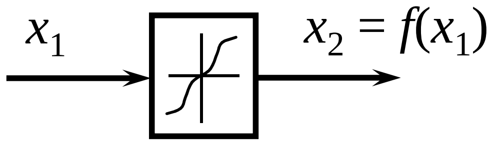
Integrator



Proportional gain



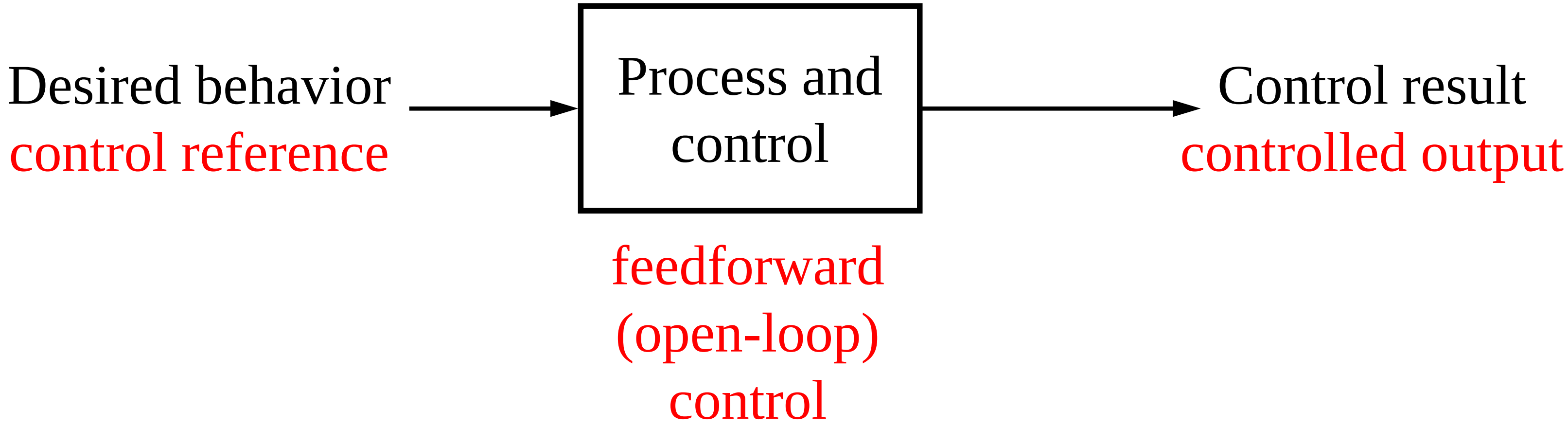
Multiplier



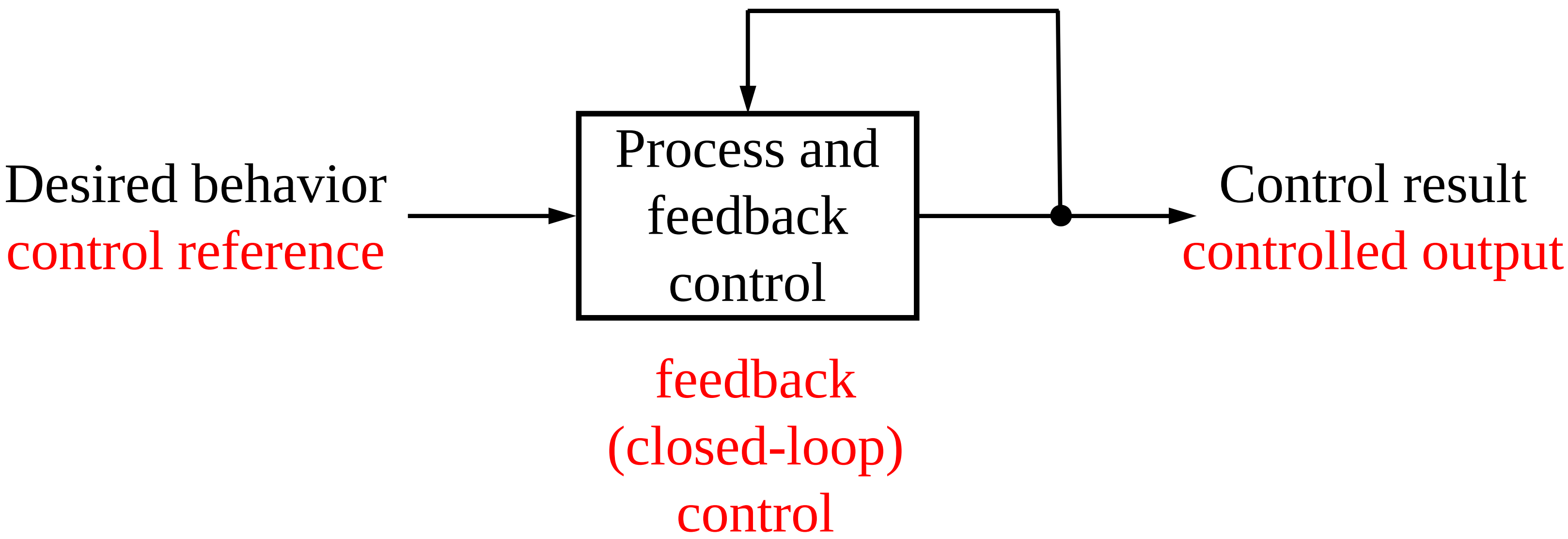
Characteristic curve

Feedforward and feedback control

feedforward control

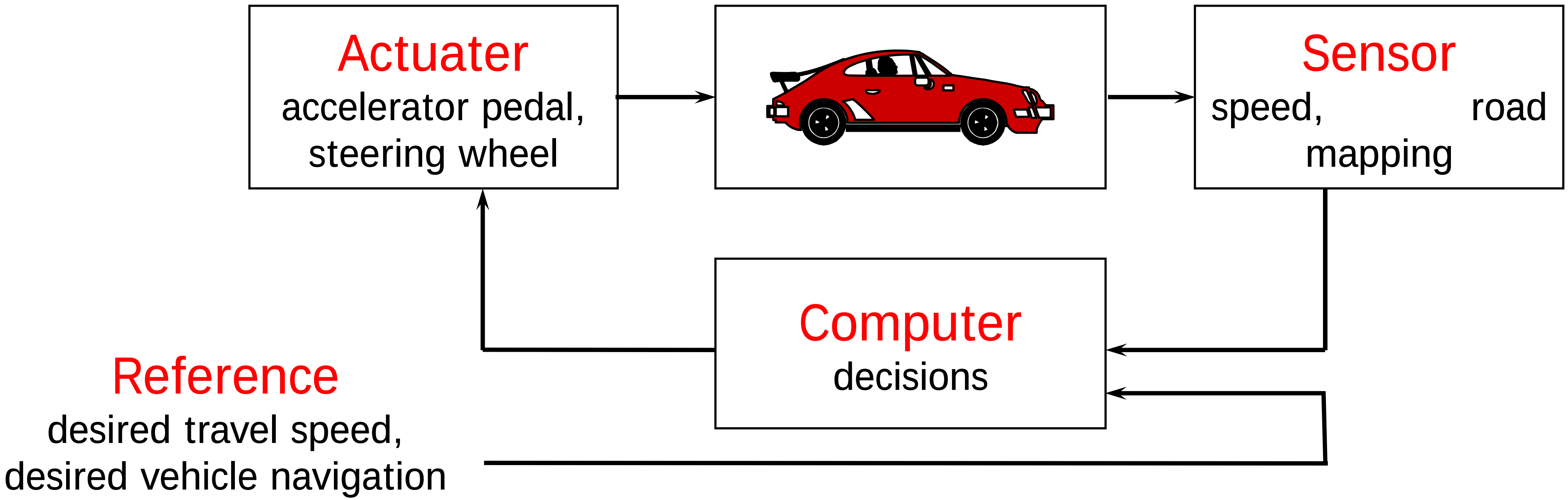


feedback control



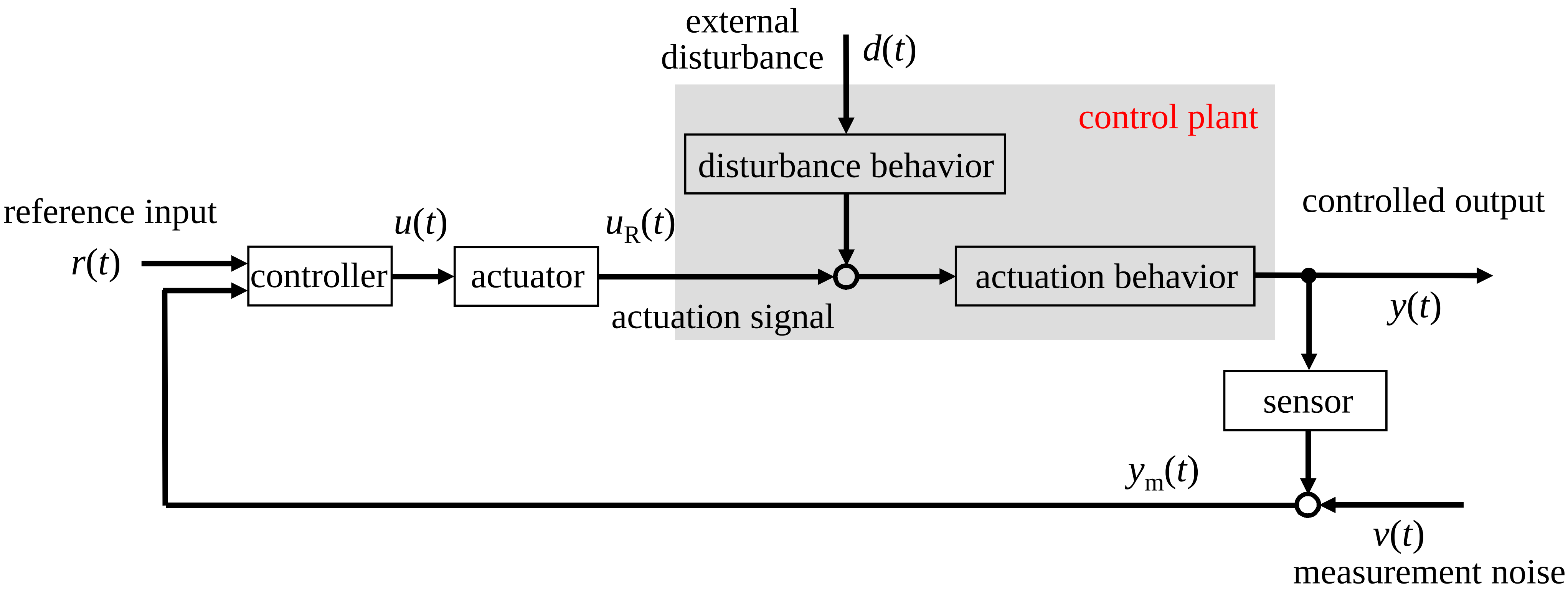
Components and structure of feedback control

Control = Sensing + Computation + Actuation = *Feedback*



Goals: stability, performance, robustness

Feedback control loop



A feedback control loop is a system which monitors its effect on the system it is controlling, returns (a part of) the output for comparing with the desired behavior and modifies its actuation signal accordingly to make the system following the desired output as closely as possible.

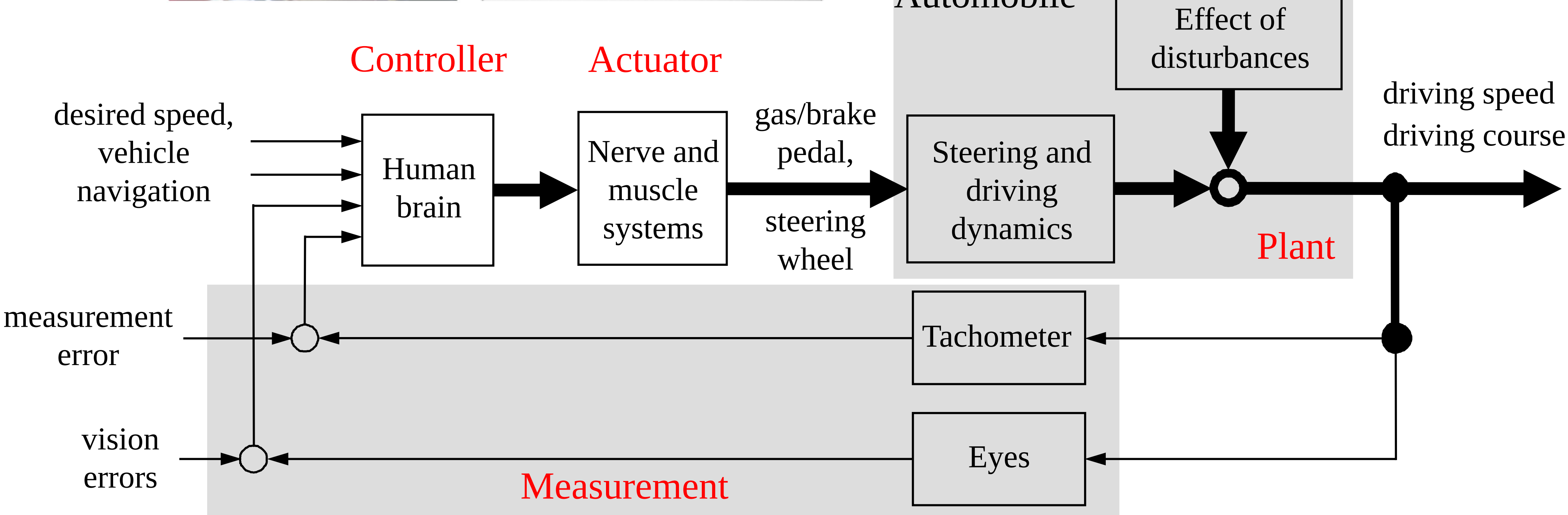
Active excise 1

Stop and think!

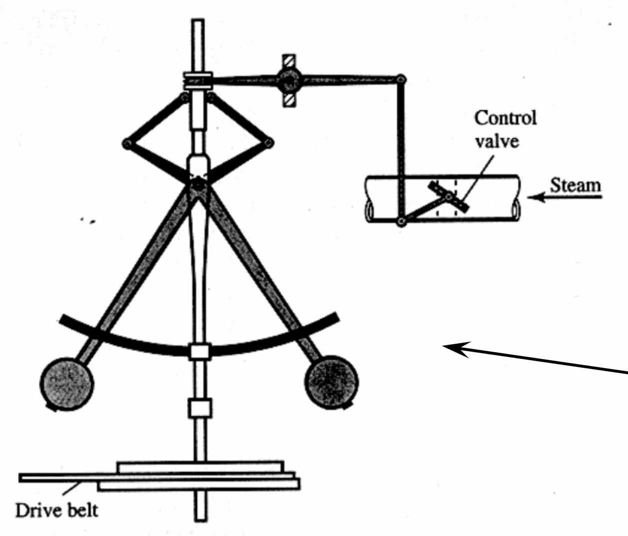
Try to sketch a block diagram of driving an automobile as a feedback control!

Think yourself and discuss with your neighbors!

Driving an automobile as a feedback control



Historical examples of the use of feedback



Flyball governor by J. Watt (1788)

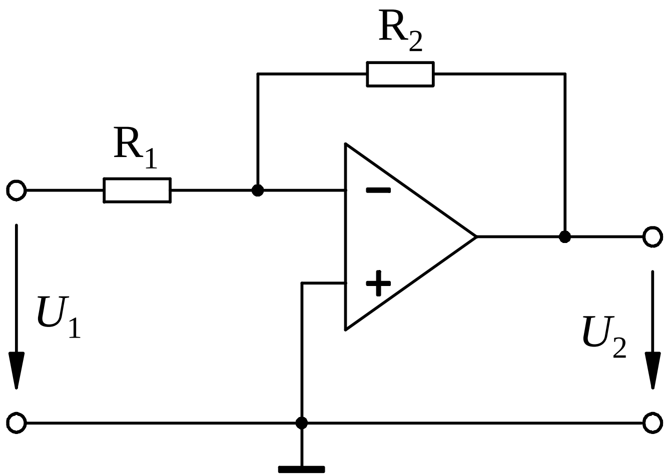
- controls the speed of a steam engine
- reduces the influence of the load (disturbance rejection)

Metal spheres move away from the shaft as the speed increases, thus closing the valve and reduces the steam supply

Negative feedback amplifier by H. S. Black (1927)

- reduces sensitivity and improves stability of an amplifier
- robustness obtained by the principle of negative feedback

Application of negative feedback removes the cause of sensitivity and instability by throw away the excess gain



Modern applications of control engineering (1)

Flight and space vehicle control (examples)

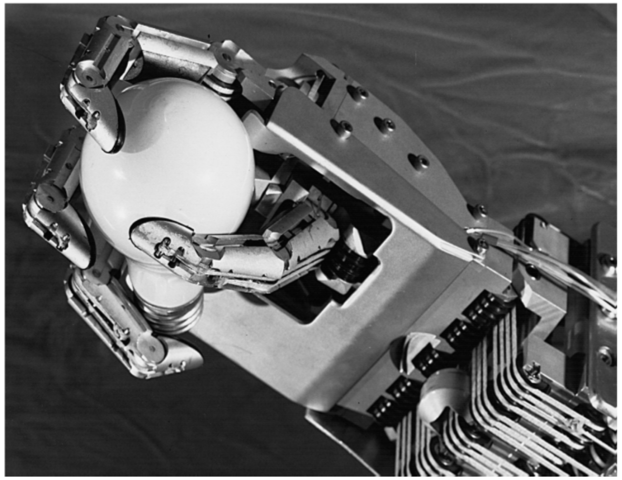
- Modern commercial and military aircrafts are completely electronically controlled (“fly by wire”) (a: airbus A380)
- Autoland systems, unmanned aerial vehicles (UAVs) are already in use
- Coordination of air traffic from airport's control tower
- Mars exploration rover mission

Robotics and mechatronics (examples)

- Highly precise positioning and force control of robot manipulators (b)
- Cooperative mobile robots with embedded sensor and communication systems
- Dynamic and exact control of magnetic head of a disk drive
- Active damping of mechanical oscillations using electromagnetic actuators

(a)

(b)



Modern applications of control engineering (2)

Chemical and process industry (examples)

- Control of mass flow, temperature, concentration etc.
- Long time horizon (low dynamic), but high model uncertainty and safety relevant

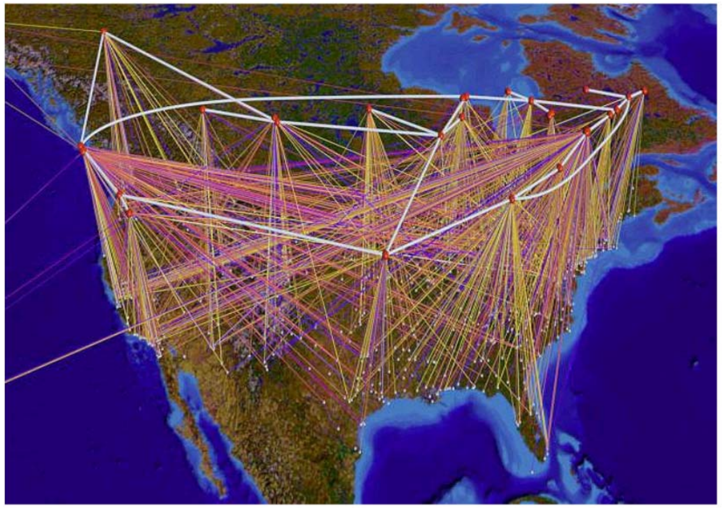
Communication and networks (examples)

- Amplifiers and transducers
- Internet congestion control (c)
- Power management for mobile communication

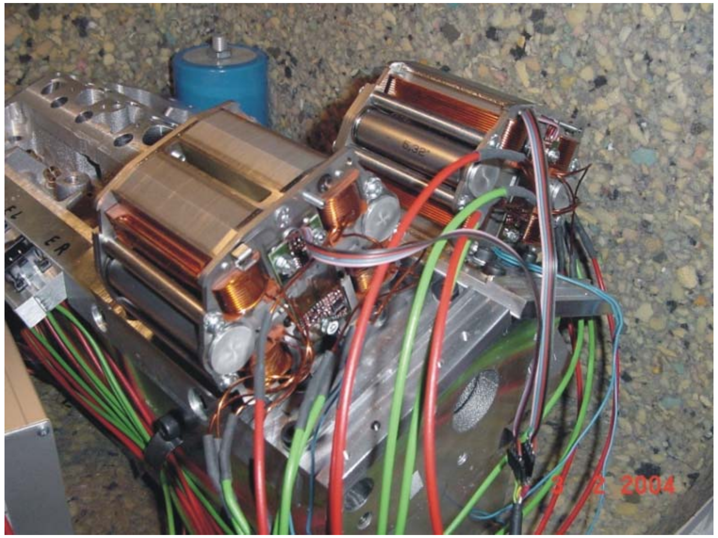
Automotive (examples)

- Engine management, fuel injection control, power train control, cruise and temperature control, vehicle power control, active suspension etc.
- ABS, ESP, ASR, „x-by-wire“ technologies
- Electronic engine valve control (d)

(c)



(d)



Modern applications of control engineering (3)

Railway transport systems (examples)

- TRANSRAPID Control (linear drive + magnetic levitation)
- Traction control at wheel-rail contact
- Energy-optimized driving of trains

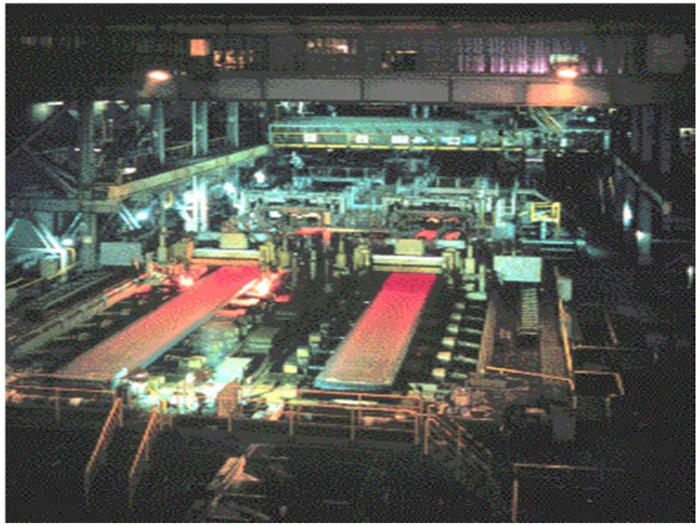
Energy systems (examples)

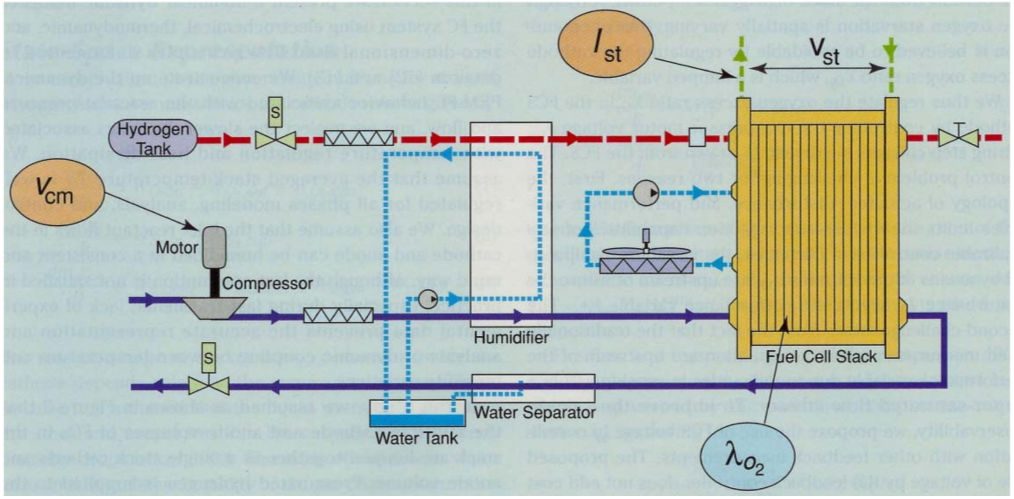
- Frequency and power control of wind energy systems
- MPP (Maximum-Power-Point) control of photovoltaic systems
- Stabilization of large power supply systems
- Control of cathode oxygen and anode hydrogen supply in fuel cell systems (f)

Industrial automation (examples)

- Control of rolling mills (multivariable control) (e)
- Chemical process control
- Production of plastic film, paper, and textile
- Machine tools

(e)





(f)

Modern applications of control engineering (4)

Biological, medical systems (examples)

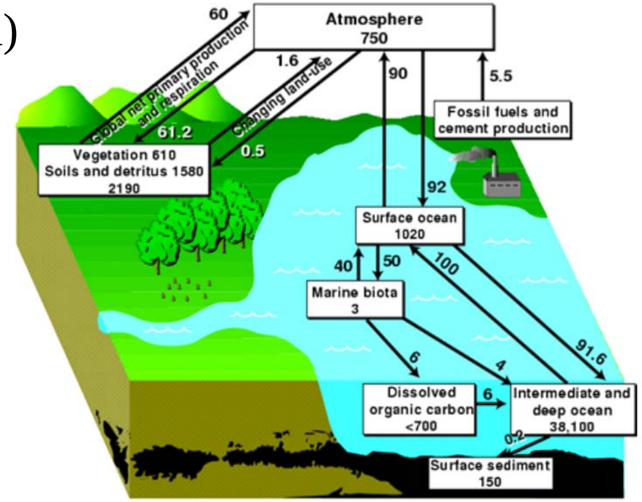
- Physiological regulation (homeostasis)
- Cellular function units (genetic regulatory and anaerobiosis networks)
- Medical robot as surgical assistant (g)

(g)

Environmental systems (examples)

- Microbial ecology (e.g. composting plant)
- Global carbon cycle (h)
- Control of sewage purification plants

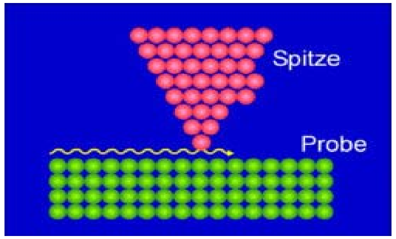
(h)



Micro, quantum, and nanotechnologies (examples)

- Actuators and sensors for Micro-Electro-Mechanical Systems (MEMS)
- Quantum computer
- Scanning Tunneling Microscope (i)

(i)



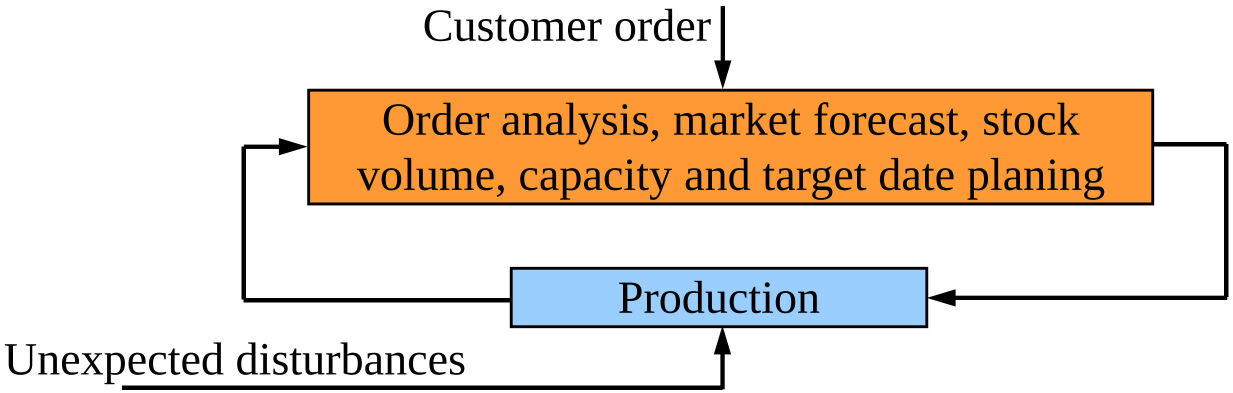
control principle in economy and society

Business management (examples)

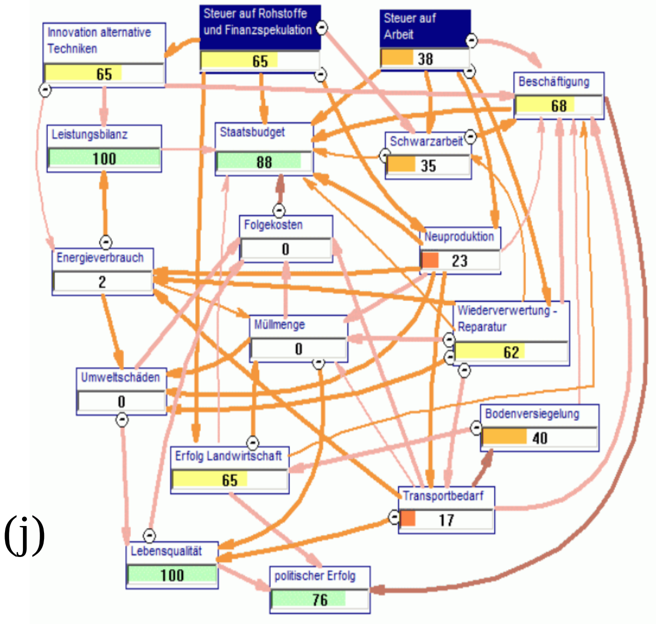
- Production planning systems
- Project controlling
- Supply and logistic chains (j)

Financial systems, economics, and society (examples)

- Tax, economic growth and public finances as control loop
- Interest rate policy, investment and inflation as control loop
- Freshmen/graduates of electrical engineering studies (pork cycle) (k)
- socio-technical dimension of technological innovations



(j)



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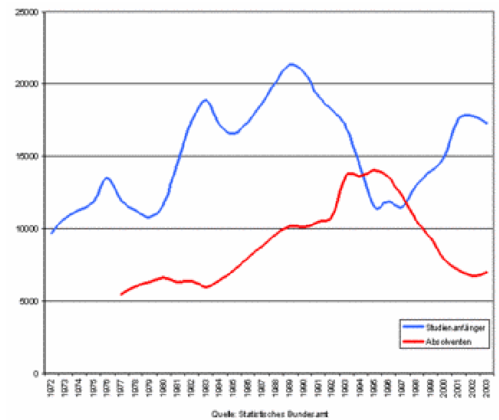


Main characteristics of closed-loop control

Robustness to uncertainty through feedback

- High performance in the presence of model uncertainty and unpredictable disturbances
- Examples: repeatable performance of electronic amplifiers in spite of large component variations; Exact hold of constant room temperature for precision measurement of lengths
- Key idea: accurate sensing to compare actual to desired quantities, correction through computation and actuation

Design of Dynamics through

- Modification of the dynamics of a system using control
- Example: stability augmentation for highly agile, unstable aircraft
- Key idea: Modification of natural system behavior through structural augmentation (feedback)

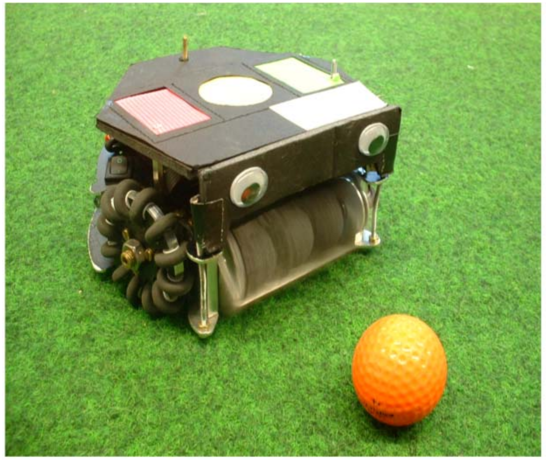
An interdisciplinary control example: control of quadcopters

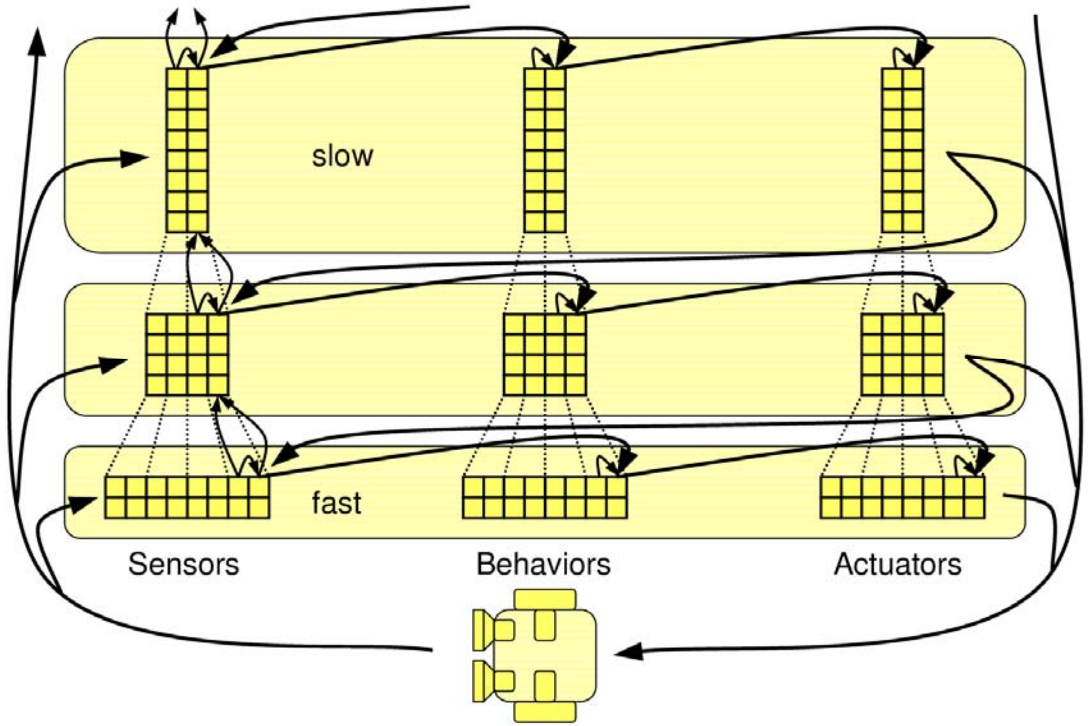
https://www.youtube.com/watch?v=w2itwFJCgFQ&ab_channel=TED

An interdisciplinary control example: the RoboCup (1)

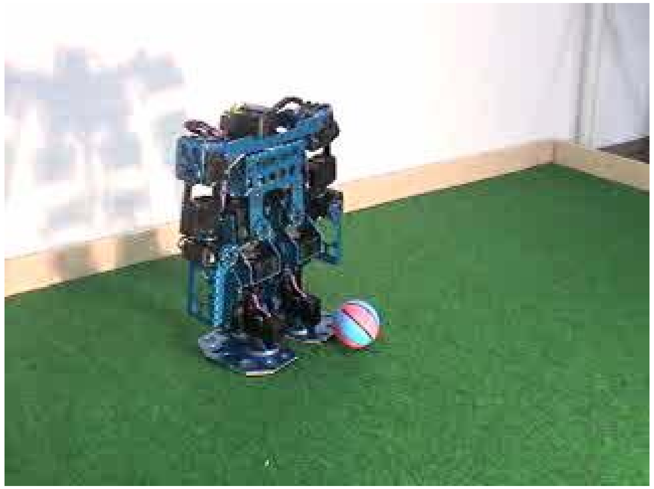
RoboCup, the soccer world championship for autonomous robots (divided in three leagues)

- Completely autonomous
- Centralized hierarchical behavior control + decentralized microcontroller-based motion control
- Central video camera as sensor
- Radio or bluetooth communication
- Linear electromagnetic shooting and dribbling mechanism





An interdisciplinary control example: the RoboCup (2)



An interdisciplinary control example: DARPA Race (1)

The 2005 DARPA Grand Challenge

- Fully autonomous ground vehicles
- 132 miles (ca. 210 km) across Mojave Desert, Nevada/USA
- Time limit: 10 h

The winner:

- Stanford University "Stanley"
- 6 h 54 min., average speed: ca. 30 km/h

Real-time control of autonomous robot vehicle with extremely complex signal and image processing and adaptive control structures

The 2007 DARPA Urban Challenge

- Fully autonomous ground vehicles
- 60 miles (ca. 95 km) urban course, Nevada/USA
- Time limit: safely in less than 6 h

An interdisciplinary control example: DARPA Race (1)

Real-time control of autonomous robot vehicle with extremely complex signal and image processing and adaptive control structures

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An interdisciplinary control example: DARPA Race (2)

The 2007 DARPA Urban Challenge

- Fully autonomous ground vehicles
- 60 miles (ca. 95 km) in urban traffic
- Time limit: 6 h
- GPS signal can be used
- Compliance with the driving laws
- Seven officially funded racing teams
- Four further track B teams (two from D)

The winner:

- Carnegie Mellon University "Tartan Racing"
- 4 h 10 min.

  Average cruising speed: ca. 23 km/h

Methods and tools

Modeling (mathematical description of technical processes)

- Input-output relationship and state-space description using differential equations (system components + interconnection rules)
- Theory and algorithms for experimental determination of system model and its parameters
- Theory and algorithms for reduction of model complexity

Analysis (determination of system properties)

- Stability of closed-loop control systems
- Control loop behavior with respect to dynamic, steady-state error, disturbance rejection and robustness to parameter variations

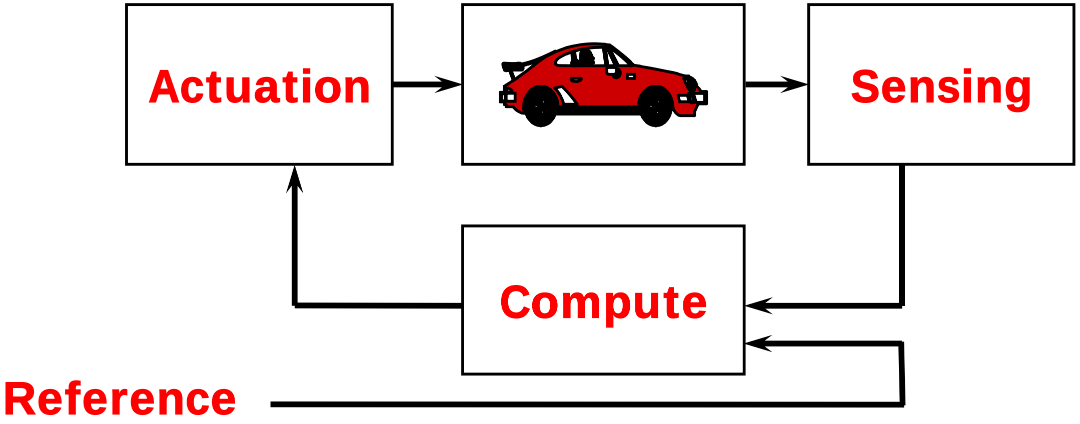
Synthesis (design of control systems)

- Design methods for meeting desired specifications
- Design methods for signal processing and state estimation
- Design methods for optimizing the control

(Software-)Tools

- MATLAB (MathWorks)
- SIMULINK (MathWorks)
- SciLab (Freeware)
- DynLab (Uni Bochum)
- LabView (Nat. Instrum.)
- …

Summary



Control =

Sensing + Compute (Compare) + Actuation

Closed-loop principle (Feedback)

- Robustness to disturbances and uncertainties
- Design/modification of dynamics

There are many examples of the feedback principle in nature and technology