Universität Stuttgart
Institut für Steuerungstechnik
der Werkzeugmaschinen
und Fertigungseinrichtungen

MEDIS – Module 2

Microcontroller based systems for controlling industrial processes

Chapter 1: Introduction to microcontrollers and process control

M. Seyfarth, Version 0.1

Aims of the module

- Understand Architecture and Programming of Microcontrollers
- Understand Basics of Industrial Processes
  - Sensors and Actuators
  - Measurement and Control
- Deep Knowledge of Functions and Programming of Microcontrollers
- Use of Project Management Methods

Organisational Structure

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- Learning activities are based on a Problem Based Learning (PBL) Approach
- Duration: 5 hours presence time on one day per week, 15 weeks; at least the same time for preparation and follow-up
- Learning activities:
  - Lectures
  - Laboratory session
  - Seminars
  - Mini-project
  - Final discussion

Contents of the module

1. Introduction to microcontrollers and process control
2. Project management and project planning
3. Input-/Output system of microcontrollers
4. Timer and interrupt functions on microcontroller systems
5. Graphic systems for microcontrollers
6. Communication systems on microcontrollers
7. Implementation of Control methods on microcontrollers
8. Integration and validation

Schedule

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Type	Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
INTRODUCTION																
Lecture	Introduction to microcontrollers; architecture of microcontrollers	x														
Lab	Development environment; connection of microcontroller to PC	x														
Lecture	Introduction to Process Control and mini project		x													
Seminar	C programming basics		x													
PROJECTMANAGEMENT																
Project	Formal specification of the mini-project		x													
Project	Analysis of project specification			x												
Seminar	Project managment			x												
Project	Project planning, management and timetable of mini-project				x											
Project	Design of mini-project					x										
Seminar	Discussing mini-project status										x					
Lab	Tools for project documentation														x	
Seminar	Project documentation strategies														x	
I/O-SYSTEM of microcontrollers																
Lecture	Digital I/Os of microcontrollers			x												
Lab	Digital I/O			x												
Lecture	Analog I/Os of microcontrollers				x											
Lab	Analog I/O				x											
Lecture	Amplifier circuits for actuators and sensors					x										
Lab	Build up a basic amplifier circuit					x										
Seminar	Libraries					x										
Lecture	State machines, scheduling						x									
Seminar	Software tools for modeling of state machines						x									
Project	Using libraries in the mini-project						x									
TIMER AND INTERRUPT HANDLING																
Lecture	Timer Handling							x								
Lab	Basic timer functions							x								
Project	Implementing digital I/O							x								
Lecture	Interrupt handling								x							
Lab	Basis interrupt functions								x							
Project	Implementing analog I/O								x							
GRAPHIC SYSTEM																
Lecture	Displays and graphic routines									x	x					
Lab	Basic Display functions									x						
Project	Implementing state machine and controller									x						
Lab	Advanced display functions										x					
Project	Implementing display										x					
Project	Implementing user interface											x				
COMMUNICATION between microcontrollers																
Lecture	Communication between different microcontrollers												x	x		
Lab	Basic communication methods (Serial)												x			
Project	Communication to other liquid tanks												x	x		
Lab	Advanced Communication Methods													x		
Lecture	Communication between different microcontrollers														x	
CONTROL METHODS																
Lecture	Closed Loop Controller: modeling and algorithms											x				
Lab	Programming closed loop controllers											x				
INTEGRATION AND VALIDATION																
Project	Module integration and documentation of the mini-project.														x	
Lecture	Testing microcontroller projects															x
Seminar	Test and validation strategies															x
Project	Test and validation of the project; documentation of the mini-project															x

1.1 Sample Applications

1.2 Definition of Basic concepts

1.3 Classification of Control Technology

1.4 Structure and Components of a Control system

1.5 Microcontrollers – Types and Architecture

1.6 Basics of Process Control in Industry

Applications with microcontrollers

Microcontrollers are often used in embedded systems. **Embedded system** means an integrated computer built-into a device for control, regulation and monitoring tasks.

Typical applications:

- Washing machine
- Microwave oven
- Air bag in a car
- Anti-lock brakes (ABS)
- DVD players
- Televisions
- Printers, scanners, cameras
- Mobile phones, phones
- Toys
- Blood glucose meter, blood pressure meter
- Inertial navigation system, …






1.1 Sample Applications
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Automation technology

Definition:

- **Automatic machine** (from the Greek "automatos": moving on its own). According to DIN 19233, an automatic machine is an artificial system in which a programmed process runs automatically.

- **Automation technology** descripes the interdisciplinary application of measurement, control, closed-loop-control and drive technology, taking into account the selection of suitable hardware and the application of software engineering methods and procedures for the automation of technical systems.

Technical process

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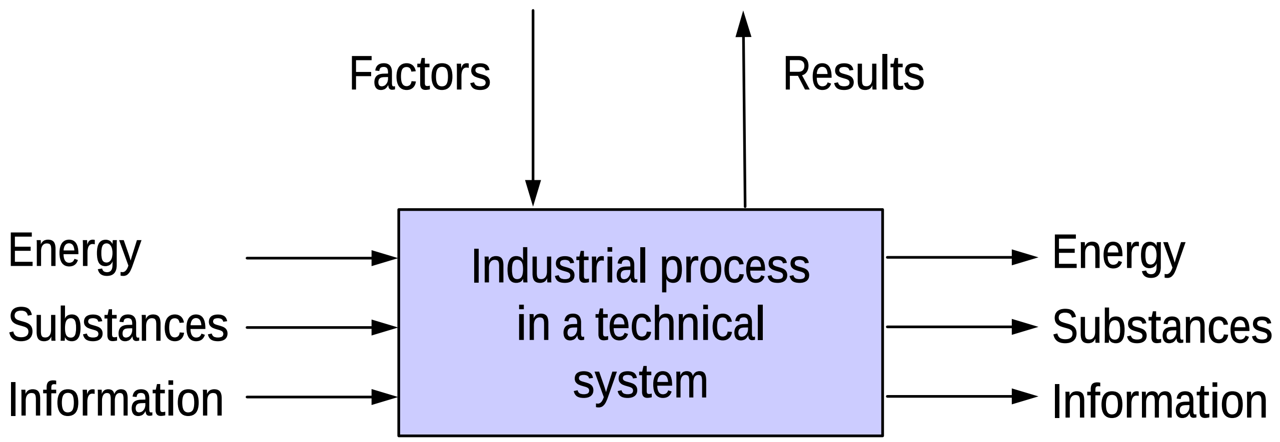
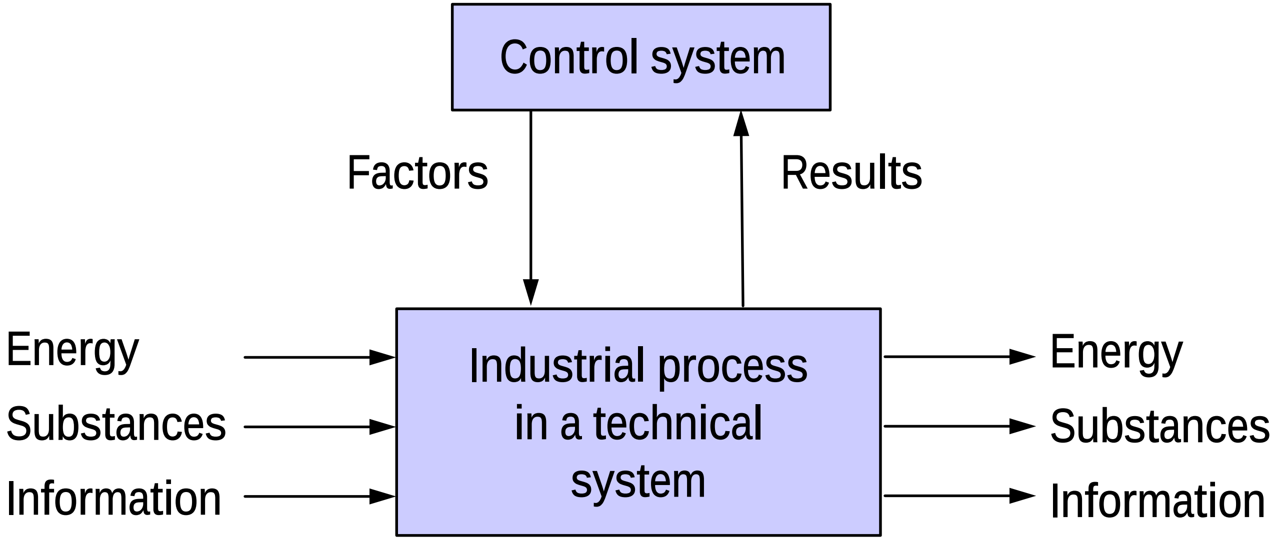
Definition (DIN 66201)

- A **process** is a set of interacting operations in a **system** by which substances, energy or information are transformed or stored.



Control Task

- Affect a process or system, so that a desired aim is reached.



Example: Industrial process

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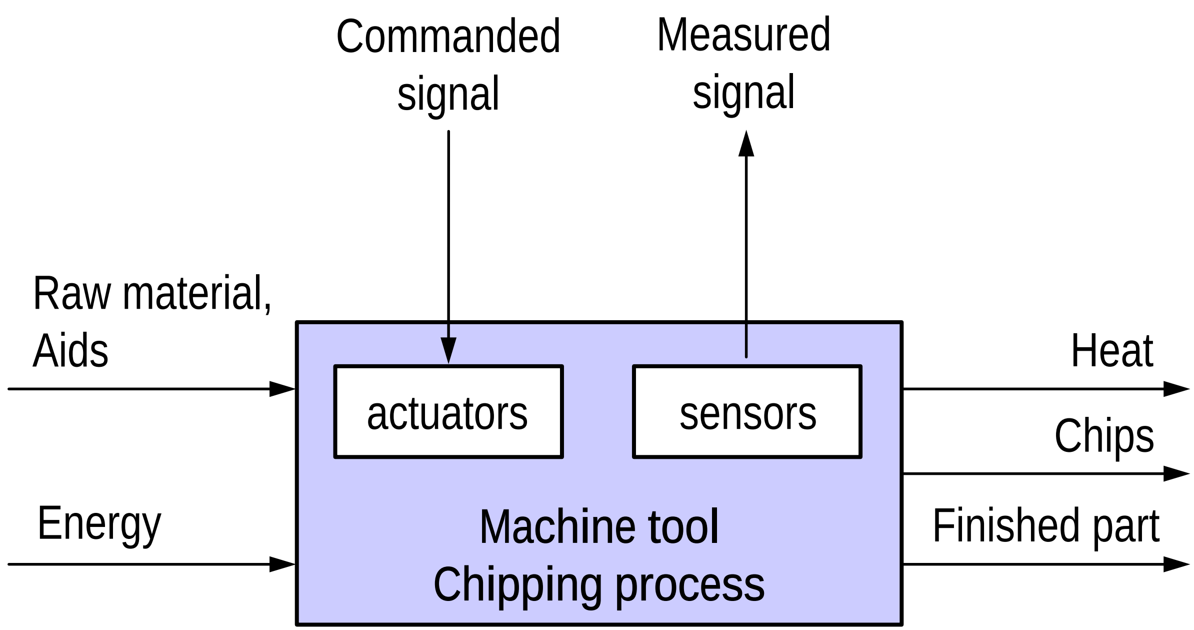
- Industrial process: chipping process
- Technical system: machine tool



Operations in industrial processes

Type of operation	Mathematical modell
• continuous processes, dynamic processes	• Differential equations, transfer functions
• sequential processes, discrete event type processes	• Flow diagrams, state models, petri nets
• discrete object type processes	• Simulation models, queue models, graphs, petri nets

Example: Operations in industrial processes

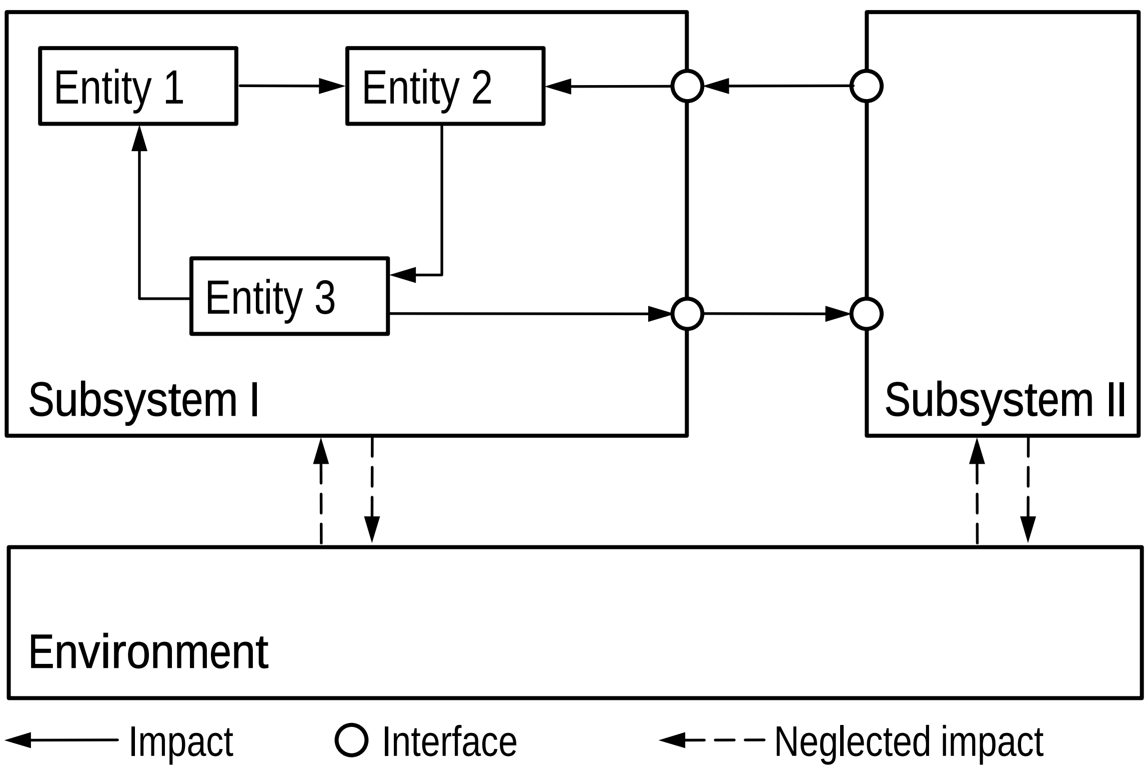
Example: Production of a turned piece

- Transportation of raw material is a discrete object type process
- Production sequence like “Clamp raw material”, “Move tail stock”, … is sequential process
- Chipping process during turning is a continous process

System

Definition (DIN 19226)

- A system is a given arrangement of entities that are interrelated. This arrangement is delimited from its environment due to certain requirements.
- The system parameters are variables whose values characterize the behavior of the system with a given structure.



Example: System delimitation electrical drive

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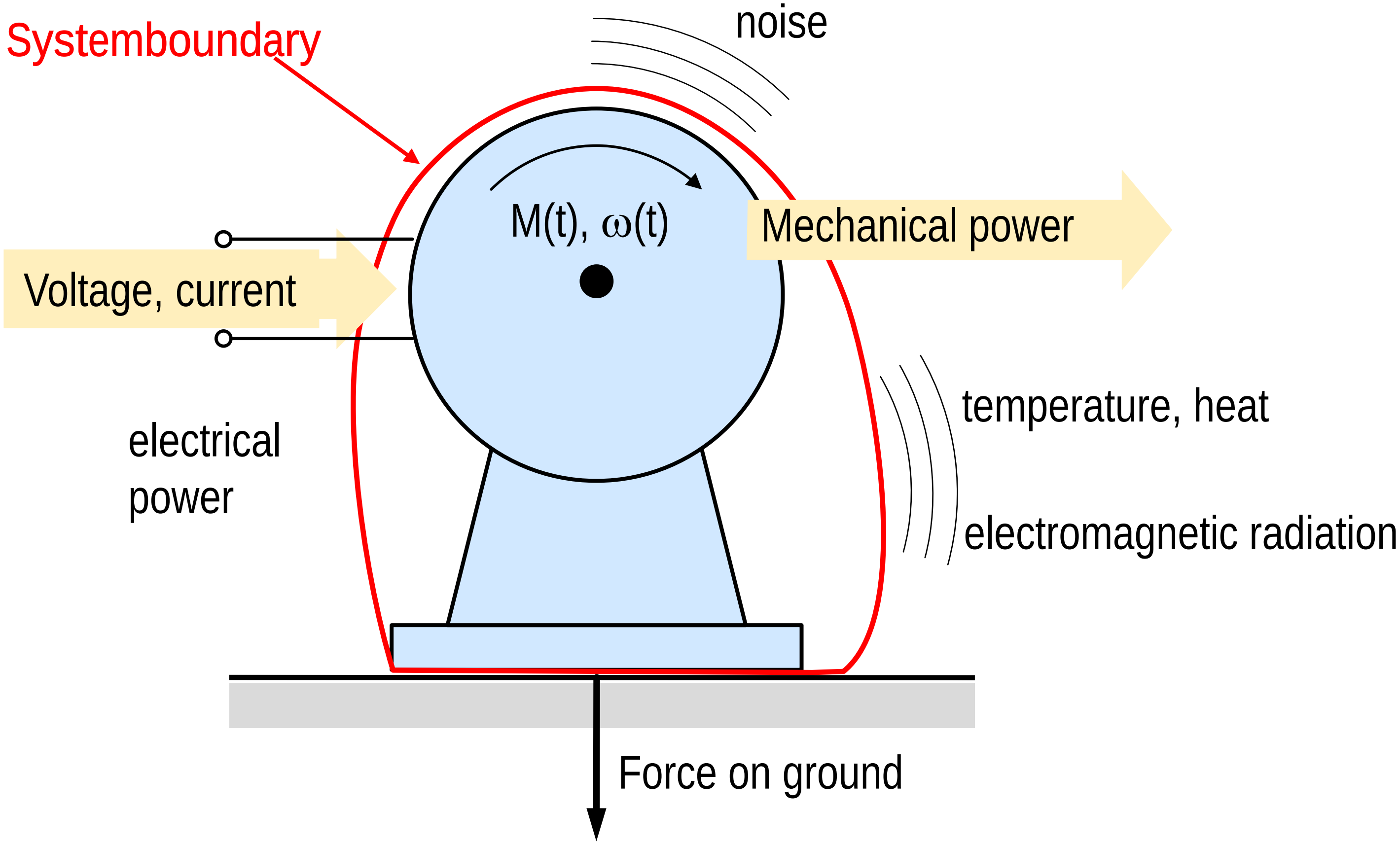
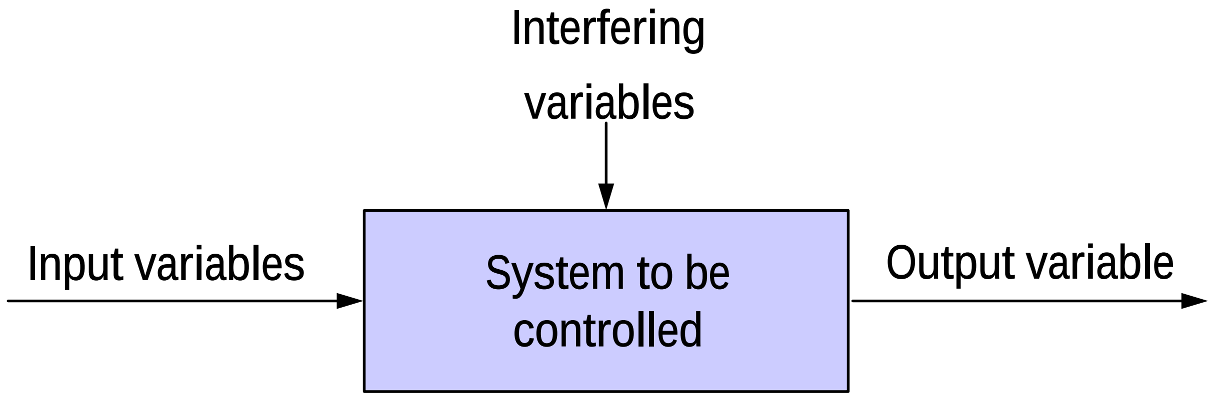


System interfaces

- Input- and Output variables
  - Known, can be measured.
- Interfering variables, disturbances
  - Unintended effects
  - Influence from outside the system boundaries
  - Incompleteness of the system model (neglected repercussions, inexact parameters)



Impact

Definition (DIN 19226)

- **Impact** is the influence of a variable to one or more other variables.
- The **impact path** is the one way along which impacts go through the system.
- The **line of impact** is the process in impact path in which the causal variable changes the influenced variable.

Control

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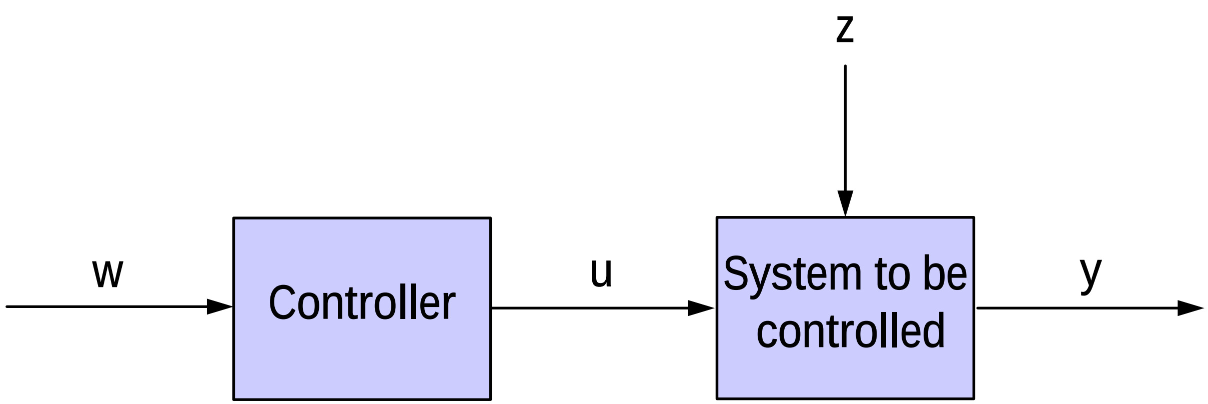
Definition (DIN 19226)

- Control is a process in a system by which the output variables can be influenced selectively through the input variables of the system.
- Indicative of a control is the open line of impact.



w: Reference variables, setpoint values

u: Control variables

y: Output variables

z: Interfering variables

Example: Control (1)

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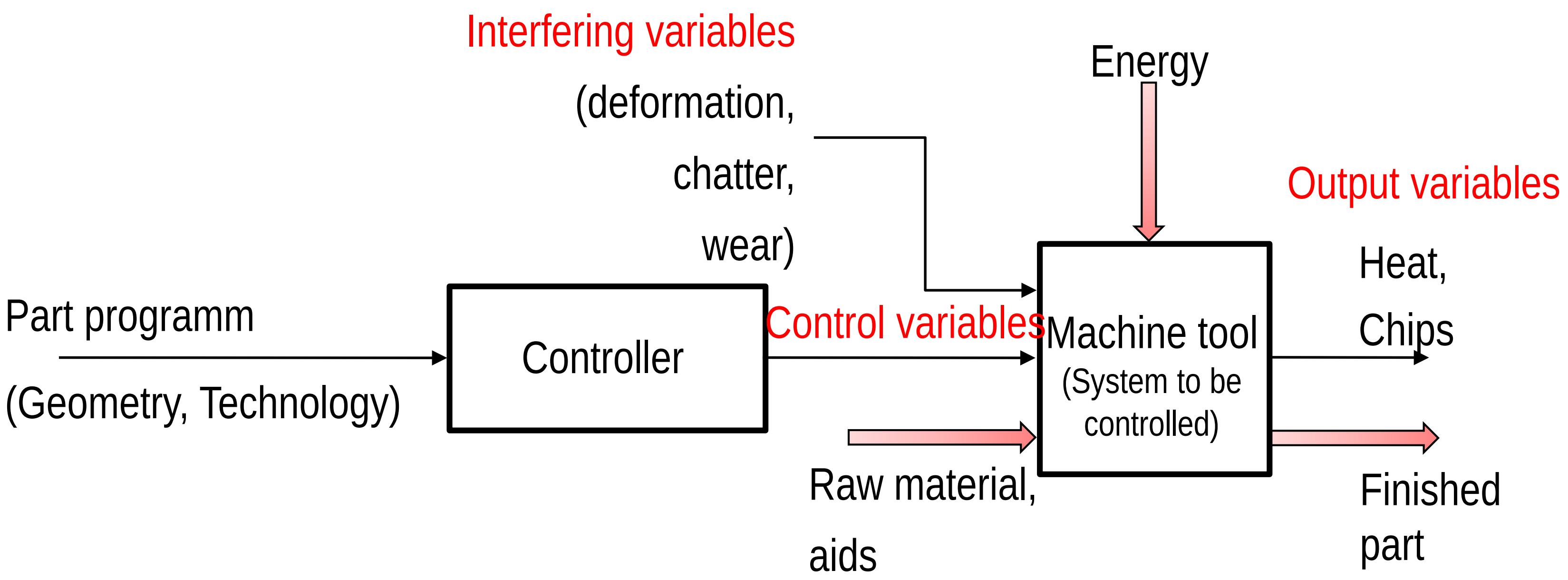
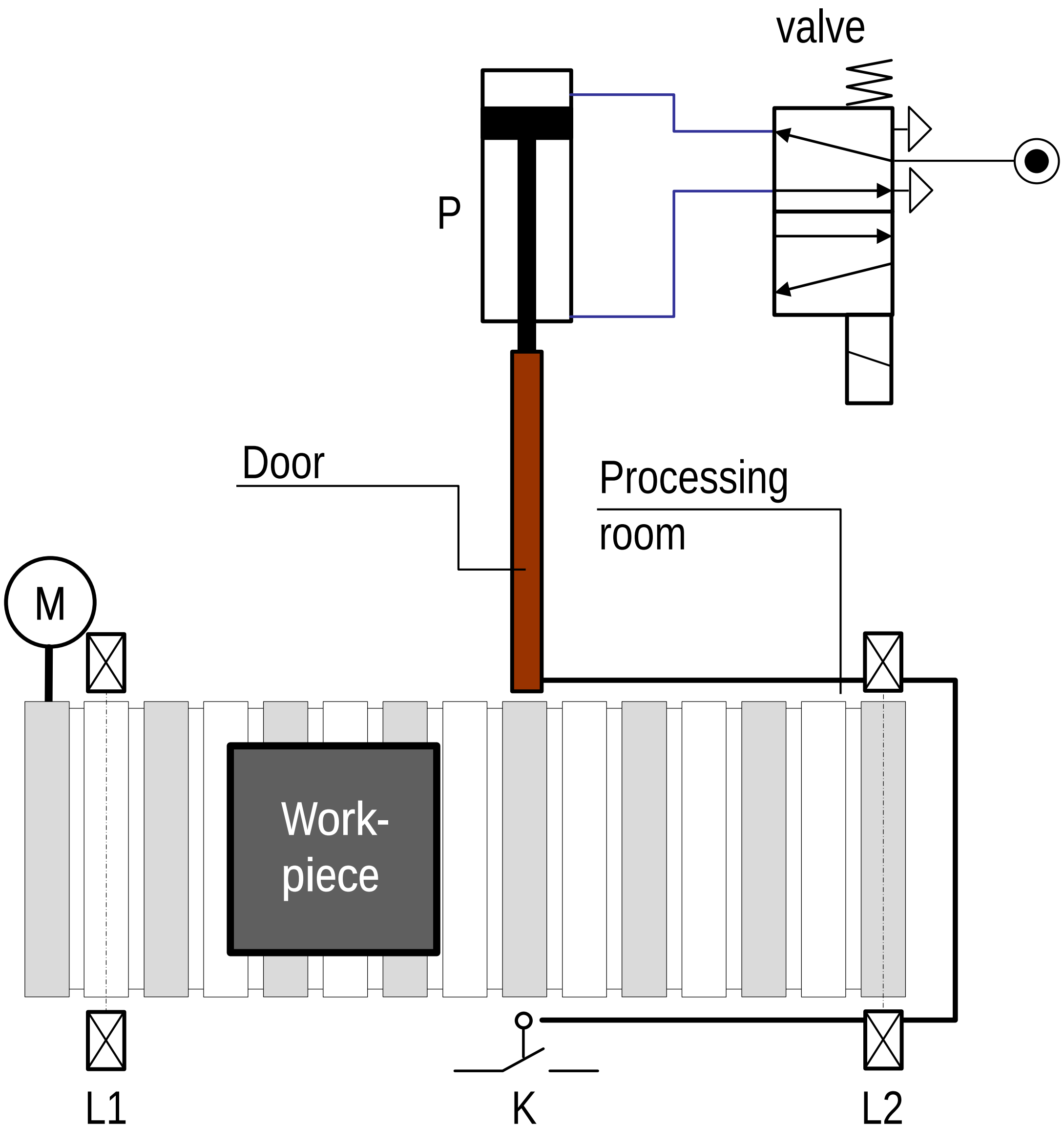


Example: Control (2)



- Task of control: shutdown of the conveyor belt when the workpiece in the processing room.
- The impact path is closed.
  But the line of impact is open, as there is no no continuous interference with constantly varying variables.

Example: Control (3)

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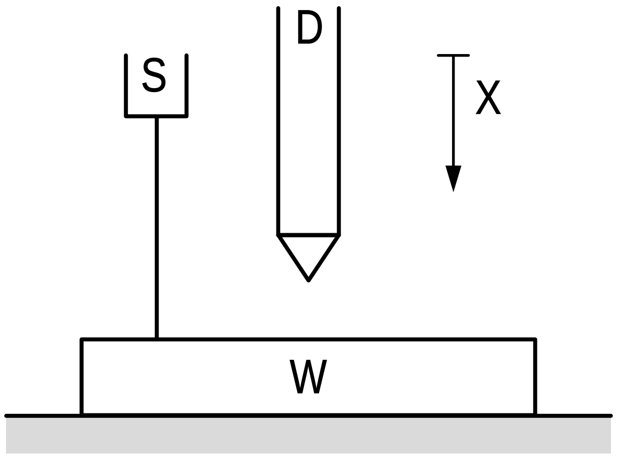


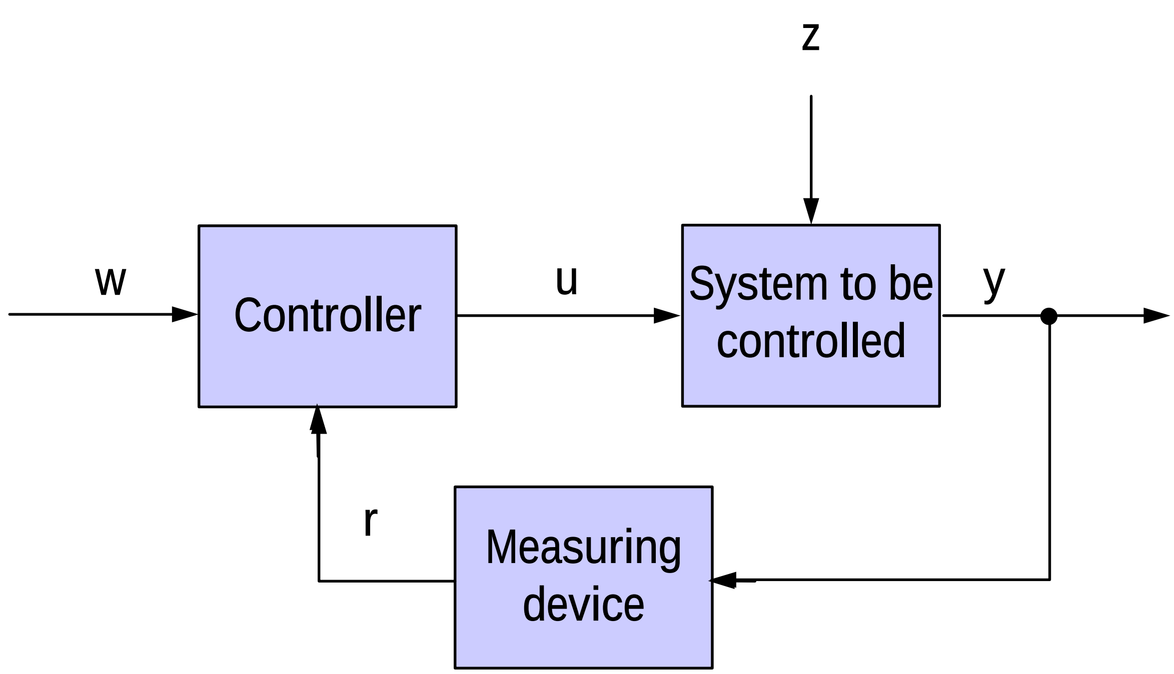
S: Sensor
D: Drill
W: Work piece

- Task of control:
  - Drill a hole with given depth.
  - Sensor measures size of work piece.
  - Control corrects drilling motion as a function of the measured workpiece thickness
- Impact of a known disturbance is compensated.

Closed loop control

Definition (DIN 19226)

- Closed loop control is a process in which a variable, the variable to be controlled, is measured and compared continuously with a different variable, the reference variable, and is affected in the sense of alignment to the reference variable.
- Indicative for the closed loop control is the closed line of impact in which the variables to be controlled affect continuously themselves.



w: Reference variables, setpoint values
u: Control variables
y: Output variables, to be controlled
z: Interfering variables
r: Feedback variables

Example: Closed Loop Control

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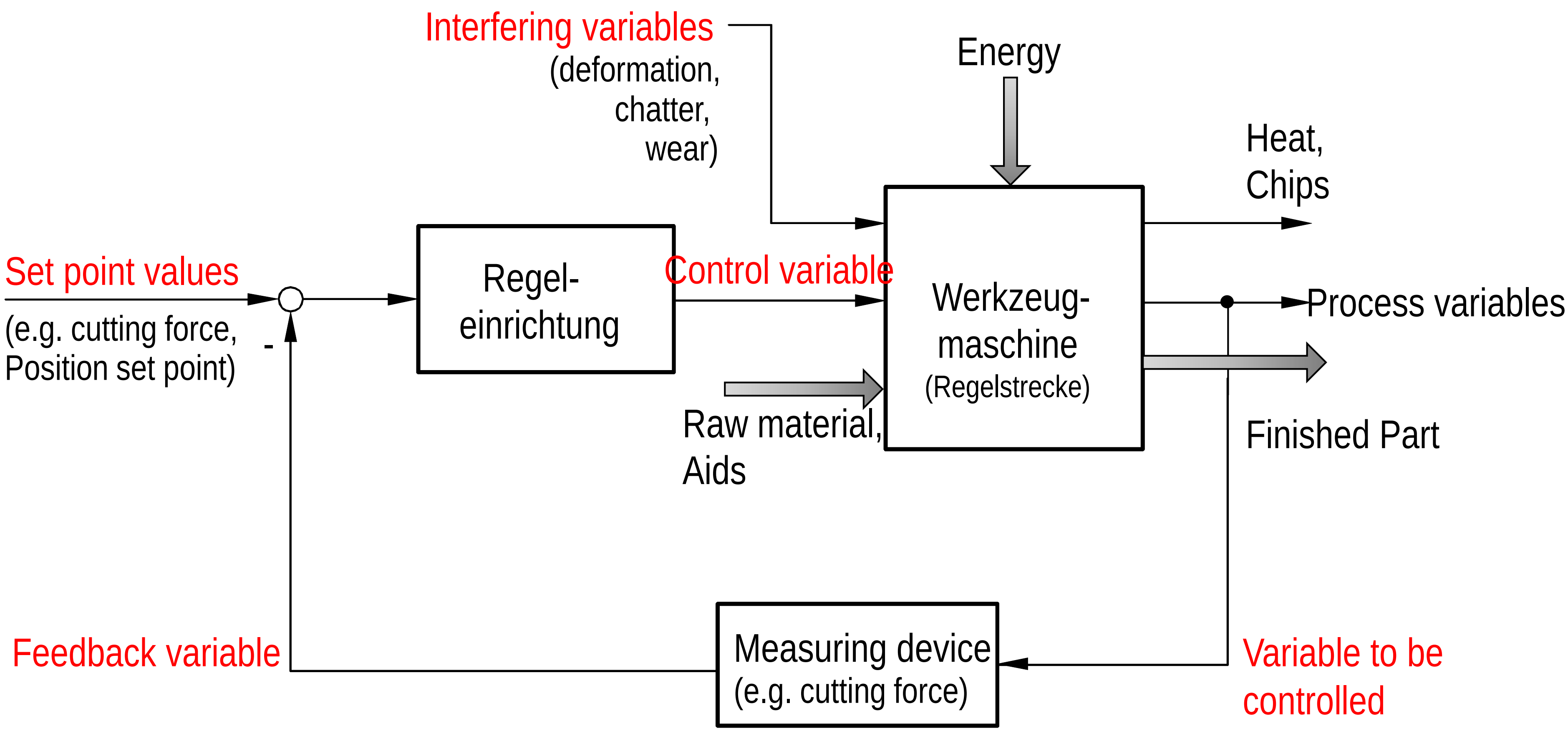

Properties: Control – Closed Loop Control

Control

- Open line of impact
- Impact of known disturbances can be compensated
- System can‘t get instable

Closed-loop Control

- Closed line of impact
- The impact of unpredictable disturbances and parameter changes in the system are largely compensated
- System can get instable

1.1 Sample Applications

1.2 Definition of Basic concepts

1.3 Classification of Control Technology

1.4 Structure and Components of a Control system

1.5 Microcontrollers – Types and Architecture

1.6 Basics of Process Control in Industry

Classification of Control systems

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Distinction on the type of Control medium

- mechanical
- Electrical
- fluidic
  - pneumatic
  - hydraulic

Distinction on the type of Information representation

- analog
- digital
  - numerical
  - binary

Classification of Control systems

Distinction on the type of Signal processing

Sequential Control
Control systems with a sequential flow of steps.
To go on from one step to the next depends on enabling conditions …

Process driven
the enabling conditions depend on signals from the process.

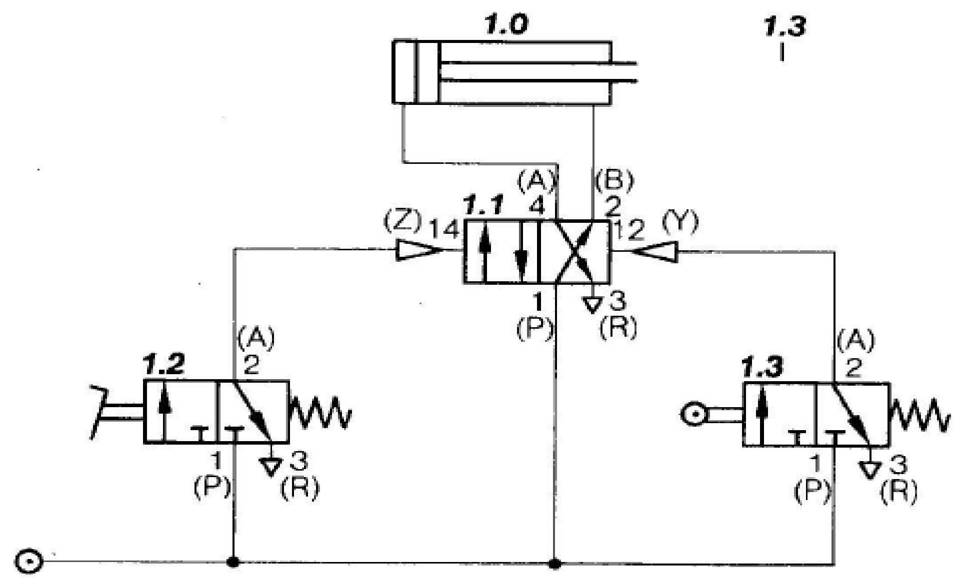
Time based
the enabling conditions depend on time signals.

Logic Control
The output signals are computed by the logic composition of the input signals (AND, OR, NOT).

Example: Sequential control, process driven

Trimming press

- If you push the start pedal (1.2) a fluidic zylinder (1.0) closes the trimming press.
- If the lower endposition is reached, the limit switch (1.3) is actuated and the zylinder returns automatically.



Source: Stawa Augsburg

Example: Sequential control, time based

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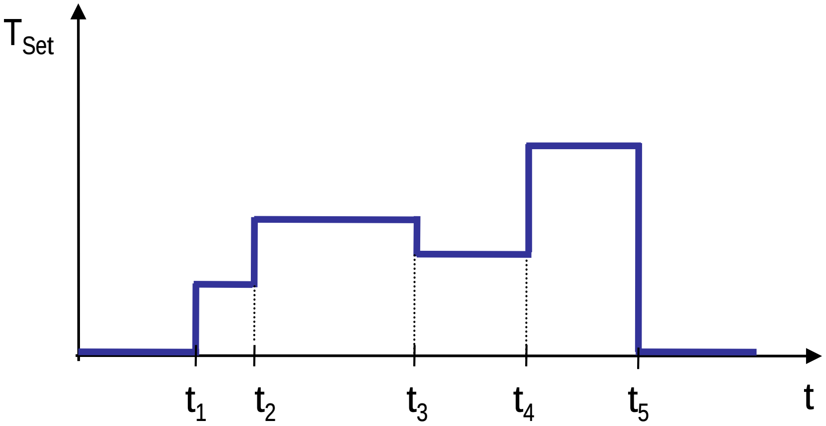
Source: TPS Thermal Product Solution (USA)

Crystal growth oven:

- The temperature is controlled in a certain given profile to grow crystals.



Example: Logic control

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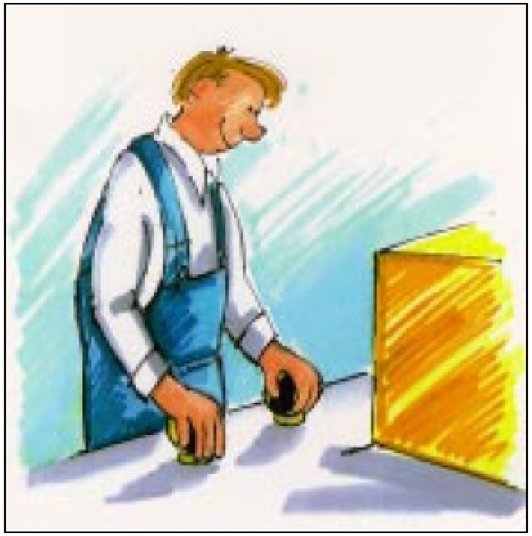

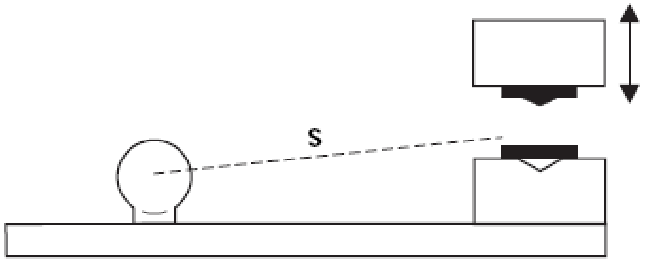

Source: Contra, Jakob Safety

Restart circuit

- Only if both safety switches are activated the machine starts.

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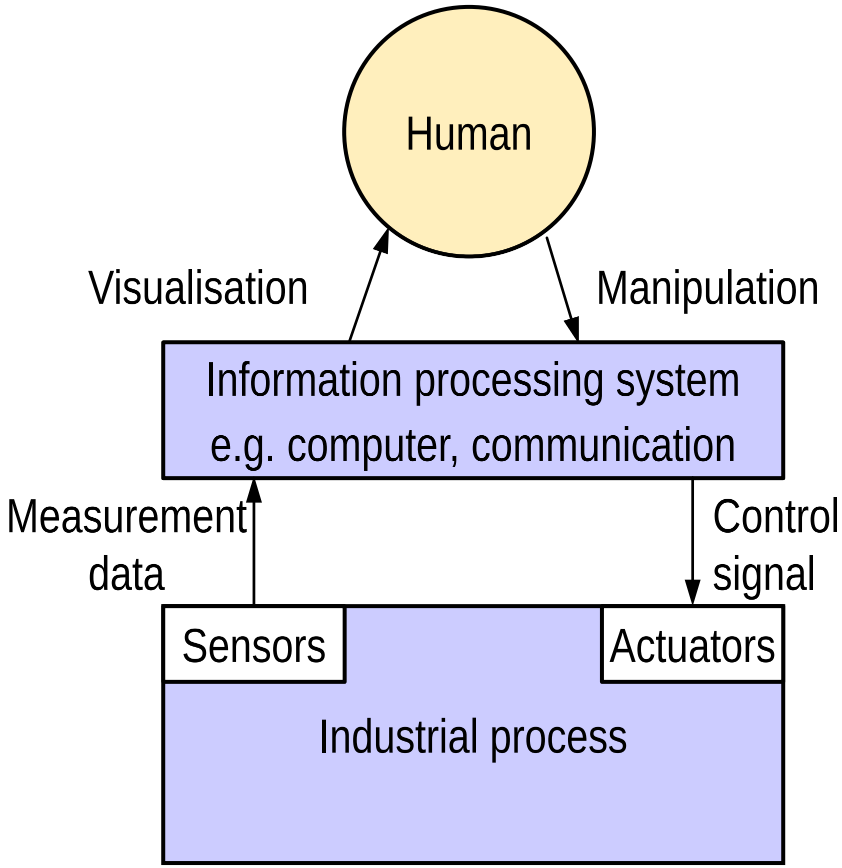
Structure of a Control system



Sensors

- Convert physical values into usually electrical signals

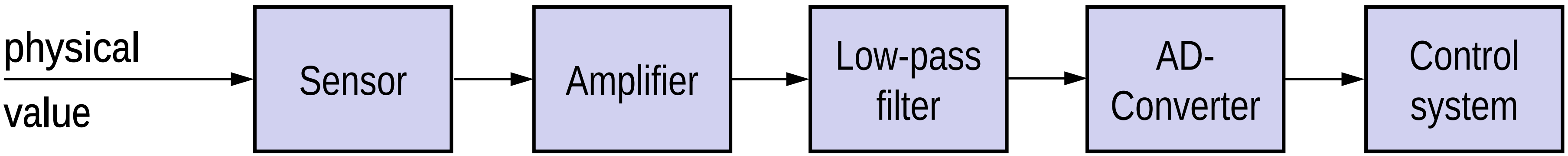
Actuators

- Influence the process through the conversion of the control signals in other values

Information processing system

- Computes the necessary actions in order to achieve the desired goals.
- Can be a Microcontroller

Signal capturing



- Analog Digital conversion
  - Sampling:
    - Receiving the signal at discrete points in time
    - Characteristics: sampling rate
  - Quantization:
    - Discretization of the range of values
    - Characteristics: quantization accuracy

Signals

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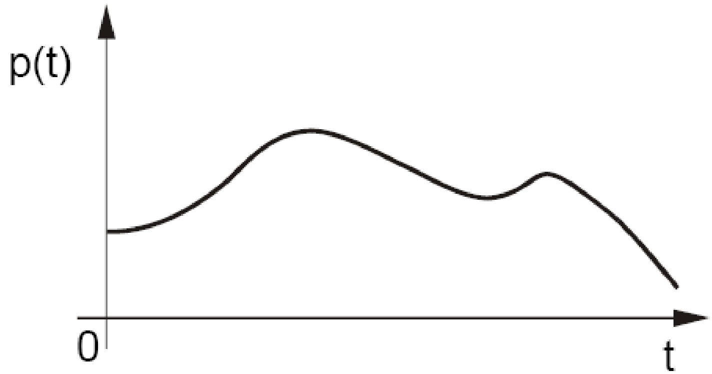
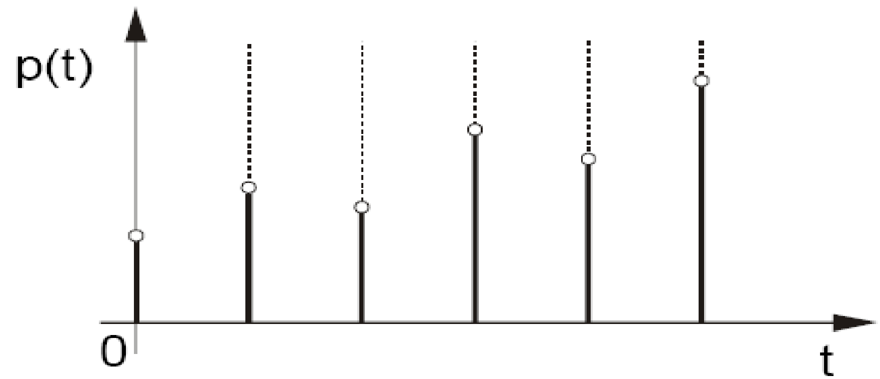
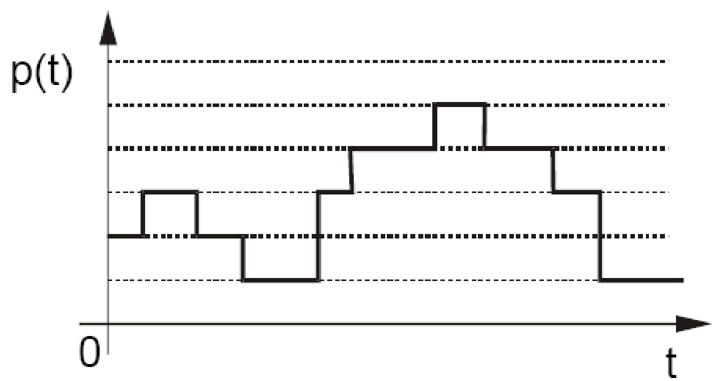
A Signal is a time variant value, which transports information



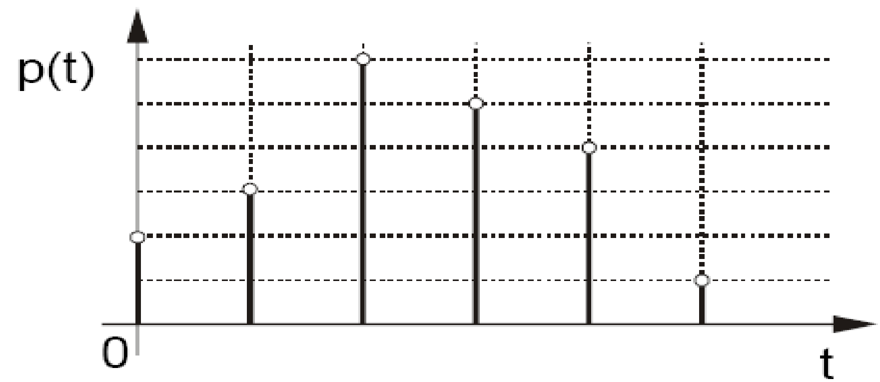
time- and value continuous



time discret and value continuous



time continuous and value discret



time- and valuediscret

Signals

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- Time continuous signal:
  - Representation by a function of one real variable
    $x(t)$, with $t \in \Re$
  - Domain is $\Re$

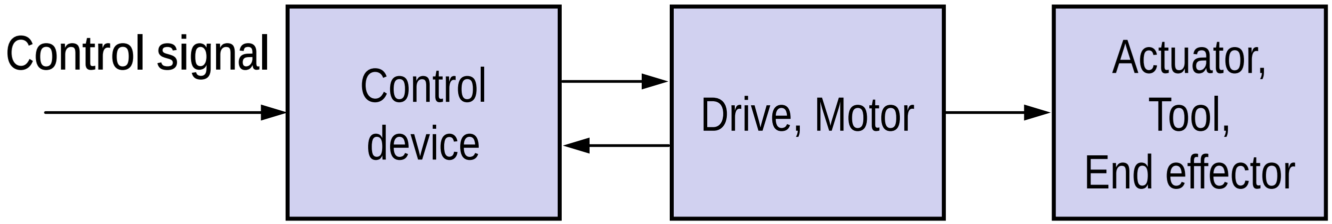
- Time discrete signal:
  - Representation through a sequence of numbers $x(k)$, with $k \in Z$
  - Domain is Z

- Range
  - continuous $x(t), x(k) \in \Re$
  - discrete $x(t), x(k) \in Z$

- **Analog signals:** time- and value continuous

- **Digital signals:** time- and value discret

Actuators



Control device

- Processing of the control signal
- Example: Power electronics for an electric drive

Drive / Motor

- Conversion of electrical signals into mechanical movements
- Form of energy: electrical, pneumatic, hydraulic

Actuator / Tool / End effector

- Direct influence of the process parameters
- Example: Milling tool, Welding device on the robot, Throttle actuator, valve

Technical Devices for the realization of information processing

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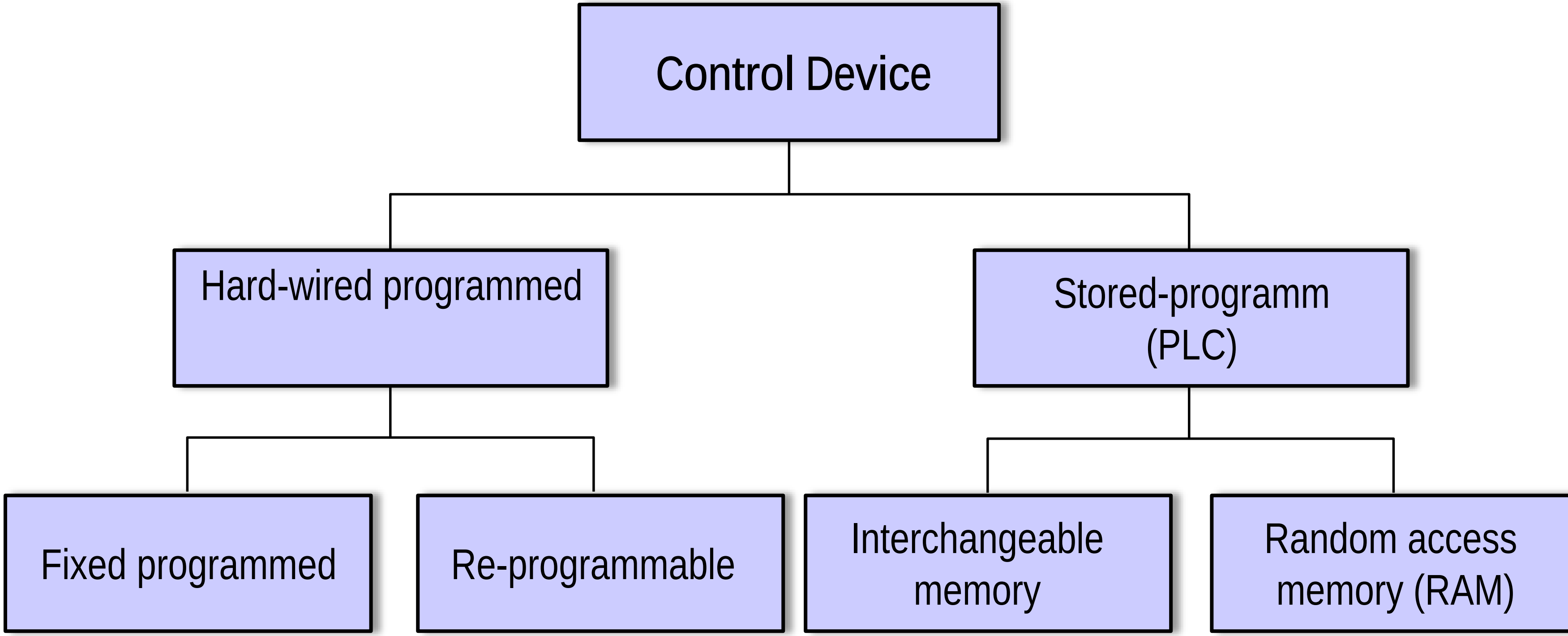

Classification of Control Devices (DIN 19237)

Hard-wired Control systems

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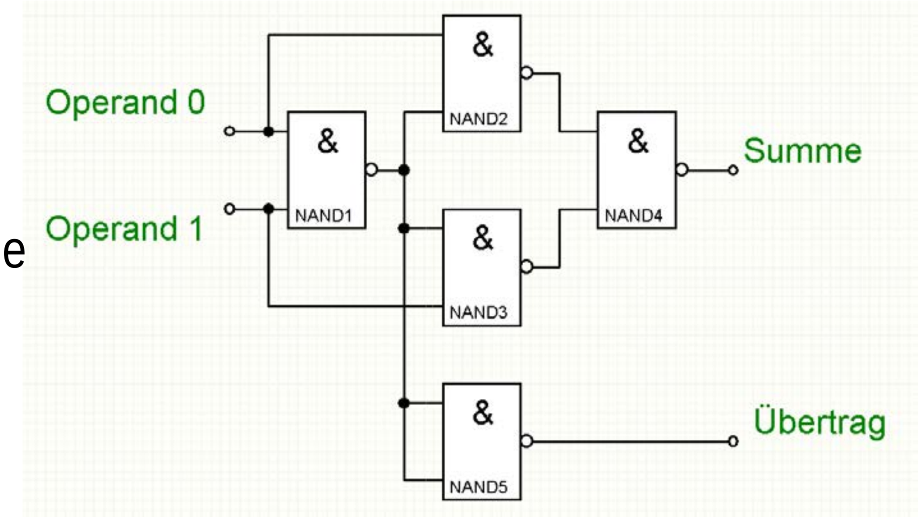
Fixed programmed

- pneumatic, hydraulic, electrical, magnetic or electronic components are wired by fixed cables/lines, to realize the desired Input-/Output-behaviour.

Re-programmable

- Programmable Logic Devices (PLD) are integrated circuits, whose function can be programmed/configured freely..



Field Programmable Gate Array (FPGA)

Quelle:Altera Cooperation

Control Devices - Equipment

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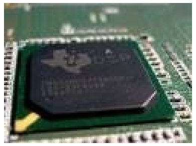
Digital Signal Processor (DSP)



(DSP) Texas Instruments

e.g. closed-loop controllers

Microcontroller (MC)

(MC) Phytec C167 Modul

e.g. drive controller

Embedded PC

Embedded PC104 Kontron

e.g. cash machine

Programmable Logic Controller (PLC)

PLC Siemens S7-400

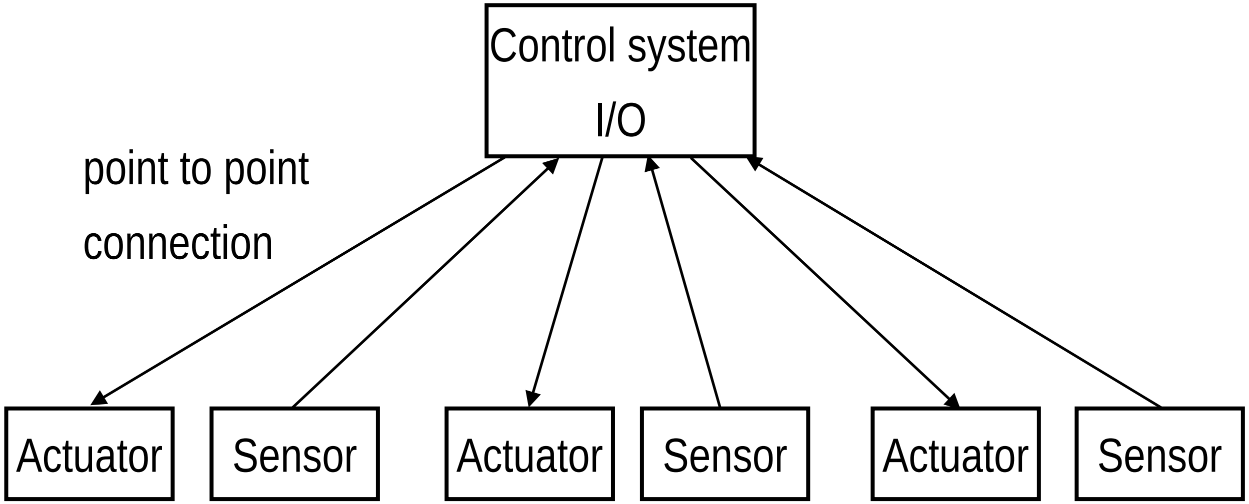
e.g. industrial automation

Beckhoff GmbH
Embedded PC for top hat rail

Industry PC (IPC)

IPC Kontron GmbH

Central Structure



Advantages

- Low cost
- Fast Communication
- Easy realization
- Lowest communication cost

Disadvantages

- Big number of interfaces
- High cabling costs
- Unflexible

I/O: Input - Output

Decentral Structure

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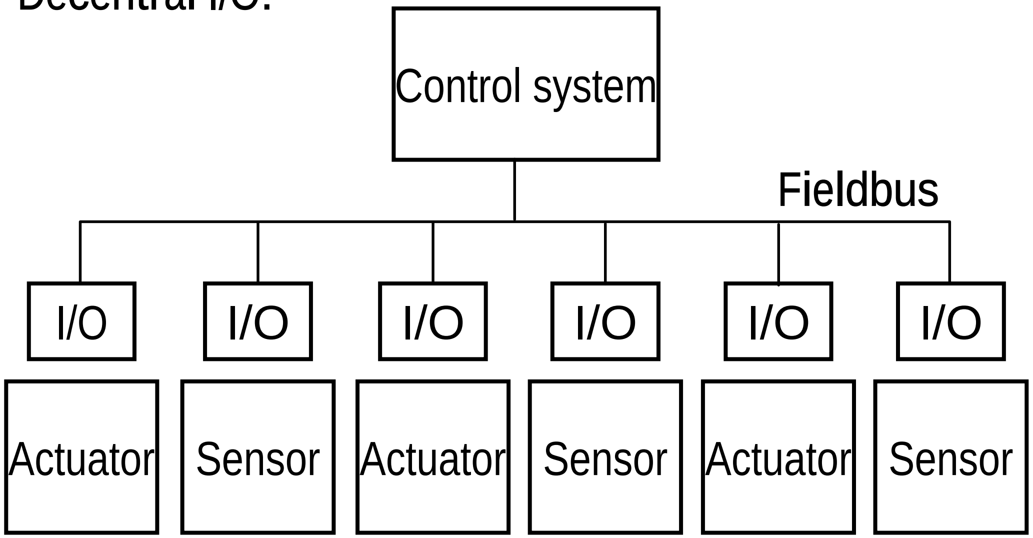
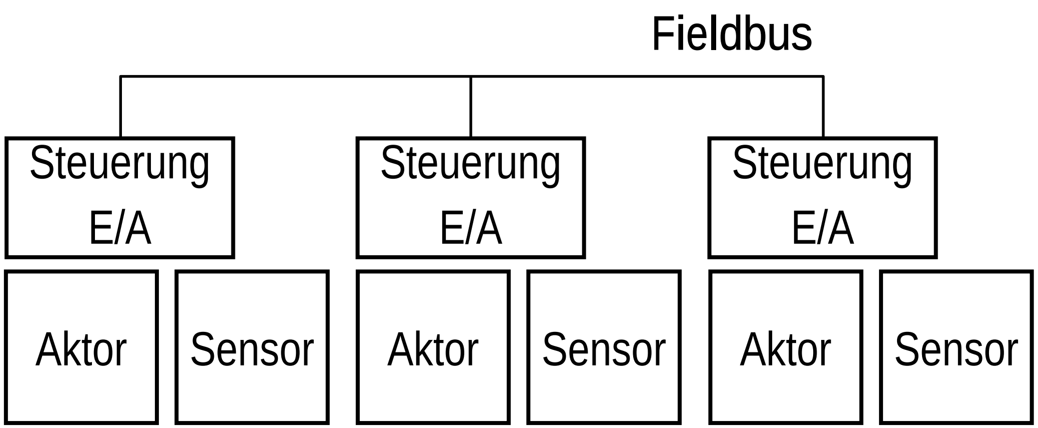
Decentral I/O:



Decentral CPU:



I/O: Input-/Output device CPU: Central Processing Unit

Advantages

- Low cabling costs
- More functionality by intelligent fieldbus devices (e.g. Diagnosis, Parametrization)
- Robust data transmission for critical analog signals
- More Flexibility by modularity

Disadvantages

- Higher cost
- Higher complexitiy (communication, engineering)
- More effort for rapid response times and low cycle times

Example: Devices for decentral control system

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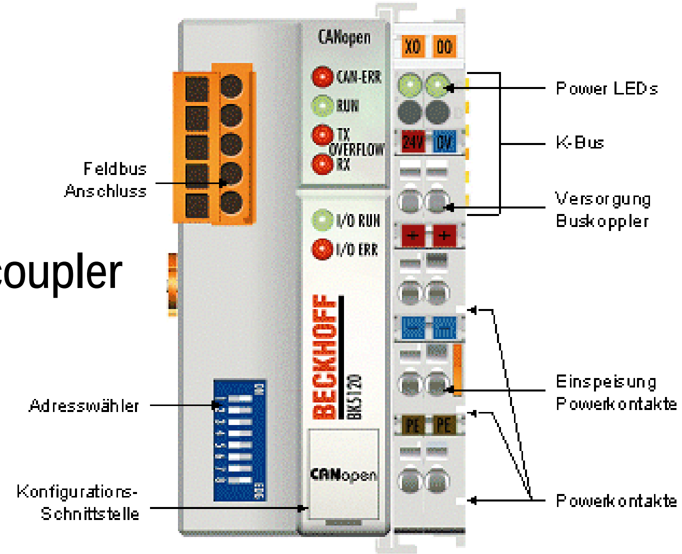
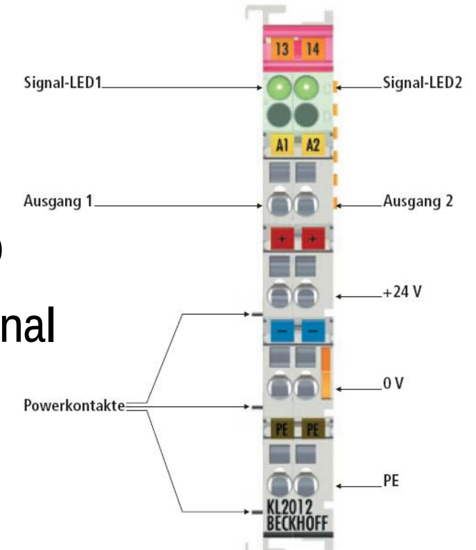
Bus coupler

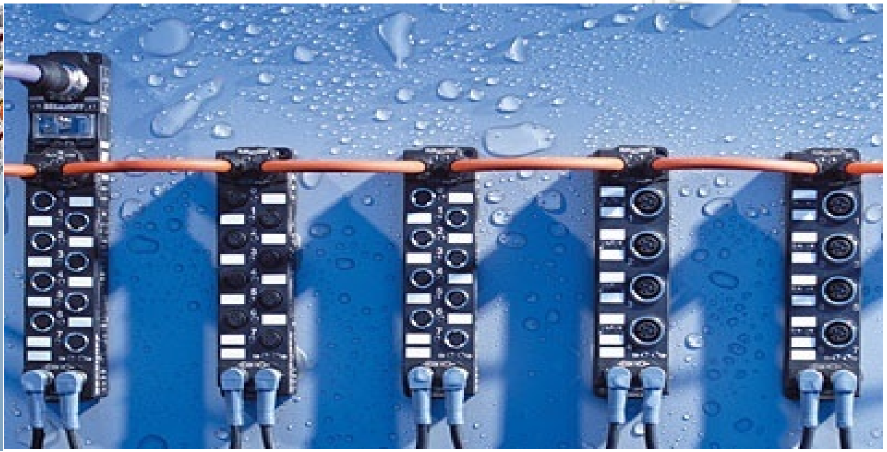


Digital-IO

Busterminal



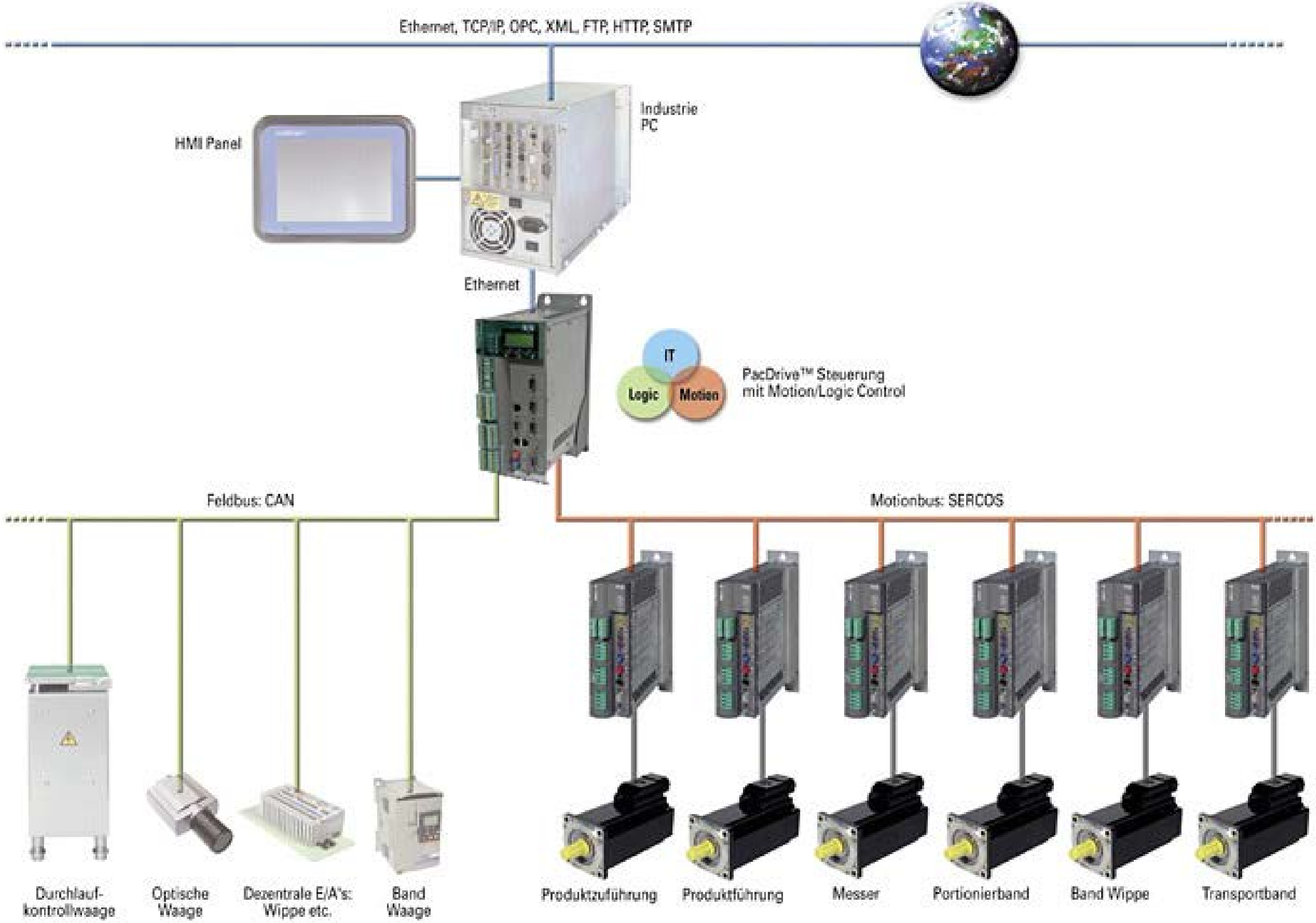
Bus coupler with terminals



IP65 version

Source: Beckhoff GmbH

Example: Packaging machine topology of a decentralized control



Source: Elau AG

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Components of Microcontrollers

Definition Microcontroller

- A single chip that contains the processor (the CPU), non-volatile memory for the program (ROM or flash), volatile memory for input and output (RAM), a clock, an I/O control unit and other periphery.

Microprocessor (CPU)

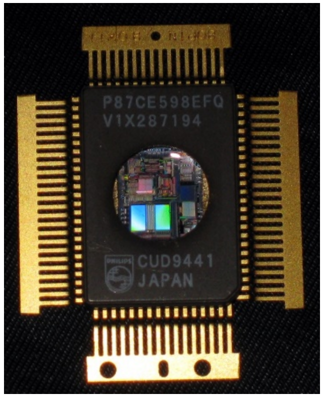
- 8-, 16-, 32-bit Processor (e.g. ATMEL, TI, PIC, …)

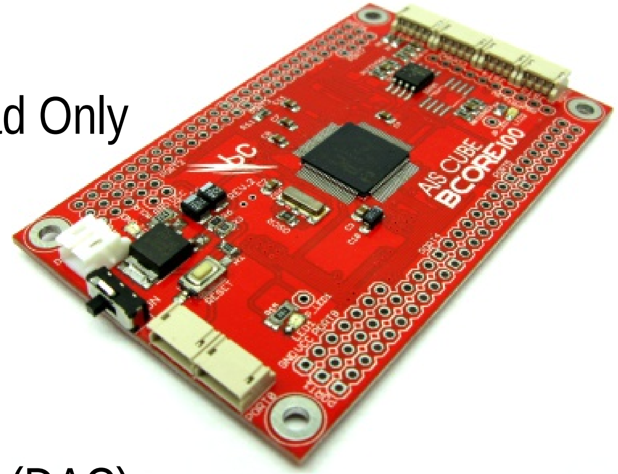
Memory

- Read Only Memory (ROM), Erasable Programmable Read Only Memory (EPROM)
- Random Access Memory (RAM), Flash-Memory

Periphery

- Timer, Counter, Watchdog
- Analog Digital Converter (ADC), Digital Analog Converter (DAC)
- Pulse Width Modulation (PWM)
- Digital Input-/Output-Ports
- Bus Interfaces (CAN, USB, I^2C, SPI)





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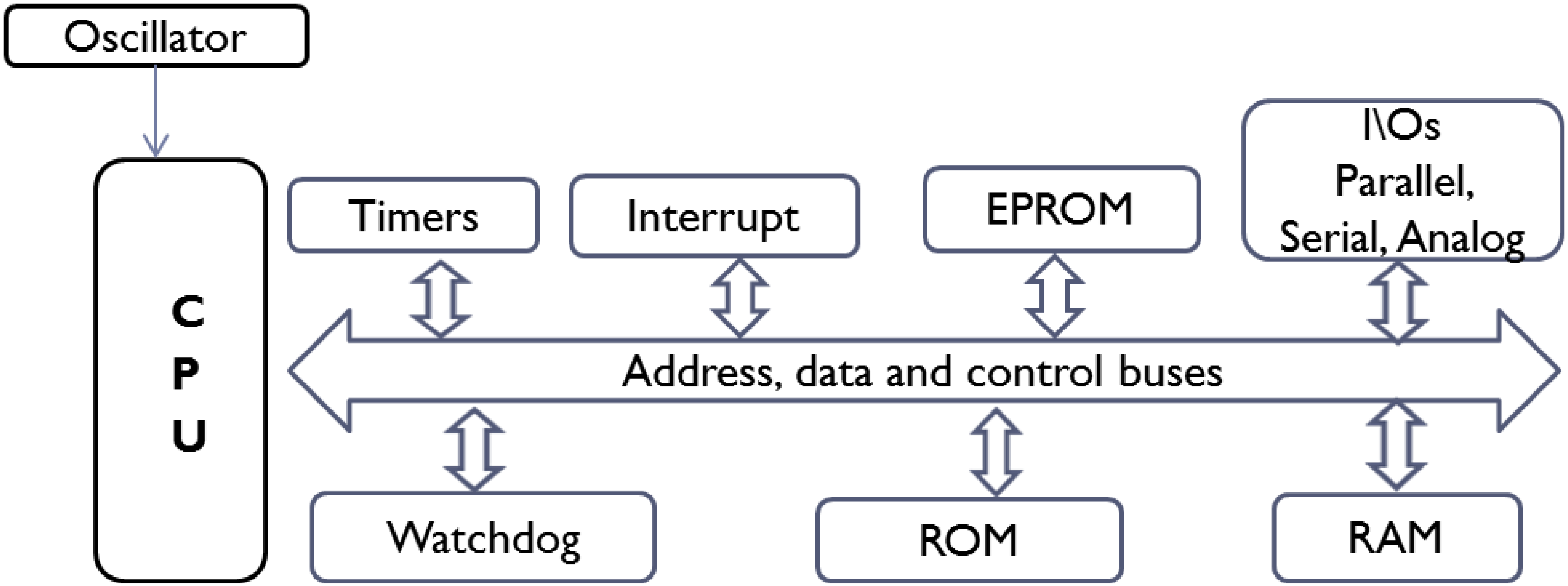
Architecture of Microcontrollers



wiki.zimt.uni-siegen.de

Architecture of Microcontrollers – Example AtmelMega1260

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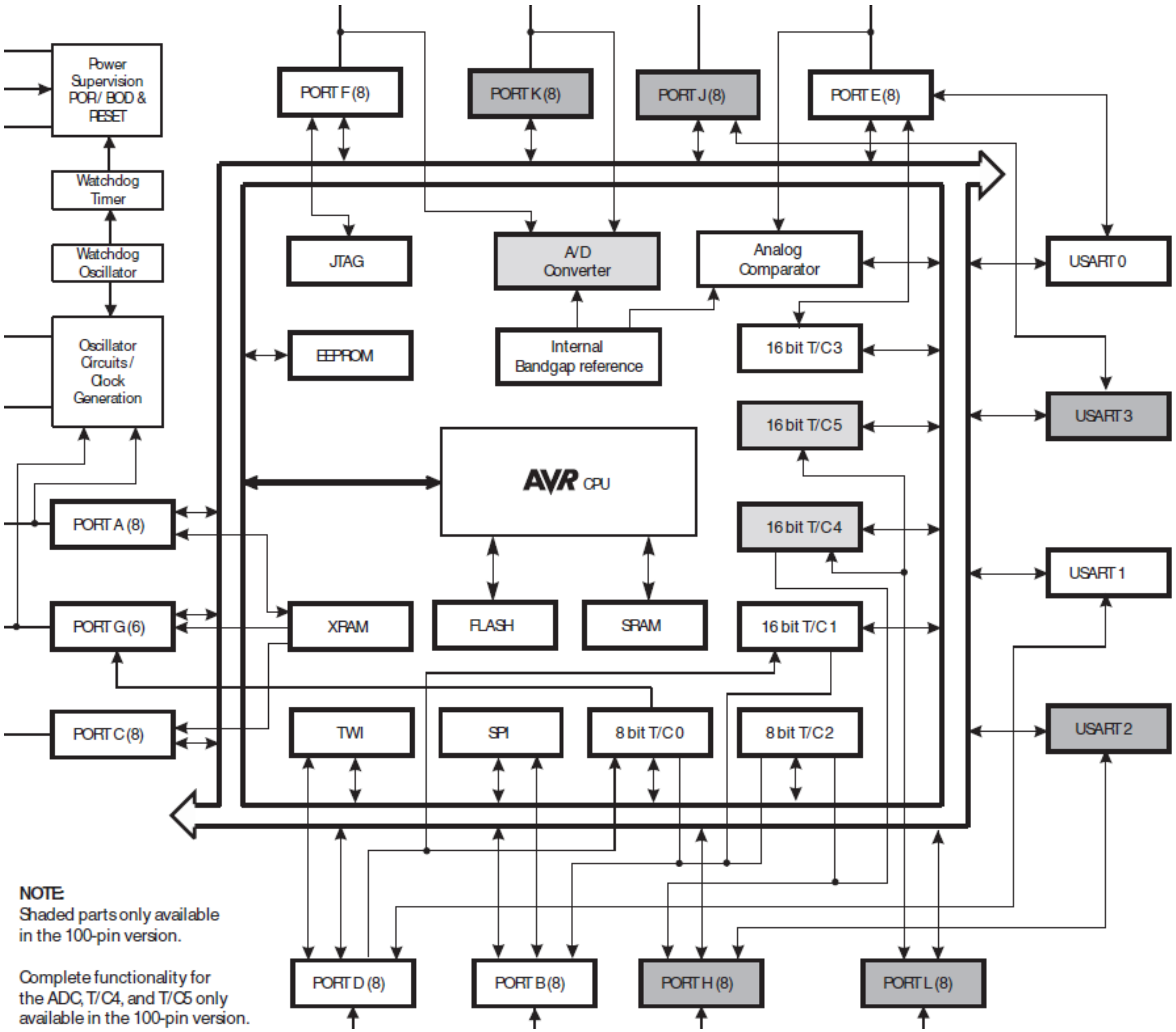


www.atmel.com

Harvard architecture
Separate memories and buses for program and data

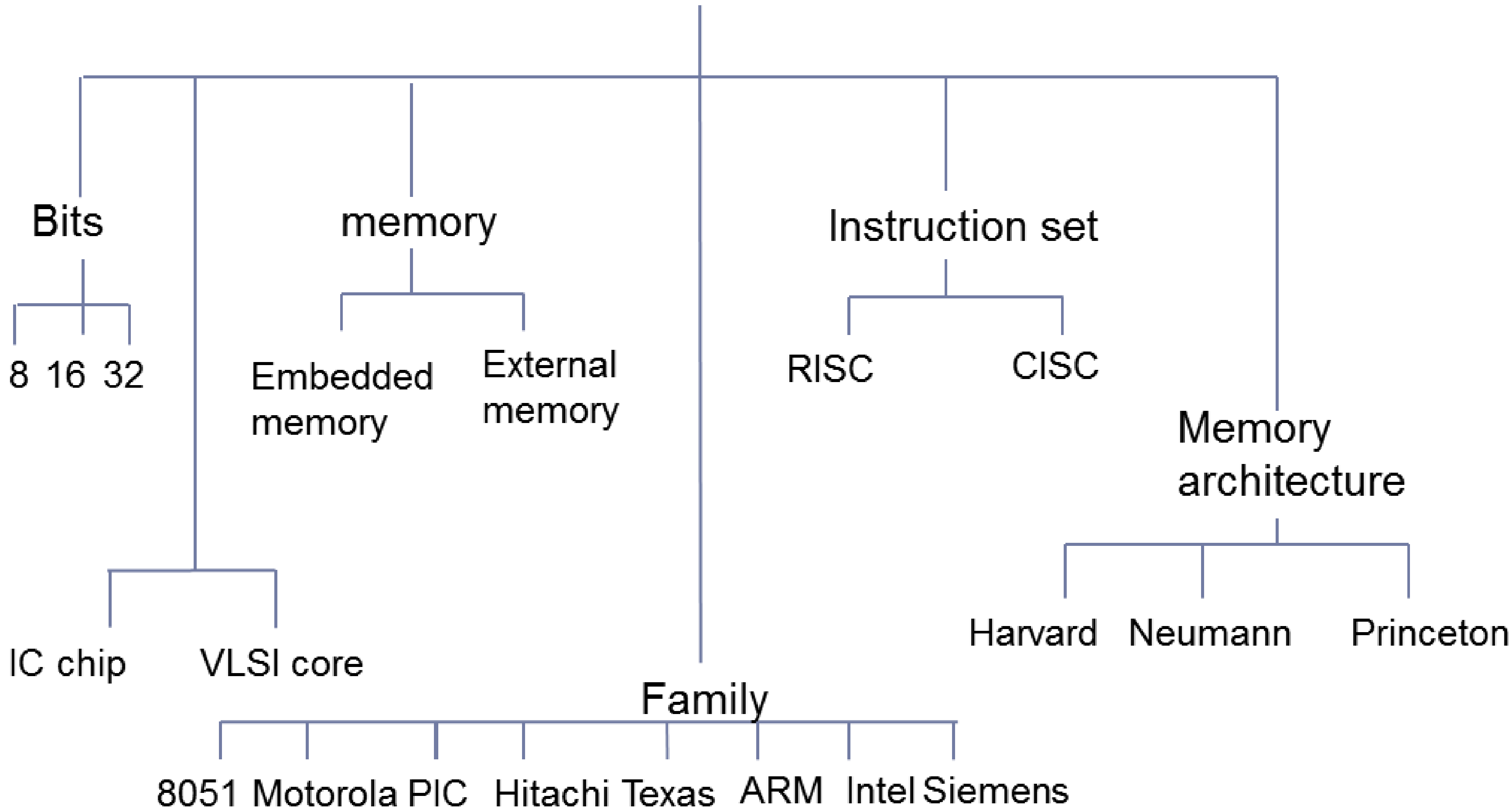
32 8bit general purpose working registers

Single-cycle Arithmetic Logic Unit (ALU)

Real Time Counter (RTC)

54 general purpose I/O-lines

Types of Microcontrollers – Classification criteria



Seminar

- Give an overview on latest, relevant Microcontrollers. Classify them on defined criteria (e.g. number of bits of registers, memory, clock-speed, manufacturer, programming, price, integrated periphery…).
- Give examples for typical microcontroller applications for each type.
- Present the results in an oral presentation of about 30 minutes.
- Make a handout with the most important facts.
- Work in a team of 3-4 students.

Vendors of Microcontrollers (selection):

Altera, Atmel, Cypress, Freescale Semiconductor (Motorola), Infineon, Intel, Microchip, Texas Instruments, and many others.

1.1 Sample Applications
1.2 Definition of Basic concepts
1.3 Classification of Control Technology
1.4 Structure and Components of a Control system
1.5 Microcontrollers – Types and Architecture
1.6 Basics of Process Control in Industry

Levels of automation in Process Industry

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Closer to process

Increasing real-time orientation

- L7 — Factory control
- L6 — Planning Level (e.g. process planning)
- L5 — Control Level (e.g. work-piece flow)
- L4 — Cell Level (e.g. Tool management, Tool handling)
- L3 — Machine-control Level (e.g. Geometry and technology data processing)
- L2 — Single control Level (e.g. set-points, logical connections)
- L1 — Process Level (actuators, sensors)

Factory control/ Planning Level:

- Strategic and tactical management
- Activities in purchasing, selling, long-term planning, management of production sites, logistics, human resources
- Development

Levels of automation in Process Industry

Closer to process

Increasing real-time orientation

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Control Level:

- Order management and system availability
- Process control and monitoring
- Transport management
- Resource management
- Material handling and warehouse management
- Quality assurance
- Backup

Levels of automation in Process Industry

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L2	Single control Level (e.g. set-points, logical connections)
L1	Process Level (actuators, sensors)

Cell Level:

- Control of the enforcement order
- Controlling the tool and workpiece flow
- data collection
- diagnosis

Levels of automation in Process Industry

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- **L1** Process Level (actuators, sensors)

Machine-control Level / Single Control Level:

- Path generation
- Control and regulation
- data collection
- diagnosis

Process Level:

- Technical Process, including sensors and actuators

Siemens AG

Pepperl+Fuchs GmbH

Principle way of working in process control in industry

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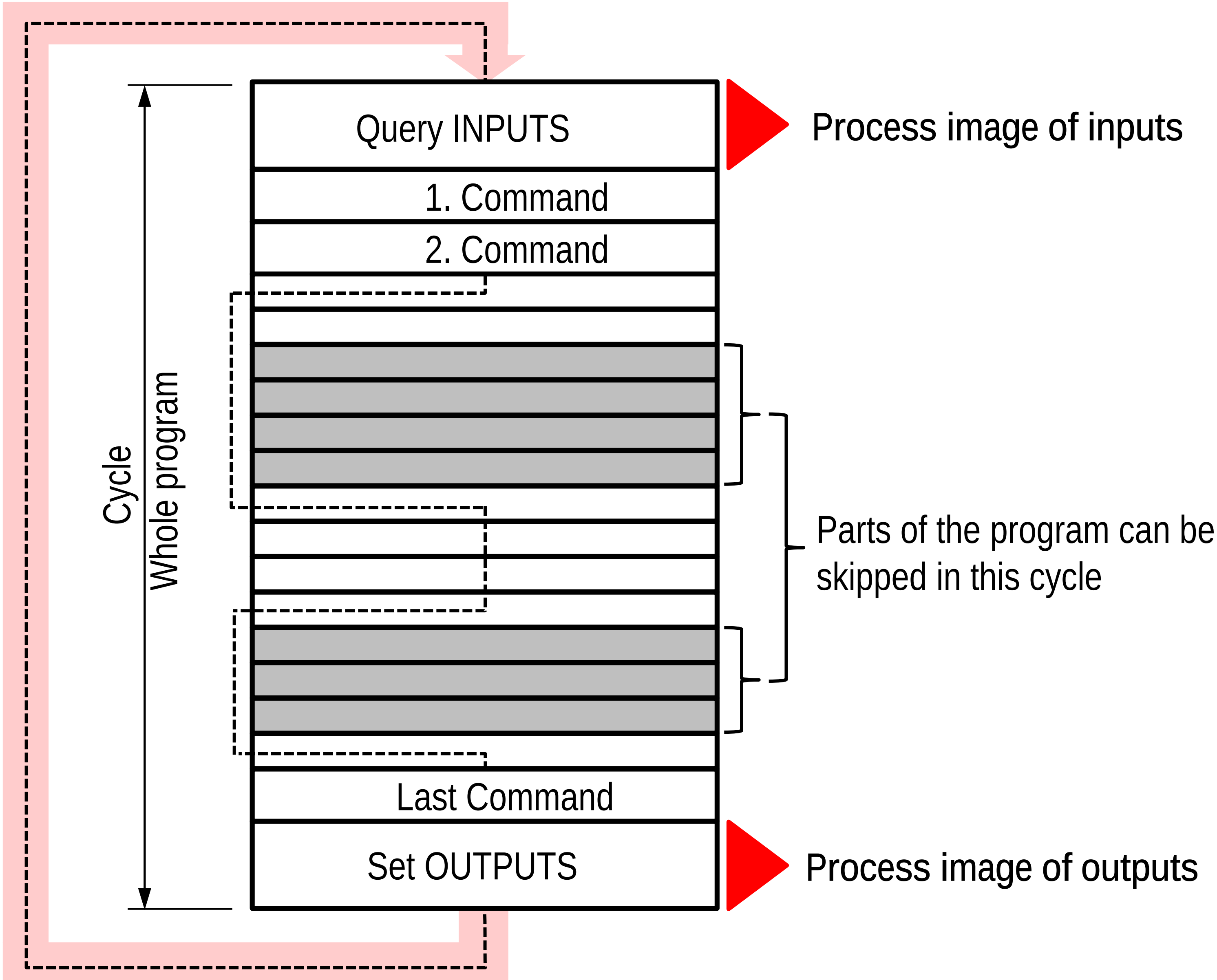


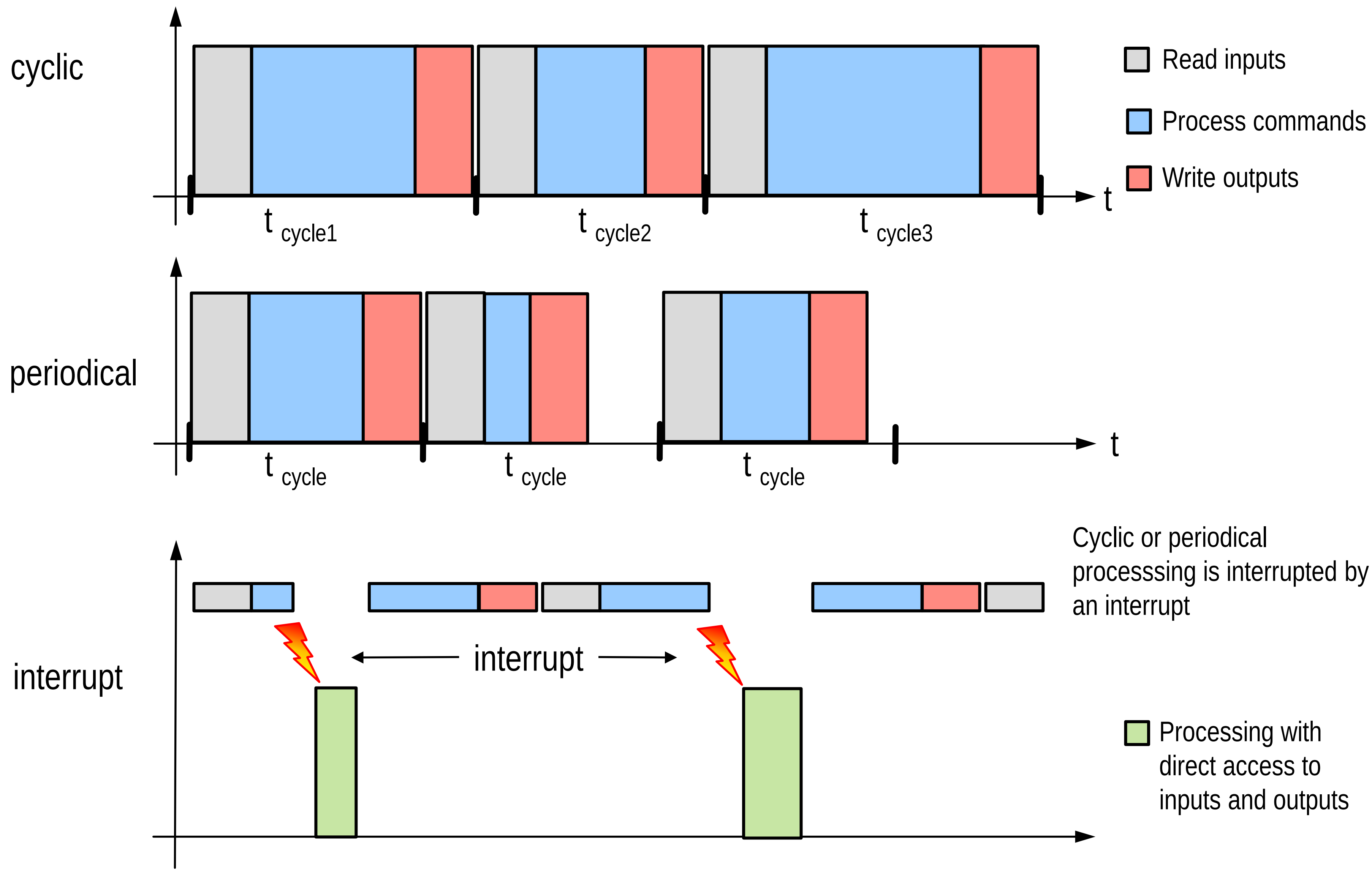
Process Image

The process image is a special memory area, in which:

- At a defined time all available input signals (input image) are transferred.
- During a cycle, the occurring outputs are collected (output image) and then at a defined time given to the physical outputs.

→ Consistency of the signals during one cycle is ensured.

Processing of a program



Principle of Response Time

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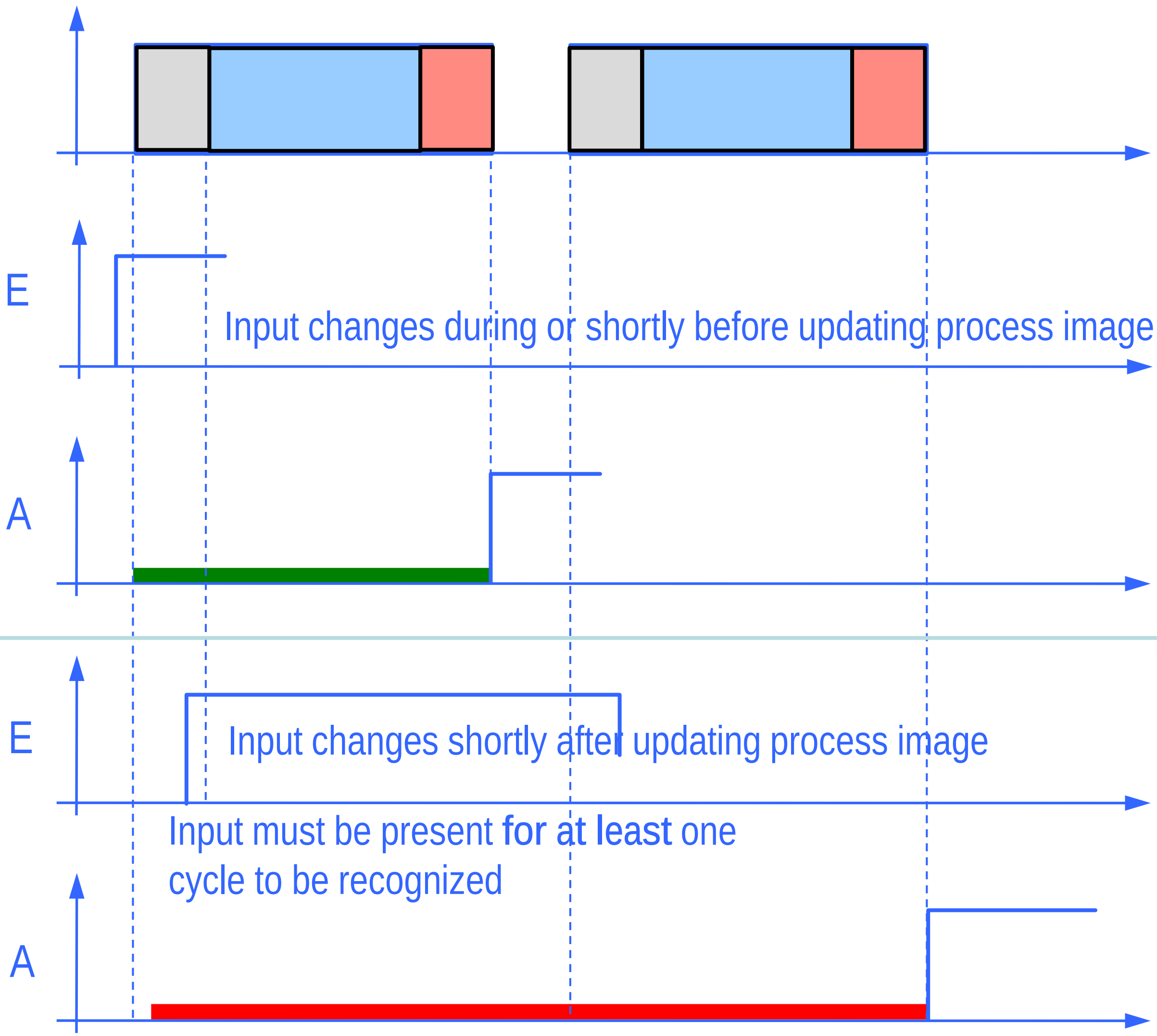

Load E
Store A

Response time
best case is
time of 1 cycle

Response time
worst case is
time of 2 cycles

Conclusion

- Microcontrollers have a wide area of application; there is a very big number of available microcontrollers
- Definition of basic terms:
  - Control technology, process, system, control, signal, sensors and actuators
- A classification of the controllers can be done for example by the type of control resources, information representation and signal processing.
- The basic structure of a control system includes sensors, actuators and processing of information.
- The functional classification of automation in production technology can be represented by a hierarchical level model.

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Introduction to mini-project

Introduction to Mini-project

- ………
- ………