# Communication

Jian-Jia Chen
(slides are based
on Peter Marwedel)
Informatik 12
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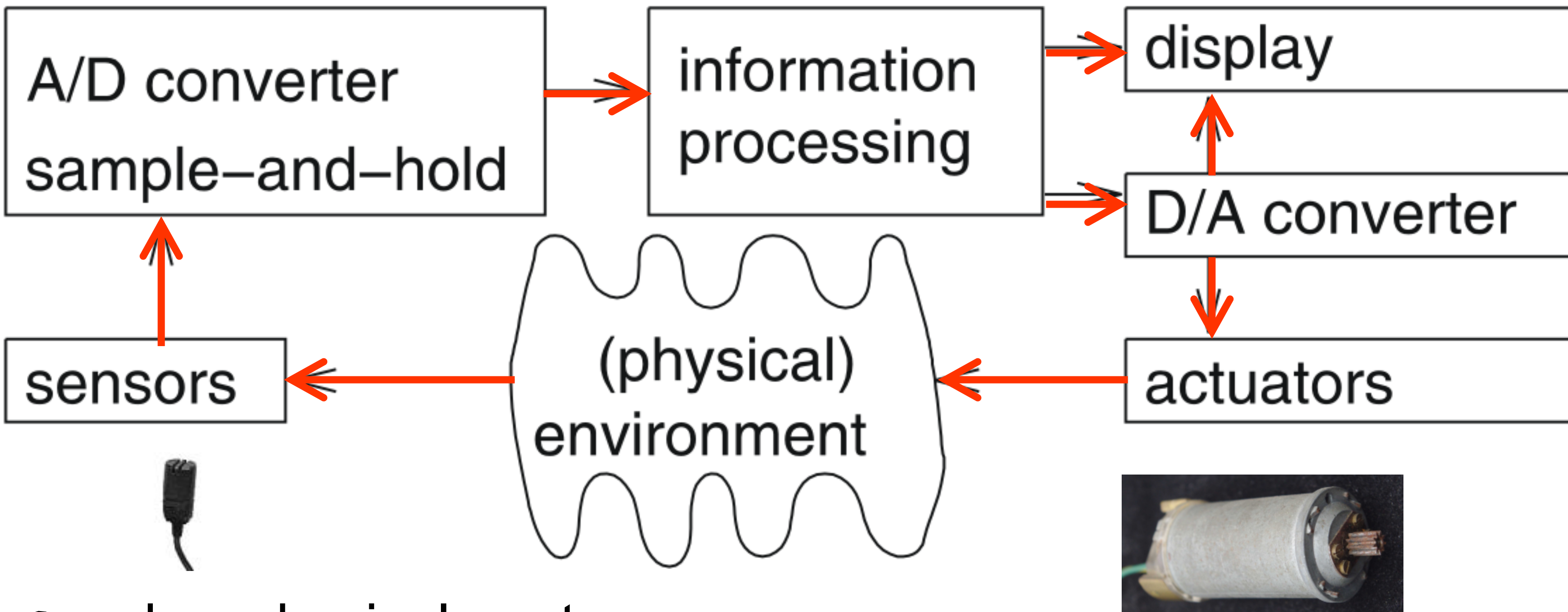
2019年11月20日

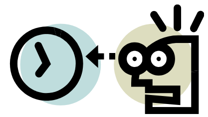
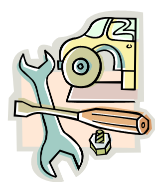
# Embedded System Hardware

Embedded system hardware is frequently used in a loop (***"hardware in a loop"***):



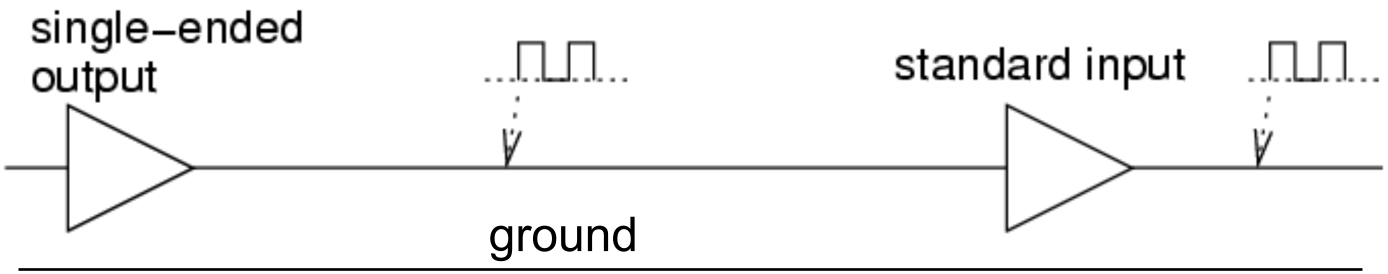

☞ cyber-physical systems

# Communication
# - Requirements -

- Real-time behavior 
- Efficient, economical
  (e.g. centralized power supply) 
- Appropriate bandwidth and communication delay
- Robustness
- Fault tolerance
- Diagnosability
- Maintainability 
- Security 
- Safety 

# Basic techniques: Electrical robustness

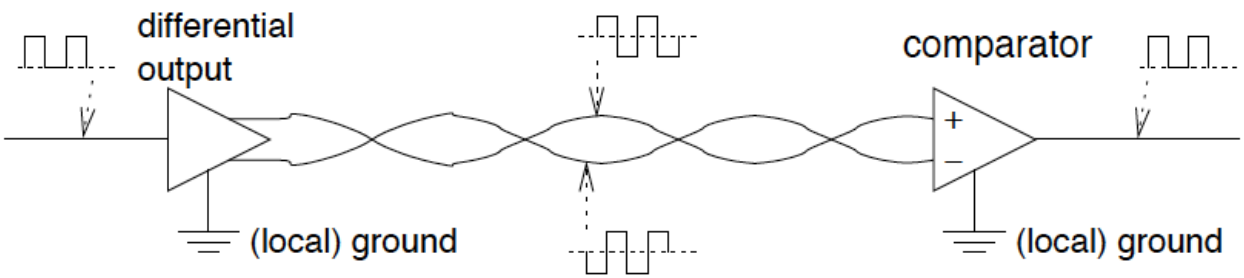
- Single-ended signals

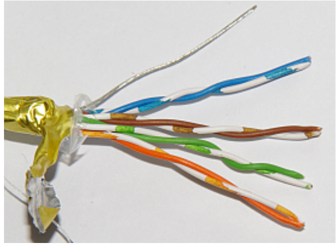



e.g.: RS-232

Voltage at input of Op-Amp positive → '1'; otherwise → '0'

- Differential signals



Combined with twisted pairs; Most noise added to both wires.

# Evaluation

**Advantages:**

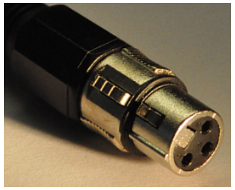
- Comparison removes most of the noise
- Changes of voltage levels have no effect
- Reduced importance of ground wiring
- Higher speed

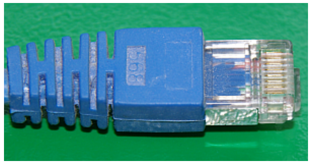
**Disadvantages:**

- Requires negative voltages
- Increased number of wires and connectors

**Applications:**

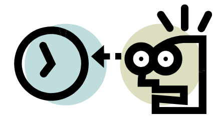
- High-quality analog audio signals (XLR)
- differential SCSI
- Ethernet (STP/UTP CAT 5/6/7 cables)
- FireWire, ISDN, USB





# Communication
# - Requirements -

- Real-time behavior



- Efficient, economical
  (e.g. centralized power supply)


- Appropriate bandwidth and communication delay
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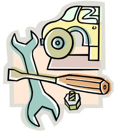
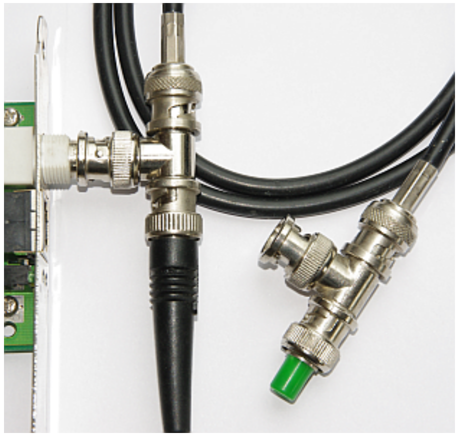


# CSMA/CD vs. CSMA/CA



Carrier-sense multiple-access/collision-**detection** (CSMA/C**D**, variants of Ethernet): collision ☞ retries;
no guaranteed response time.

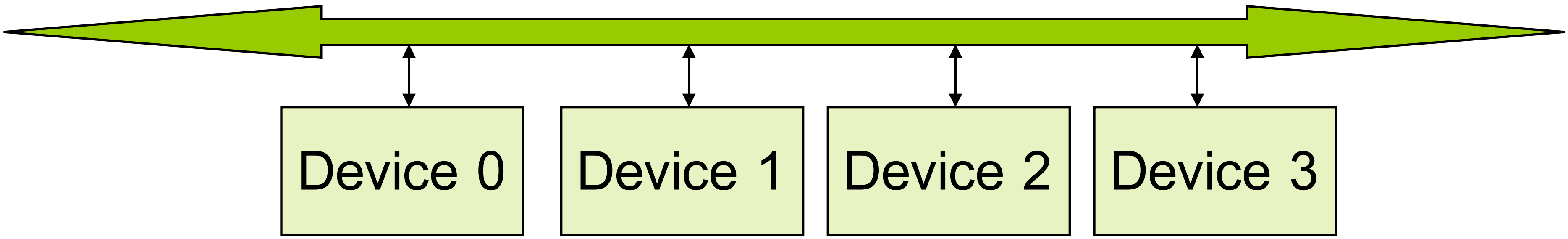
Alternatives:

- Carrier-sense multiple-access/collision-**avoidance** (CSMA/C**A**): IEEE 802.11, WLAN
- Carrier-sense multiple-access/collision-**resolution** (CSMA/C**R**): CAN (controller area network)
- token rings, token busses

☞ chapter 5

# Priority-based arbitration of communication media

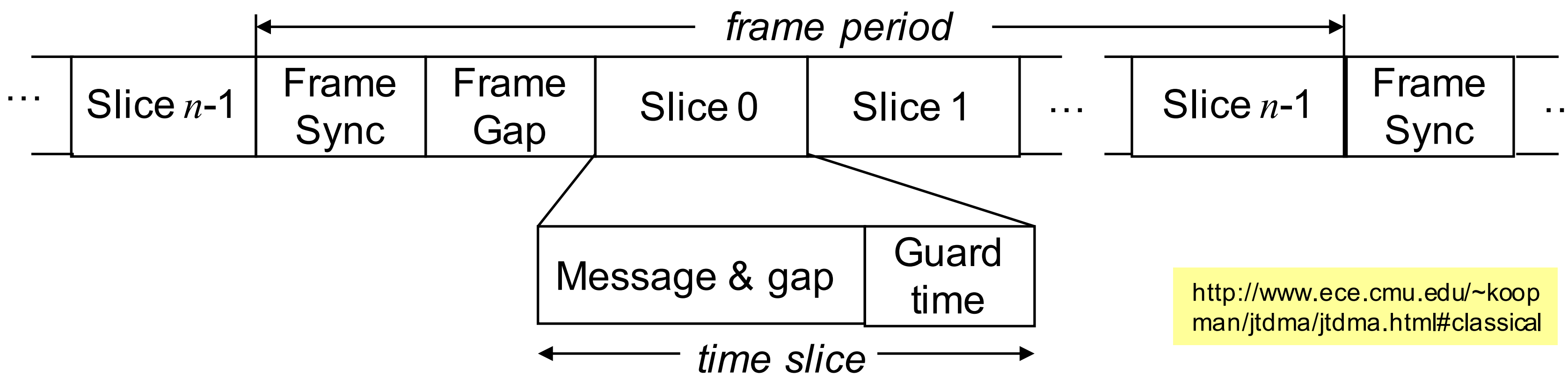
Example: bus




- Bus arbitration (allocation) is frequently priority-based
- ☞ Communication delay depends on communication traffic of other partners
- ☞ Real-time guarantees can be provided

# Time division multiple access (TDMA) busses

Each communication partner is assigned a fixed time slot.
Example:




http://www.ece.cmu.edu/~koopman/jtdma/jtdma.html#classical

- Master sends sync
- Some waiting time
- Each slave transmits in its time slot
- ∃ variations (truncating unused slots, >1 slots per slave)
- TDMA resources have a deterministic timing behavior
- TDMA provides QoS guarantees in networks on chips

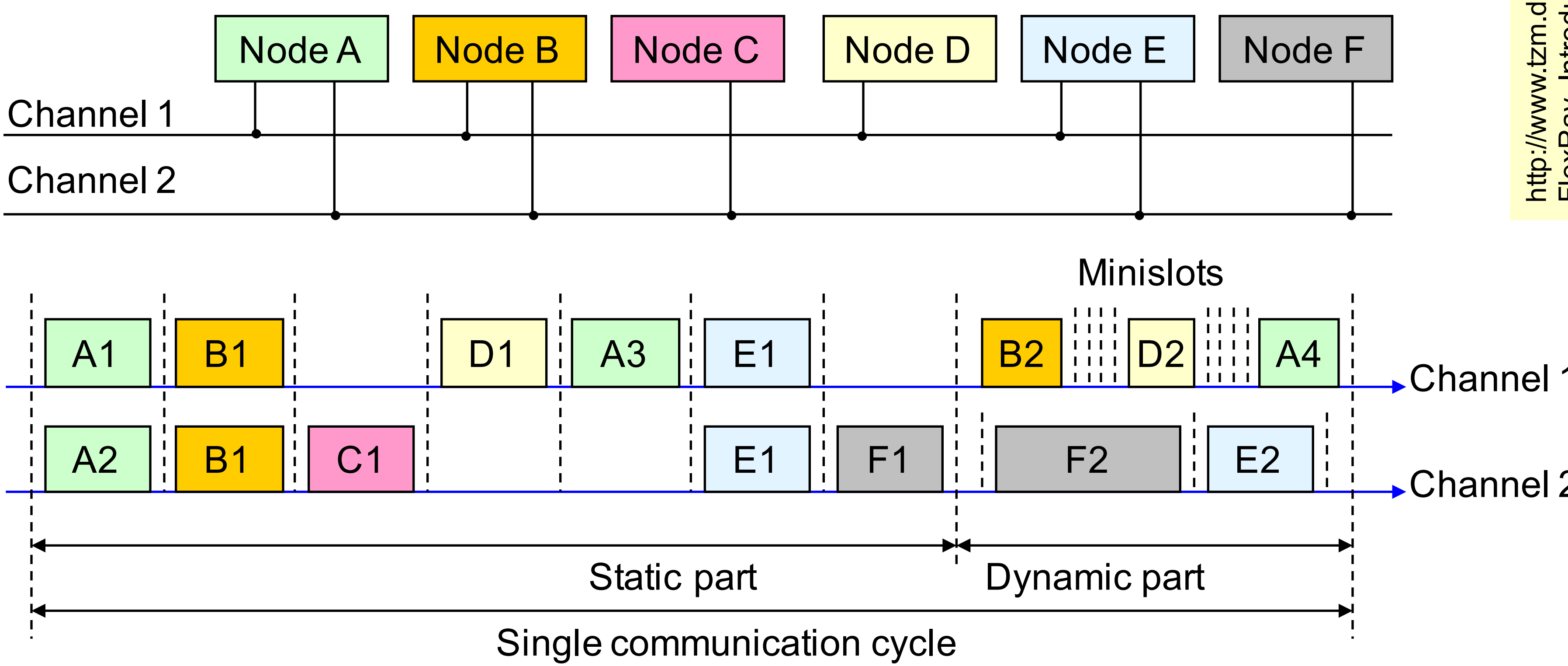
[E. Wandeler, L. Thiele: Optimal TDMA Time Slot and Cycle Length Allocation for Hard Real-Time Systems, ASP-DAC, 2006]

# FlexRay

- Developed by the FlexRay consortium (BMW, Ford, Bosch, DaimlerChrysler, …)
- Specified in SDL
- Meets requirements with transfer rates
  **High data rate can be achieved:**
  - initially targeted for ~ 10Mbit/sec;
  - design allows much higher data rates
- Improved error tolerance and time-determinism
- TDMA protocol
- Cycle subdivided into a static and a dynamic segment.

# TDMA in FlexRay

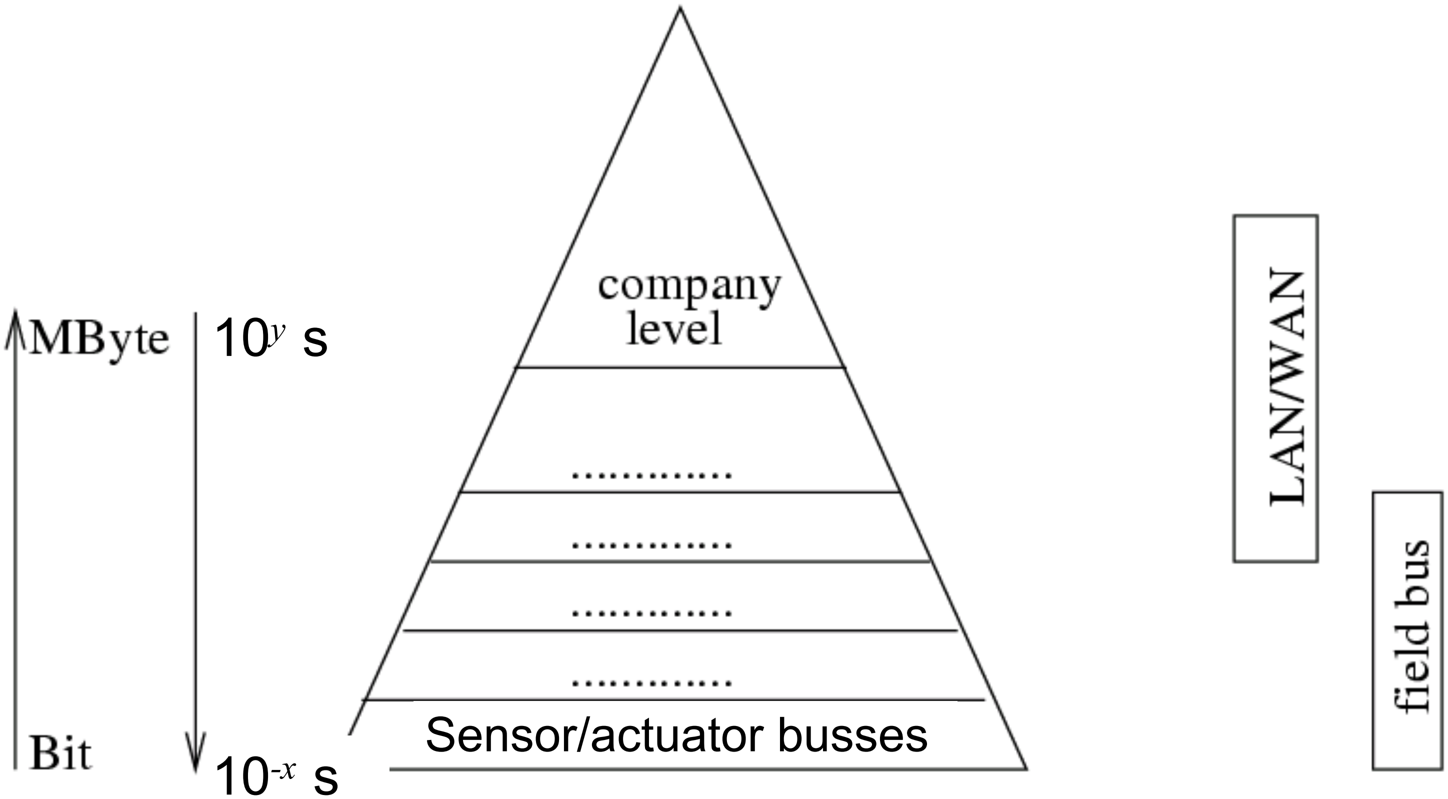
Exclusive bus access enabled for short time in each case.
Dynamic segment for transmission of variable length information.
Fixed priorities in dynamic segment: Minislots for each potential sender.
Bandwidth used only when it is actually needed.




http://www.tzm.de/FlexRay/FlexRay_Introduction.html

# Communication: Hierarchy

Inverse relation between volume and urgency quite common:



# Other busses

- **IEEE 488:** Designed for laboratory equipment.
- **CAN:** Controller bus for automotive
- **LIN:** low cost bus for interfacing sensors/actuators in the automotive domain
- **MOST:** Multimedia bus for the automotive domain (not a field bus)
- **MAP:** bus designed for car factories.
- **Process Field Bus (Profibus):** used in smart buildings
- **The European Installation Bus (EIB):** bus designed for smart buildings; CSMA/CA; low data rate. **Upgrade: KNX-Bus**
- Attempts to use Ethernet. Timing predictability an issue.

# Wireless communication: Examples

- IEEE 802.11 a/b/g/n
- UMTS; HSPA; LTE
- DECT
- Bluetooth
- WirelessHART
- ZigBee

Timing predictability of wireless communication?

☞ chapter 5

# D/A-Converts

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# Embedded System Hardware

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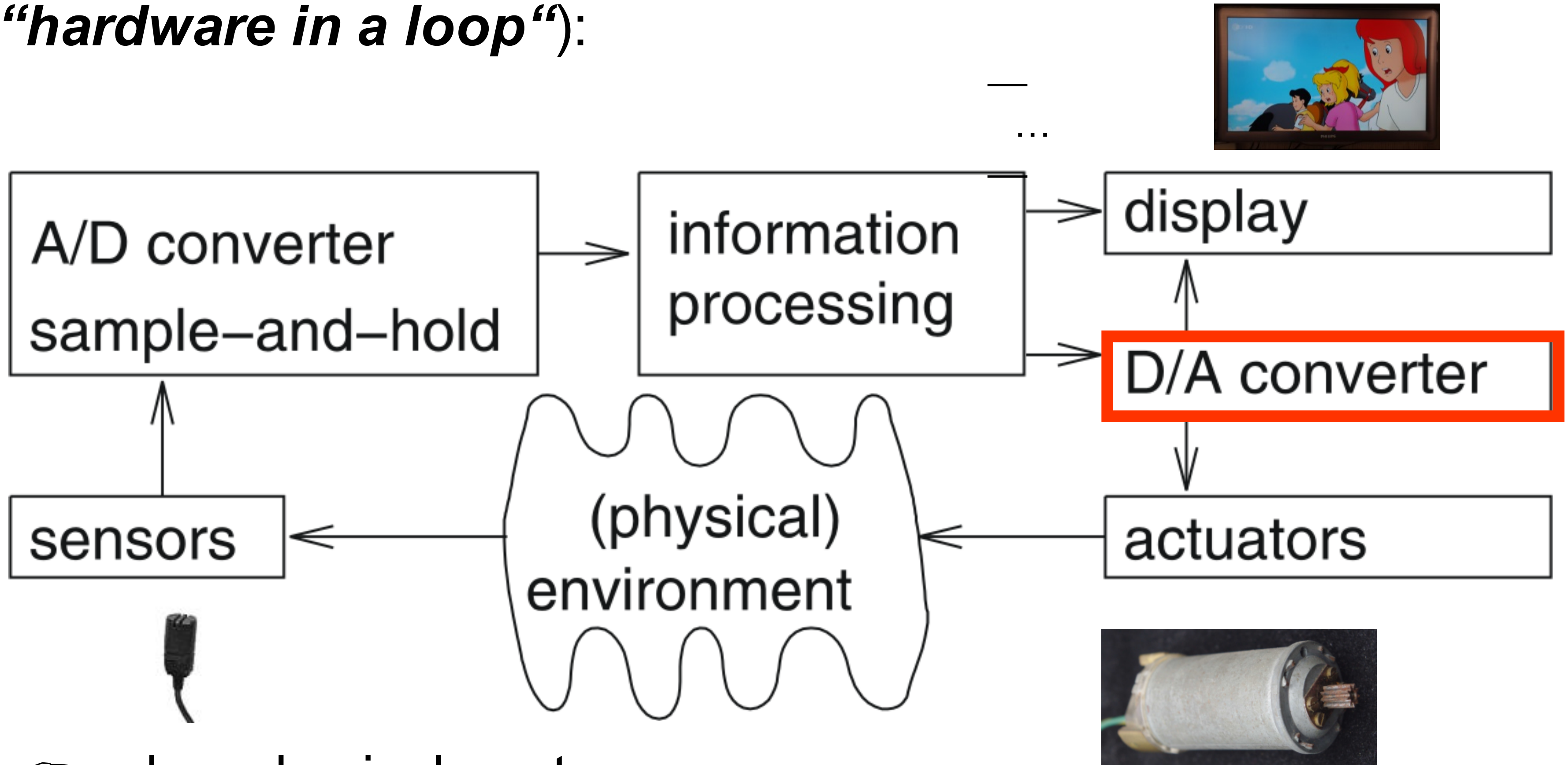
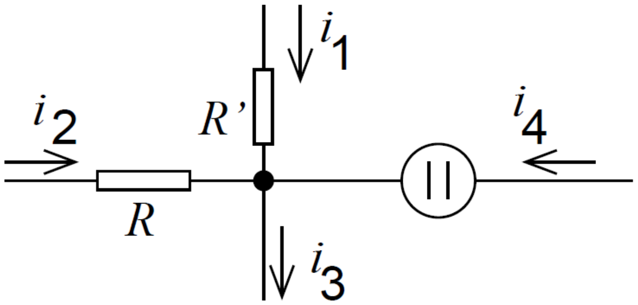



☞ cyber-physical systems

# Kirchhoff‘s junction rule
## Kirchhoff‘s Current Law, Kirchhoff‘s first rule

**Kirchhoff’s Current Law:**
At any point in an electrical circuit, the sum of currents flowing towards that point is equal to the sum of currents flowing away from that point.
(Principle of conservation of electric charge)

Example:




$$i_1 + i_2 + i_4 = i_3$$

Formally, for any node in a circuit:

$$\sum_k i_k = 0$$

$$i_1+i_2-i_3+i_4=0$$

Count current flowing away from node as negative.

[Jewett and Serway, 2007].

# Kirchhoff's loop rule

## Kirchhoff‘s Voltage Law, Kirchhoff's second rule

The principle of conservation of energy implies that:

The sum of the potential differences (voltages) across all elements around any closed circuit must be zero

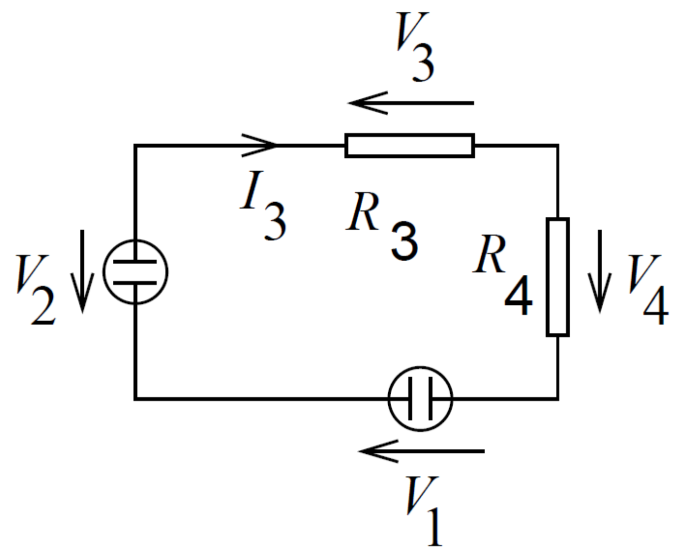
[Jewett and Serway, 2007].

Formally, for any loop in a circuit:

$$\sum_k V_k = 0$$

Count voltages traversed against arrow direction as negative

Example:



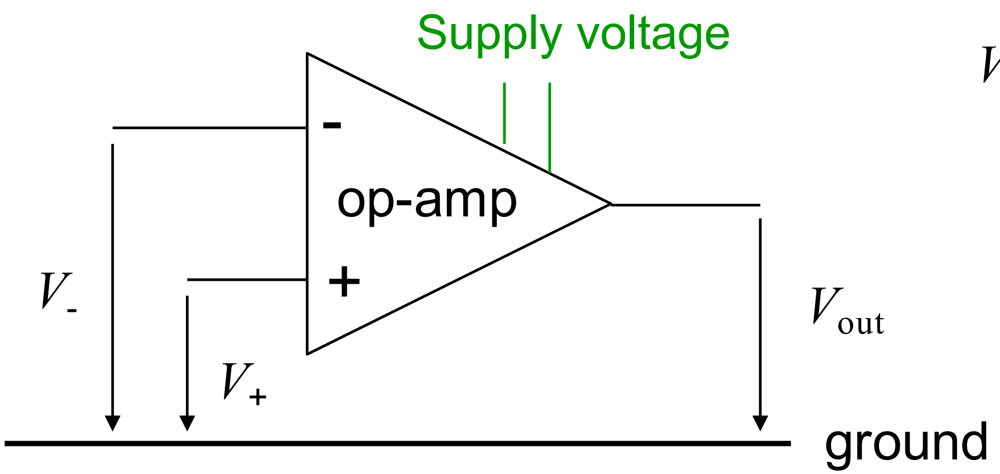

$V_1 - V_2 - V_3 + V_4 = 0$

$V_3 = R_3 \times I_3$ if current counted in the same direction as $V_3$

$V_3 = -R_3 \times I_3$ if current counted in the opposite direction as $V_3$

# Operational Amplifiers (Op-Amps)

Operational amplifiers (op-amps) are devices amplifying the voltage difference between two input terminals by a large gain factor $g$

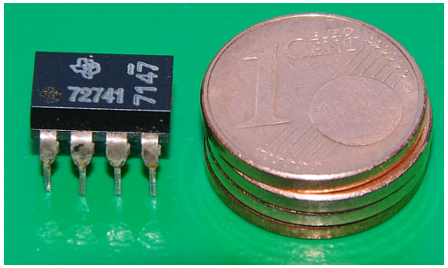



$$V_{out} = (V_+ - V_-) \cdot g$$

For an **ideal** op-amp: $g \rightarrow \infty$

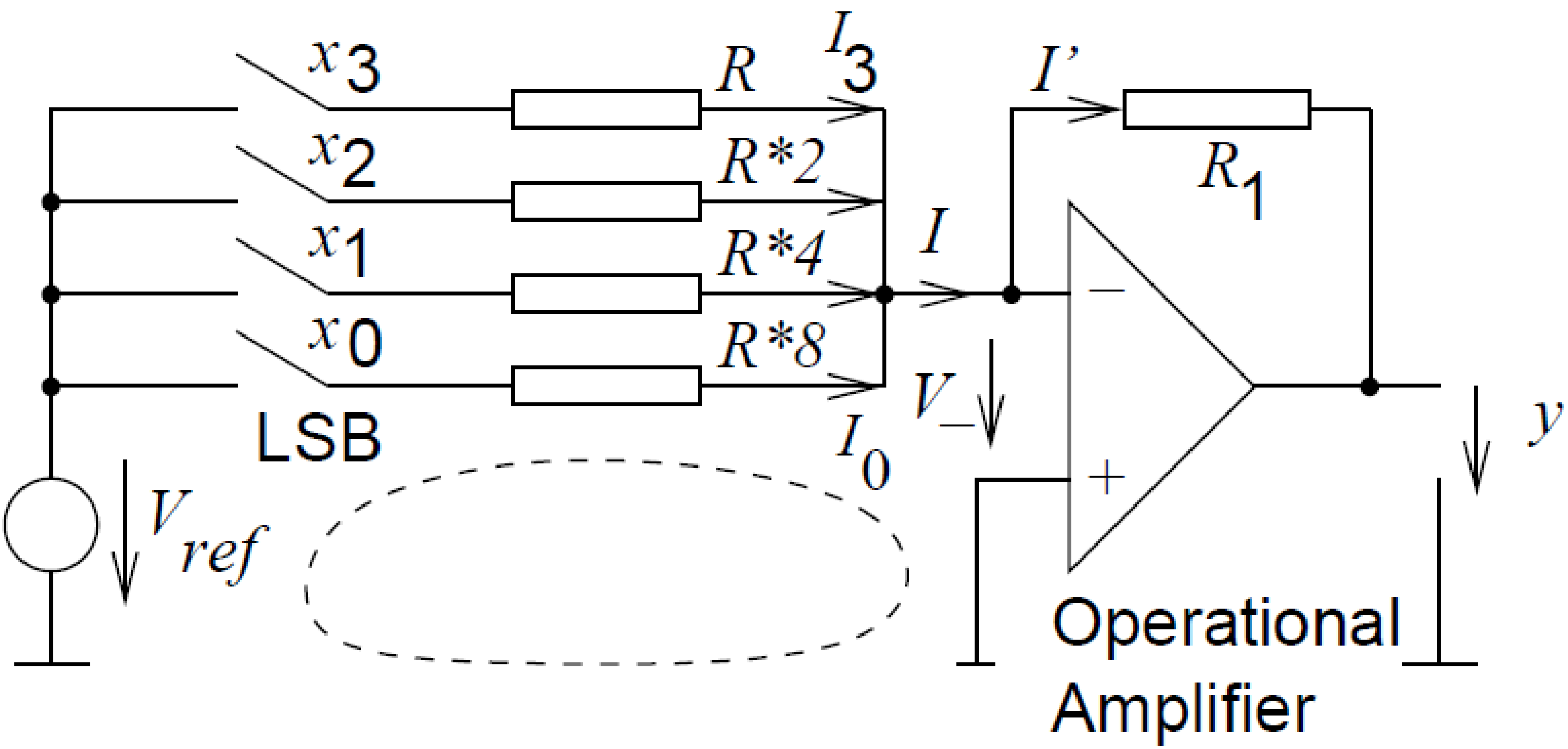
(In practice: $g$ may be around $10^4..10^6$)

Op-amp in a DIL package



# Digital-to-Analog (D/A) Converters

Various types, can be quite simple, e.g.:

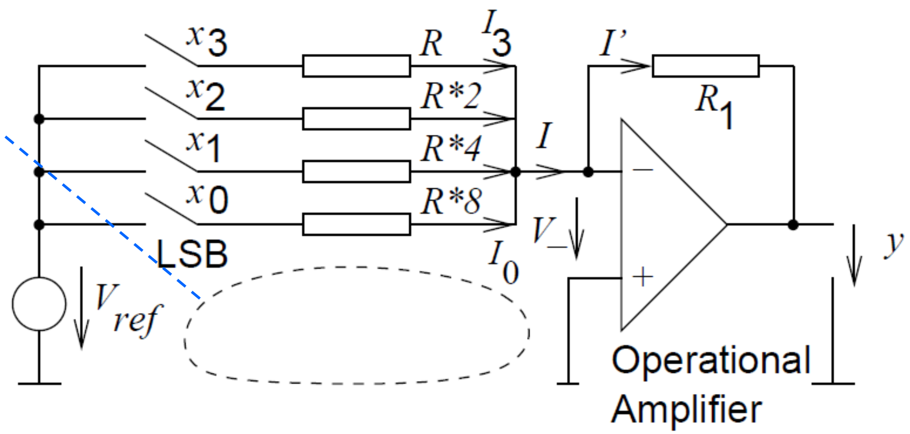



$$I = x_3 \times \frac{V_{ref}}{R} + x_2 \times \frac{V_{ref}}{2 \times R} + x_1 \times \frac{V_{ref}}{4 \times R} + x_0 \times \frac{V_{ref}}{8 \times R} = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^{3} x_i \times 2^i$$

# Current $I$ proportional to the number represented by $x$

Loop rule:

$$x_0 \cdot I_0 \cdot 8 \cdot R + V_{\_} - V_{ref} = 0$$




☞ $$I_0 = x_0 \times \frac{V_{ref}}{8 \times R}$$

In general: $$I_i = x_i \times \frac{V_{ref}}{2^{3-i} \times R}$$

Junction rule: $$I = \sum_i I_i$$

☞ $$I = x_3 \times \frac{V_{ref}}{R} + x_2 \times \frac{V_{ref}}{2 \times R} + x_1 \times \frac{V_{ref}}{4 \times R} + x_0 \times \frac{V_{ref}}{8 \times R} = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^{3} x_i \times 2^i$$

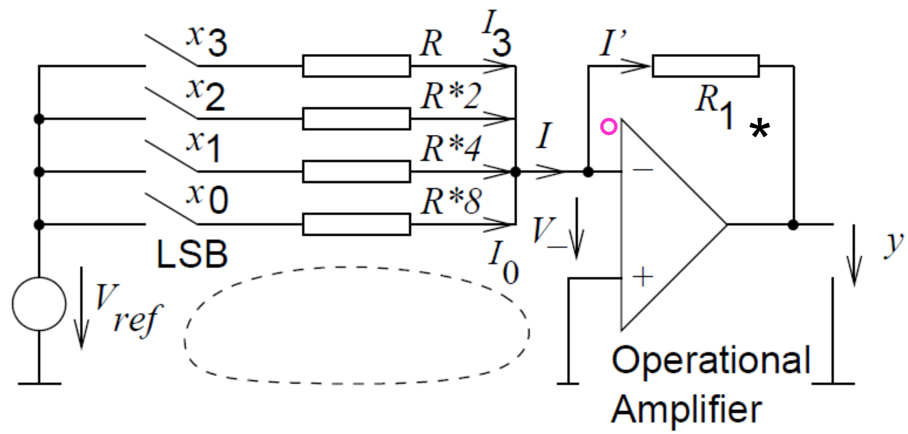
$I \sim nat(x)$, where $nat(x)$: natural number represented by $x$;

# Output voltage proportional to the number represented by $x$

Loop rule*: $y + R_1 \times I' = 0$

Junction rule°: $I = I'$

☞ $y + R_1 \times I = 0$




From the previous slide

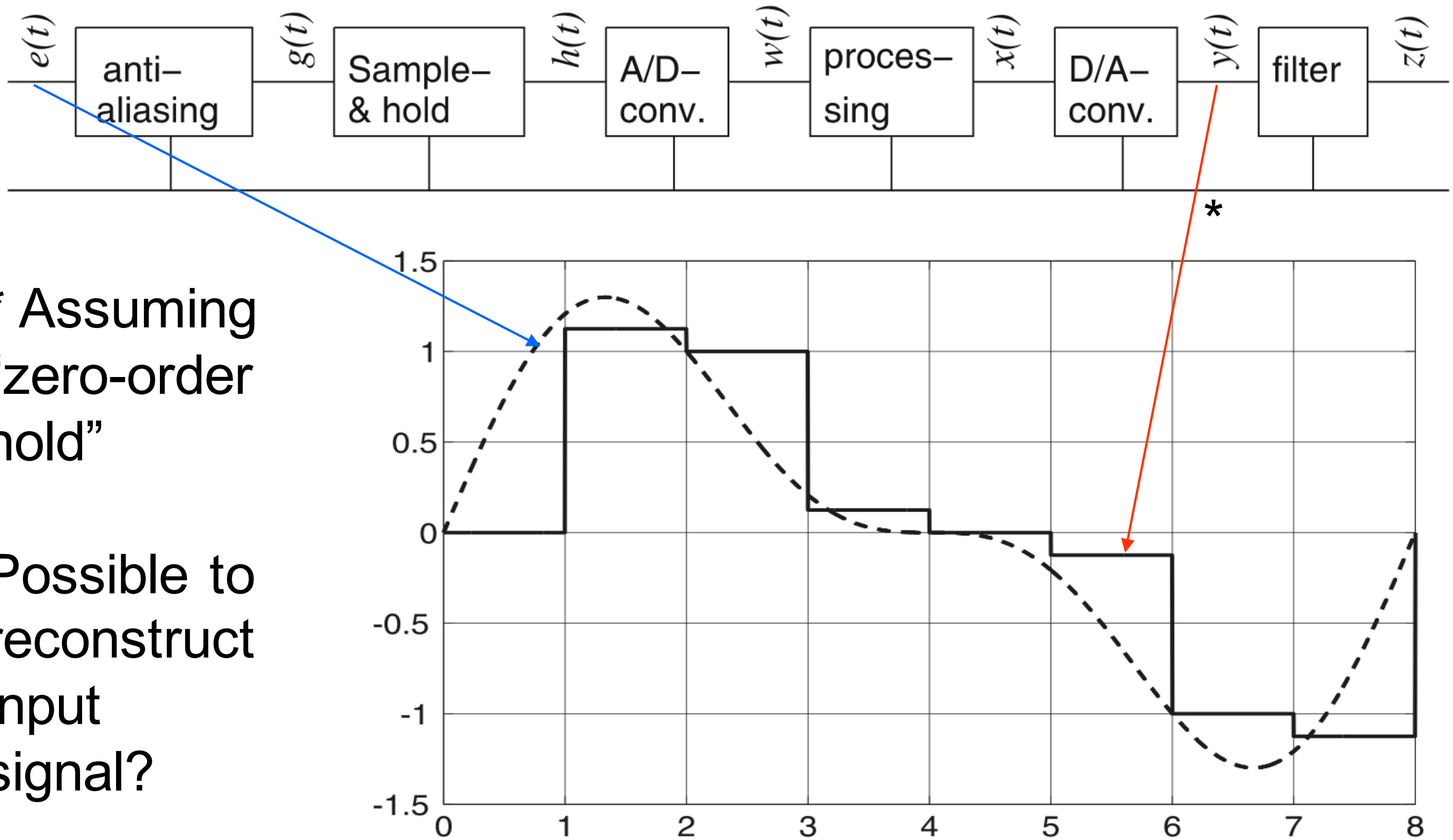
$$I = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^{3} x_i \times 2^i$$

Hence:

$$y = -V_{ref} \times \frac{R_1}{8 \times R} \sum_{i=0}^{3} x_i \times 2^i = -V_{ref} \times \frac{R_1}{8 \times R} \times nat(x)$$

Op-amp turns current $I \sim nat\ (x)$ into a voltage $\sim nat\ (x)$

# Output generated from signal $e_3(t)$

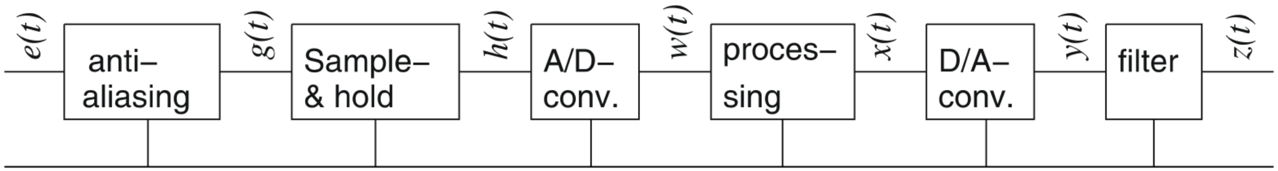


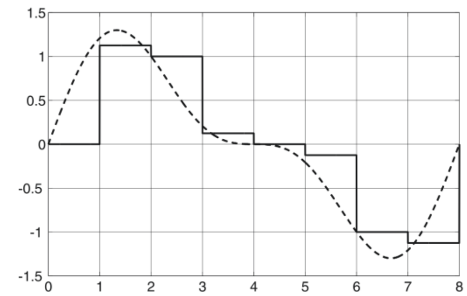

* Assuming "zero-order hold"

Possible to reconstruct input signal?

# Sampling Theorem

# Possible to reconstruct input signal?




- Assuming Nyquist criterion met
- Let $\{t_s\}, s = ..., -1, 0, 1, 2, ...$ be times at which we sample $g(t)$
- Assume a constant sampling rate of $1/p_s$ ($\forall s$: $p_s = t_{s+1} - t_s$).
- According sampling theory, we can approximate the input signal as follows:

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) \sin \frac{\pi}{p_s}(t - t_s)}{\frac{\pi}{p_s}(t - t_s)}$$

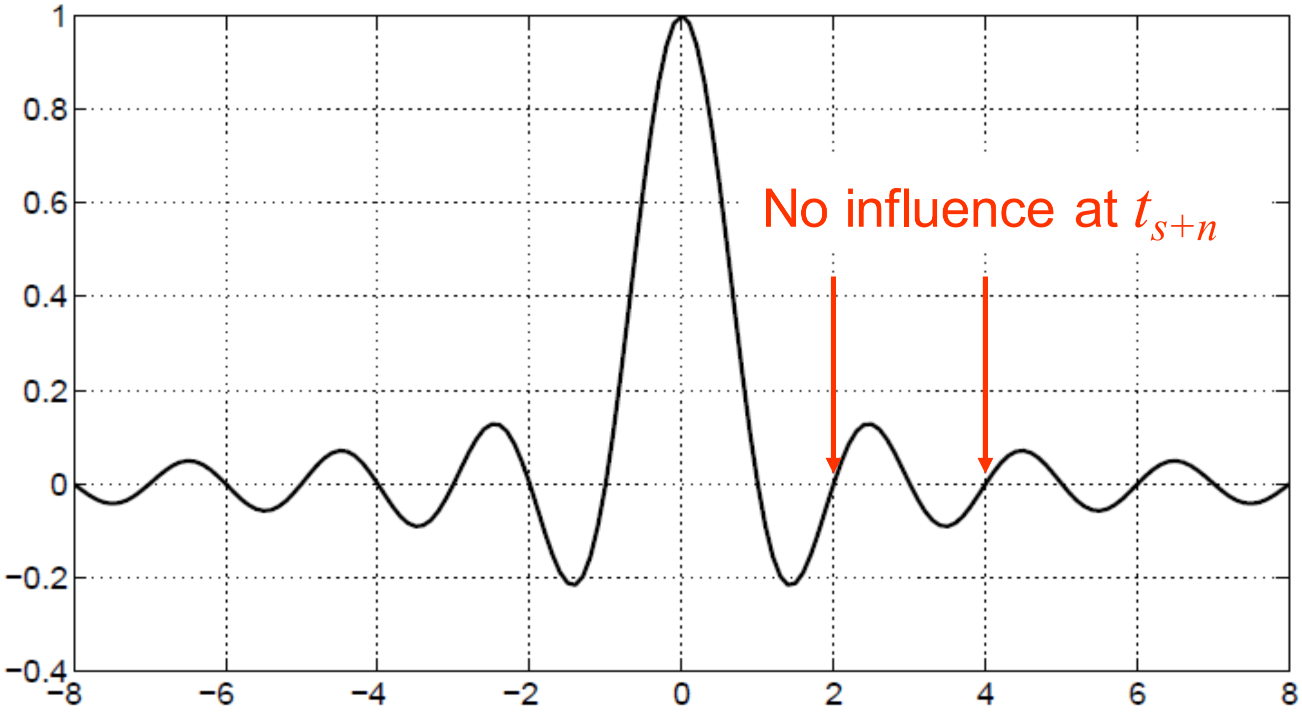
Weighting factor for influence of $y(t_s)$ at time $t$

Called sinc function

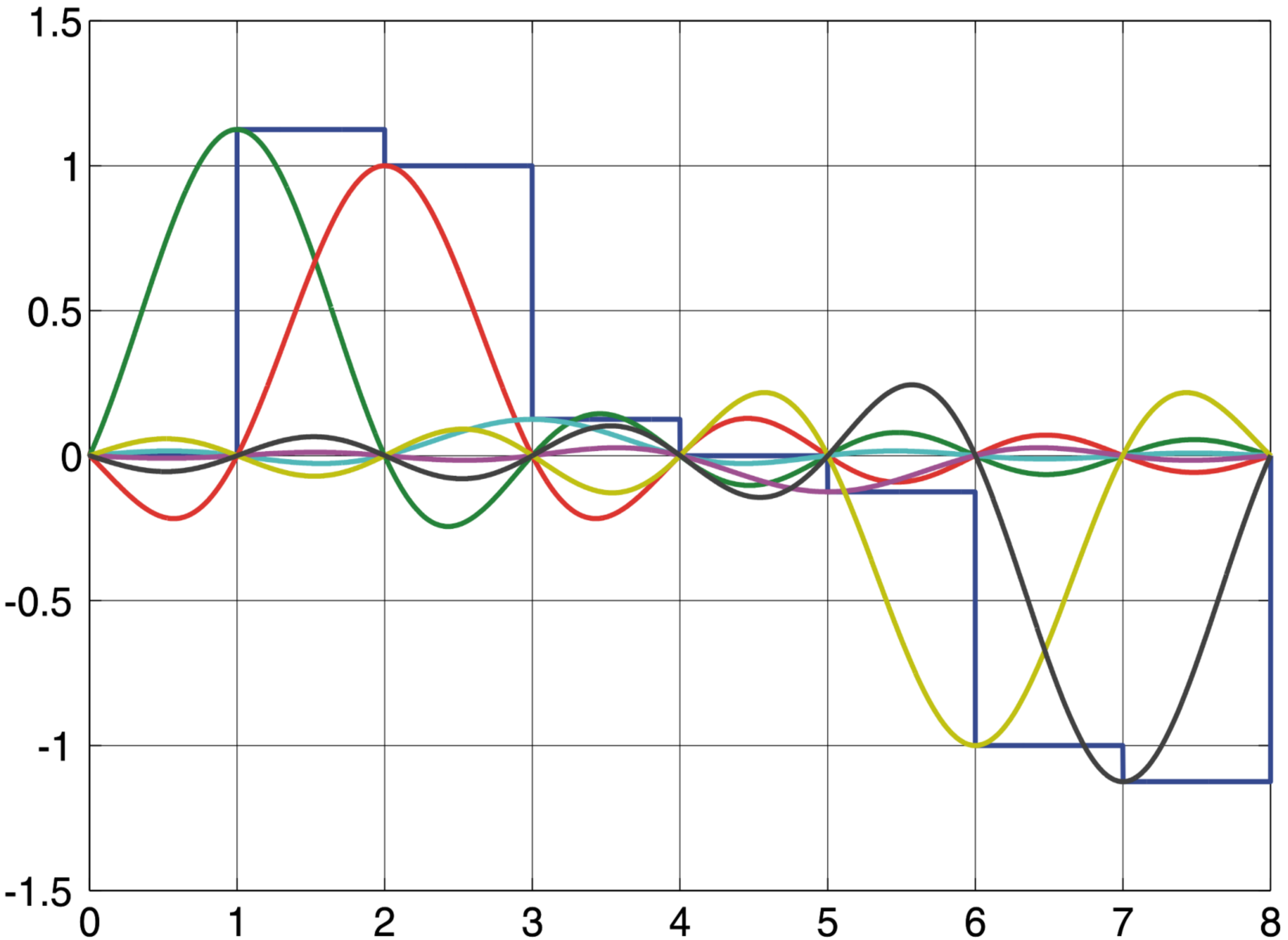
[Oppenheim, Schafer, 2009]

# Weighting factor for influence of $y(t_s)$ at time $t$

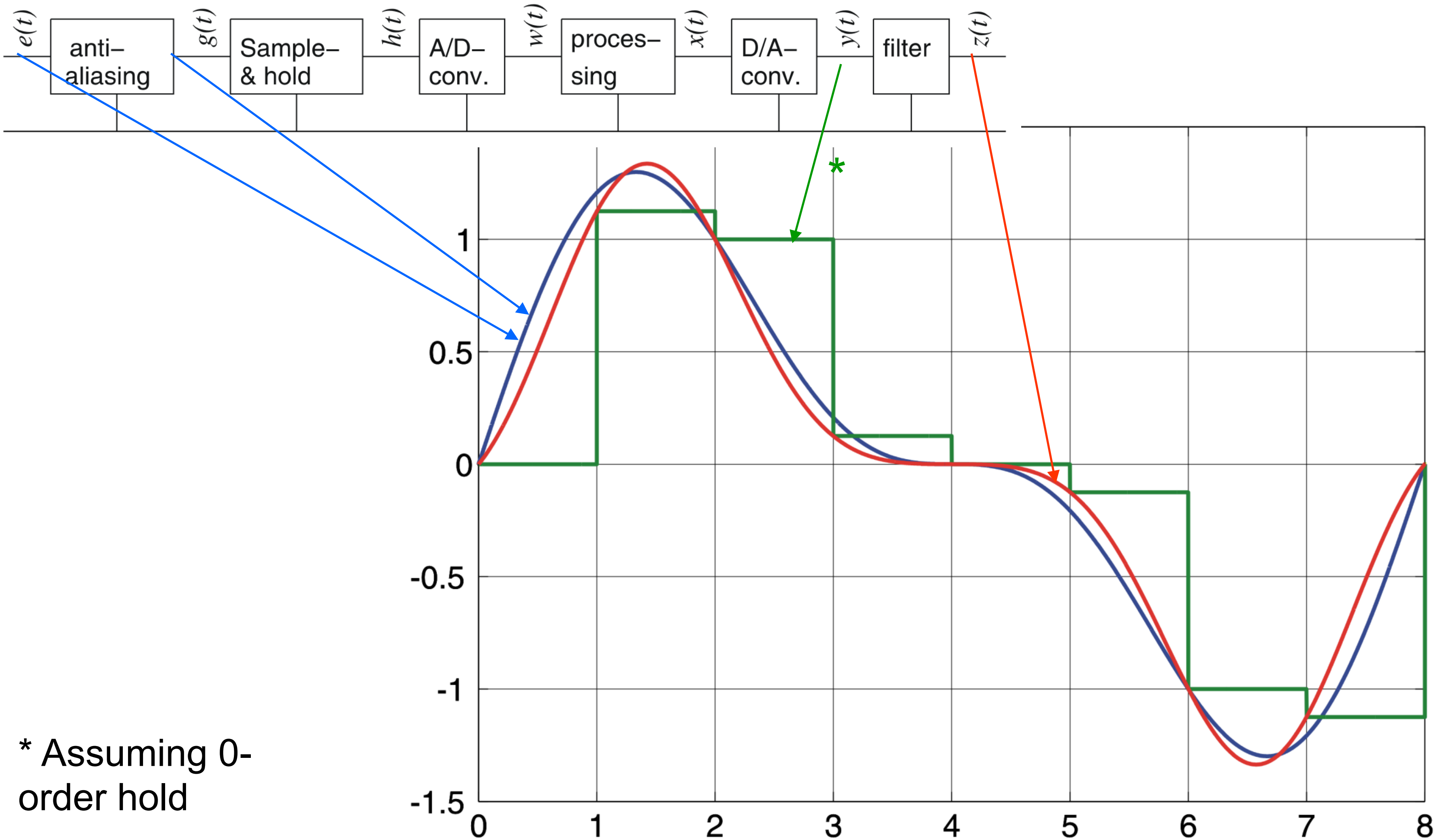
$$sinc(t - t_s) = \frac{sin(\frac{\pi}{p_s}(t - t_s))}{\frac{\pi}{p_s}(t - t_s)}$$



# Contributions from the various sampling instances



# (Attempted) reconstruction of input signal




* Assuming 0-order hold

# How precisely are we reconstructing the input?

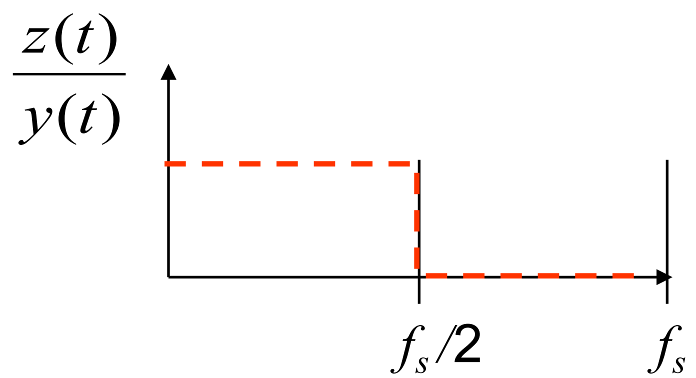
$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) sin \frac{\pi}{T_s}(t - t_s)}{\frac{\pi}{T_s}(t - t_s)}$$

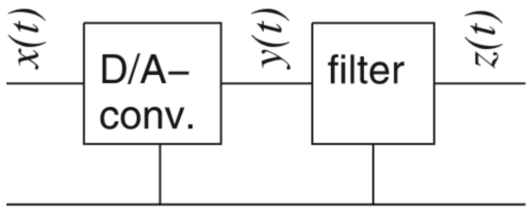
- **Sampling theory**:
  - **Reconstruction using *sinc* () is precise**
- However, it may be impossible to really compute $z(t)$ as indicated ….

# How to compute the *sinc*( ) function?

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) sin \frac{\pi}{T_s}(t - t_s)}{\frac{\pi}{T_s}(t - t_s)}$$

- **Filter theory:** The required interpolation is performed by an ideal low-pass filter (*sinc* is the Fourier transform of the low-pass filter transfer function)




Filter removes high frequencies present in $y(t)$

# Limitations

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) sin \frac{\pi}{T_s}(t - t_s)}{\frac{\pi}{T_s}(t - t_s)}$$

- Actual filters do not compute $sinc(\,)$
  In practice, filters are used as an approximation.
  Computing good filters is an art itself!
- All samples must be known to reconstruct $e(t)$ or $g(t)$.
  ☞ Waiting indefinitely before we can generate output!
  In practice, only a finite set of samples is available.
- Actual signals are never perfectly bandwidth limited.
- Quantization noise cannot be removed.

# Actuators/Display

# Embedded System Hardware

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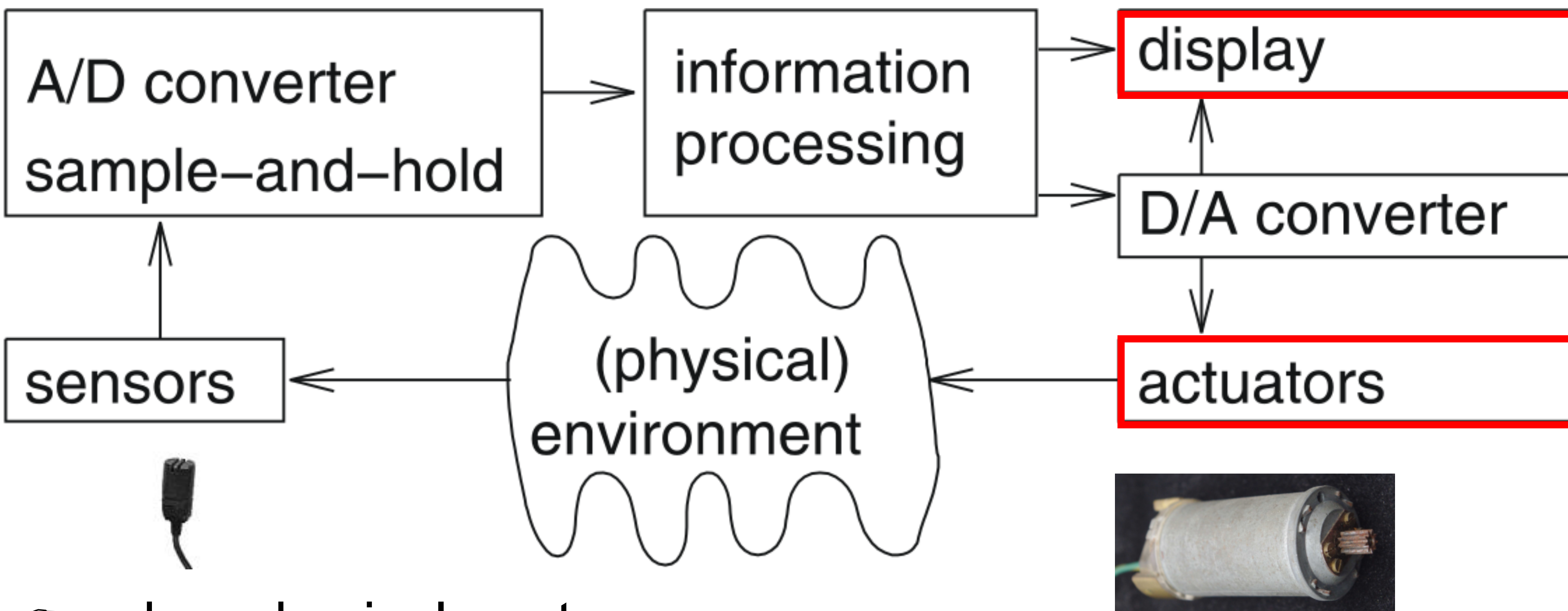


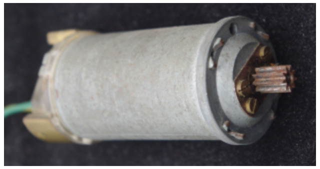

☞ cyber-physical systems

# Output

Output devices of embedded systems include

- **Displays:** Display technology is extremely important. Major research and development efforts

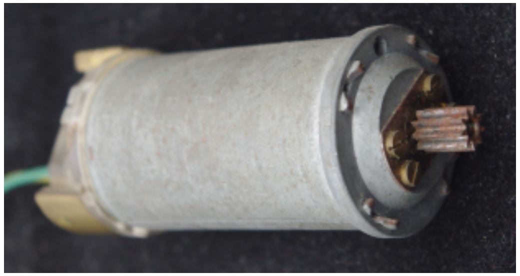
- **Electro-mechanical devices:** these influence the environment through motors and other electro-mechanical equipment. Frequently require analog output.



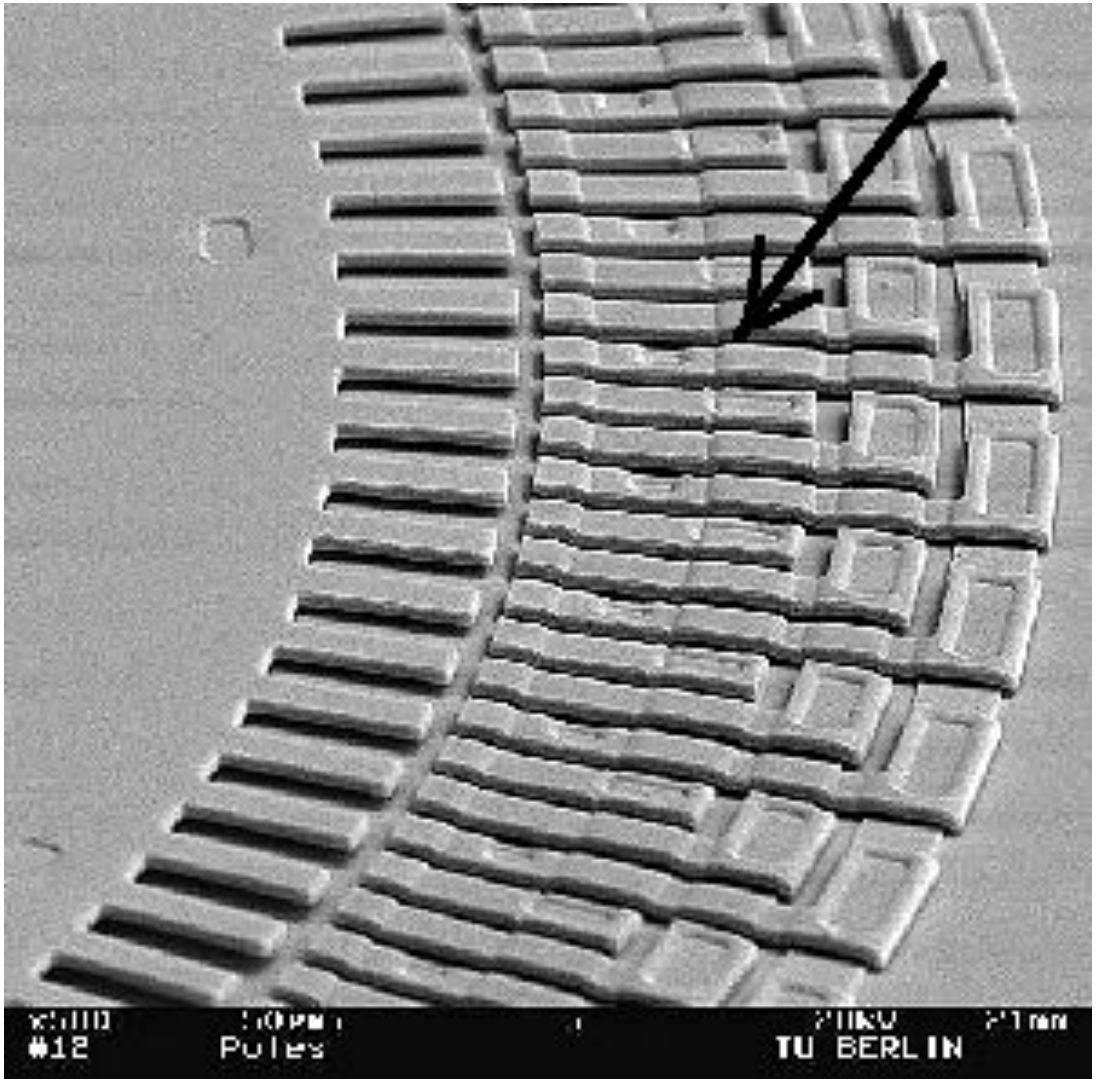
# Actuators

Huge variety of actuators and output devices, impossible to present all of them.

Motor as an example



# Actuators (2)




Courtesy and ©: E. Obermeier, MAT, TU Berlin

http://www.piezomotor.se/pages/PWtechnology.html

http://www.elliptec.com/fileadmin/elliptec/User/Produkte/Elliptec_Motor/Elliptecmotor_How_it_works.h

# Secure Hardware


- Security needed for communication & storage
- Demand for special equipment for cryptographic keys
- To resist side-channel attacks like
  - measurements of the supply current or
  - Electromagnetic radiation.

  Special mechanisms for physical protection (shielding, sensor detecting tampering with the modules).
- Logical security, using cryptographic methods needed.
- Smart cards: special case of secure hardware
  - Have to run with a very small amount of energy.
- In general, we have to distinguish between different levels of security and knowledge of "adversaries"

# Summary

Hardware in a loop

- Sensors
- Discretization
- Information processing
  - Importance of energy efficiency, Special purpose HW very expensive, Energy efficiency of processors, Code size efficiency, Run-time efficiency
  - Reconfigurable Hardware
- Communication
- D/A converters
- Sampling theorem
- Actuators (briefly)
- Secure hardware (briefly)