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Communication

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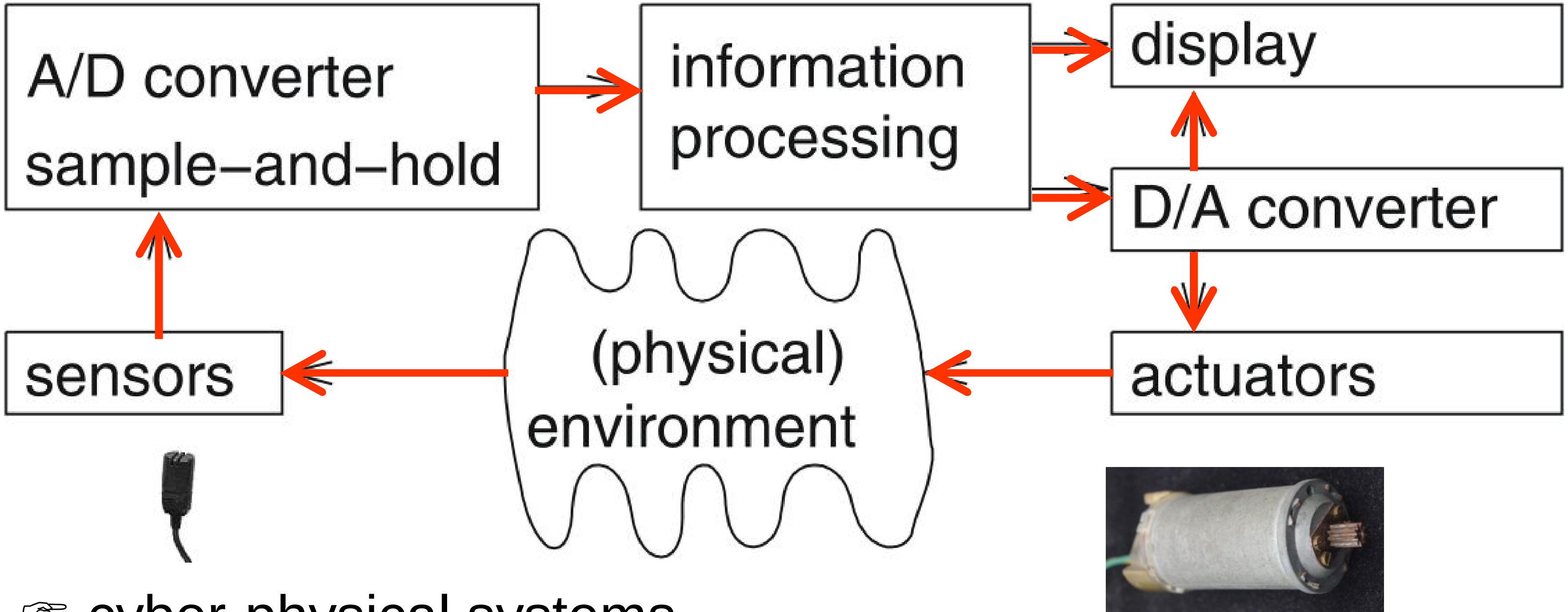
2012年 11 月 21 日

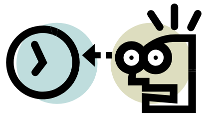
Embedded System Hardware

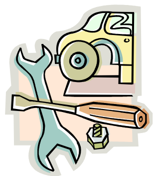
Embedded system hardware is frequently used in a loop (*“**hardware in a loop**“*):



☞ cyber-physical systems

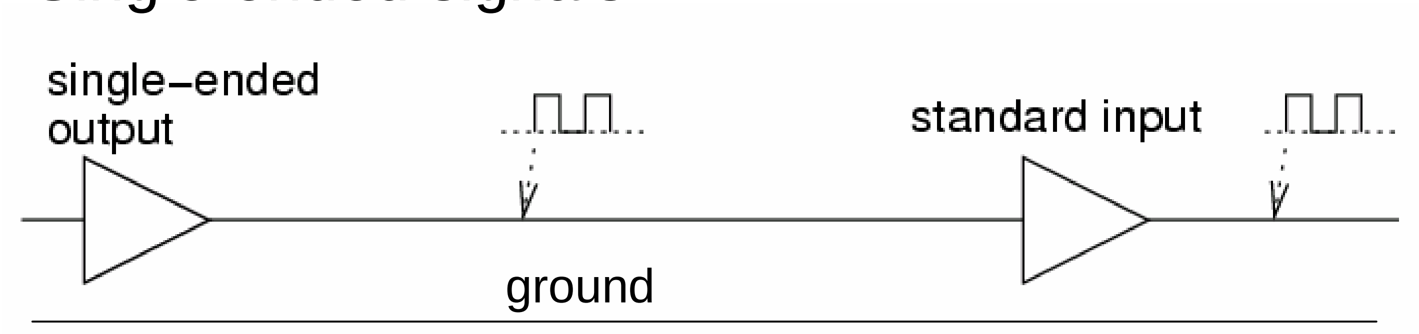
Communication
- Requirements -

- 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

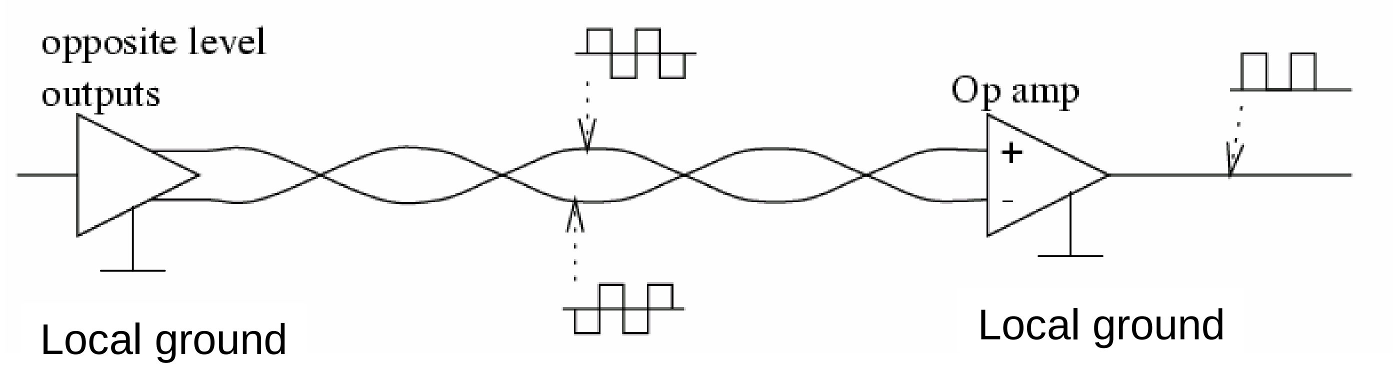
- Single-ended signals

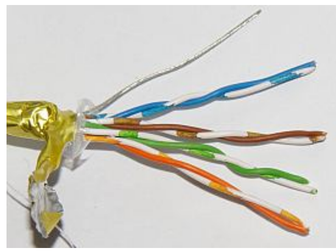


e.g.: RS-232

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

- Differential signals





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

Evaluation

Advantages:

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

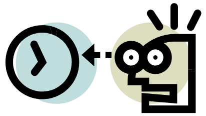
Disadvantages:

- 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
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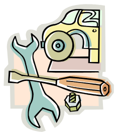


CSMA/CD vs. CSMA/CA

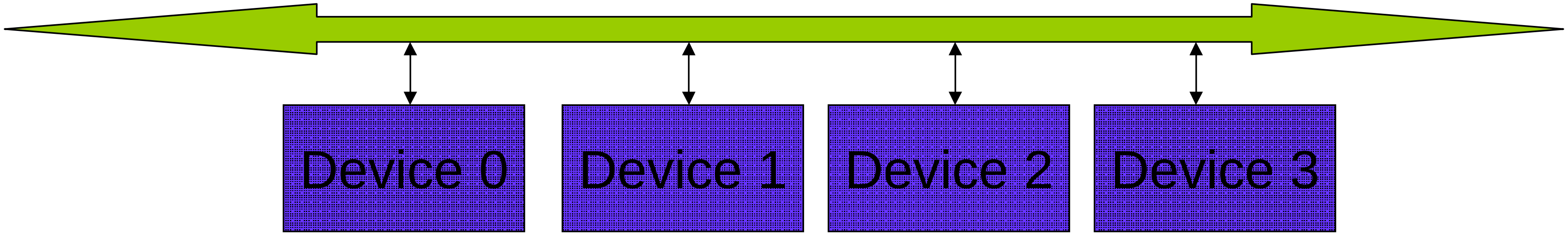
Carrier-sense multiple-access/collision-**detection** (CSMA/C**D**, variants of Ethernet): collision ☞ retries; no guaranteed response time.

Alternatives:

- Carrier-sense multiple-access/collision-**avoidance** (CSMA/C**A**)
  - WLAN techniques with request preceding transmission
  - Each partner gets an ID (priority).
    After bus transfer: partners try setting their ID;
    Detection of higher ID ☞ disconnect. Guaranteed response time for highest ID, others if given a chance.
- token rings, token busses

Priority-based arbitration of communication media

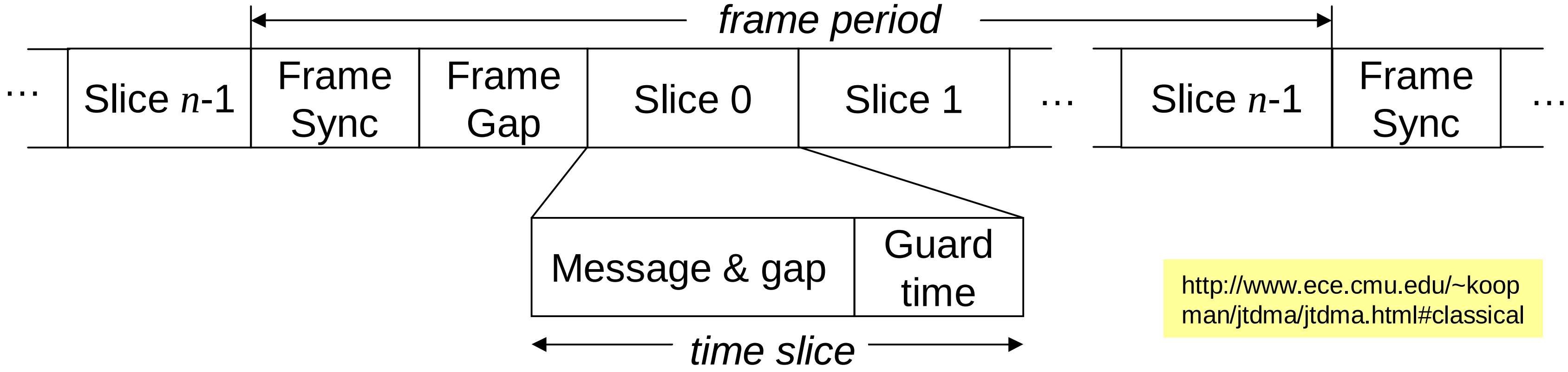
Example: bus



- Bus arbitration (allocation) is frequently priority-based
- ☞ Communication delay depends on communication traffic of other partners
- ☞ No tight real-time guarantees, except for highest priority partner

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]

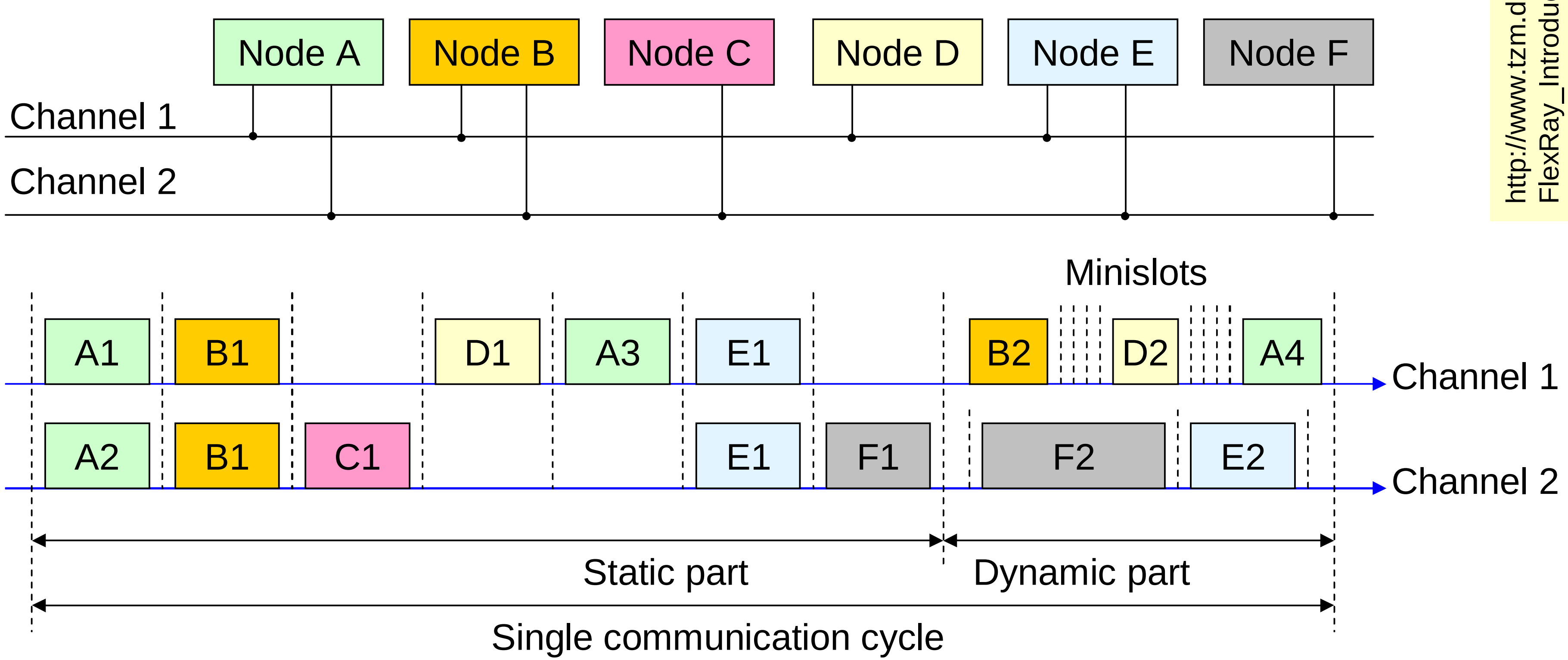
FlexRay

- Developed by the FlexRay consortium (BMW, Ford, Bosch, DaimlerChrysler, …)
- Specified in SDL
- Meets requirements with transfer rates >> CAN standard
  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.

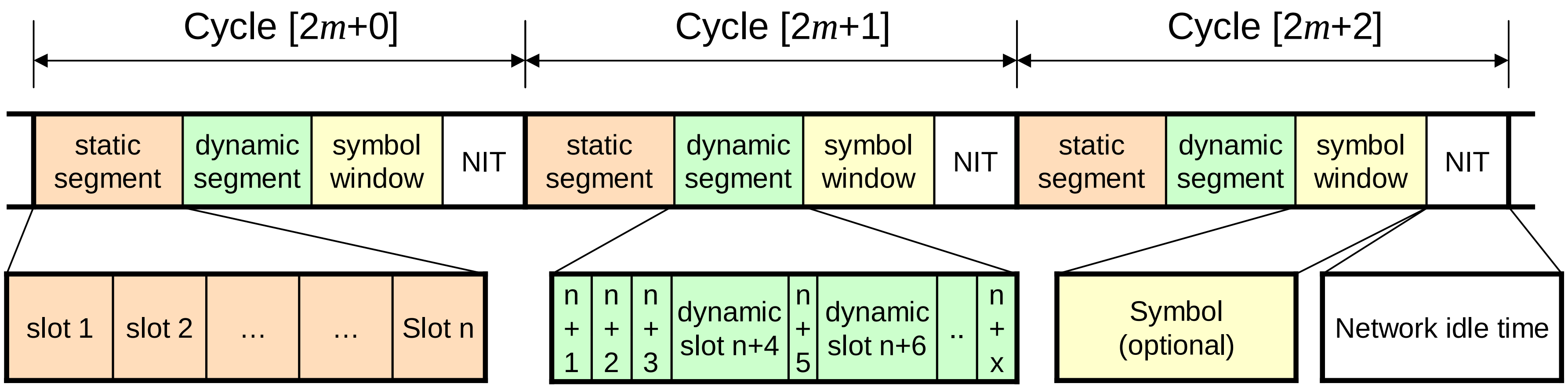
TDMA in FlexRay

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



Time intervals in Flexray



Simplified version of diagram by Prof. Form, TU Braunschweig, 2007

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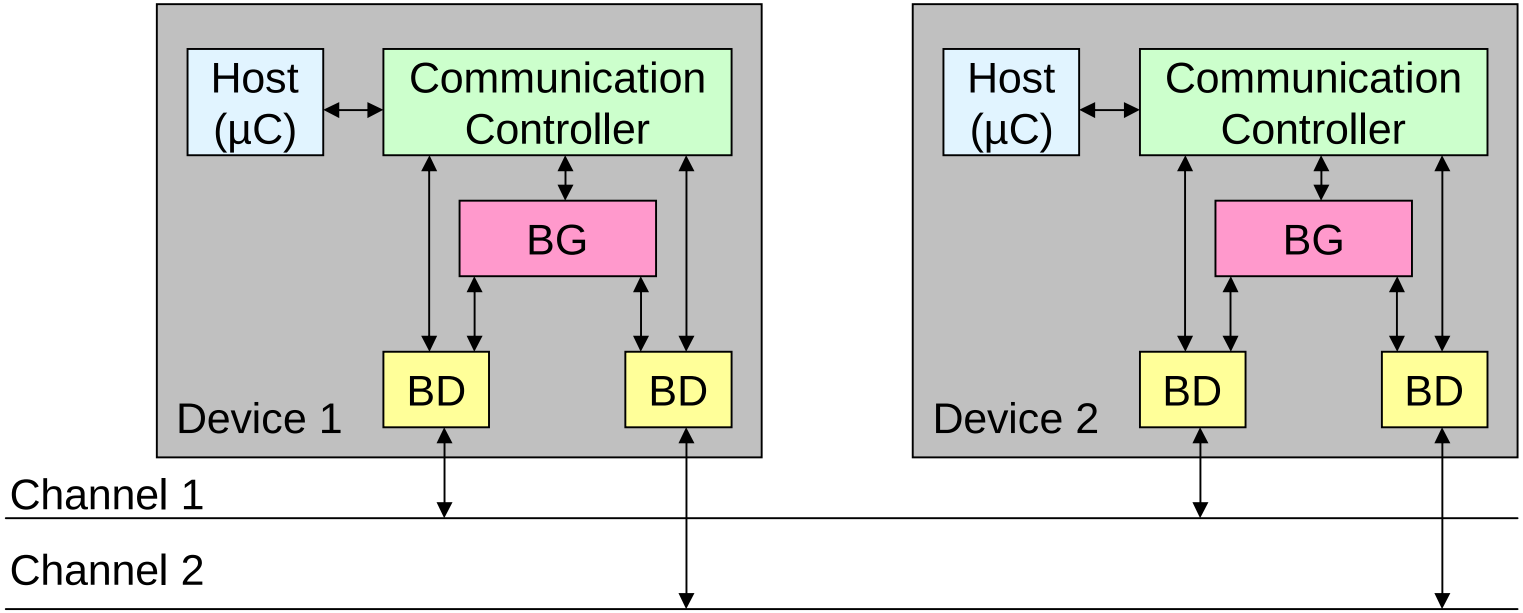
- **Cycle** = static segment + dynamic segment + symbol window/network idle time

Structure of Flexray networks

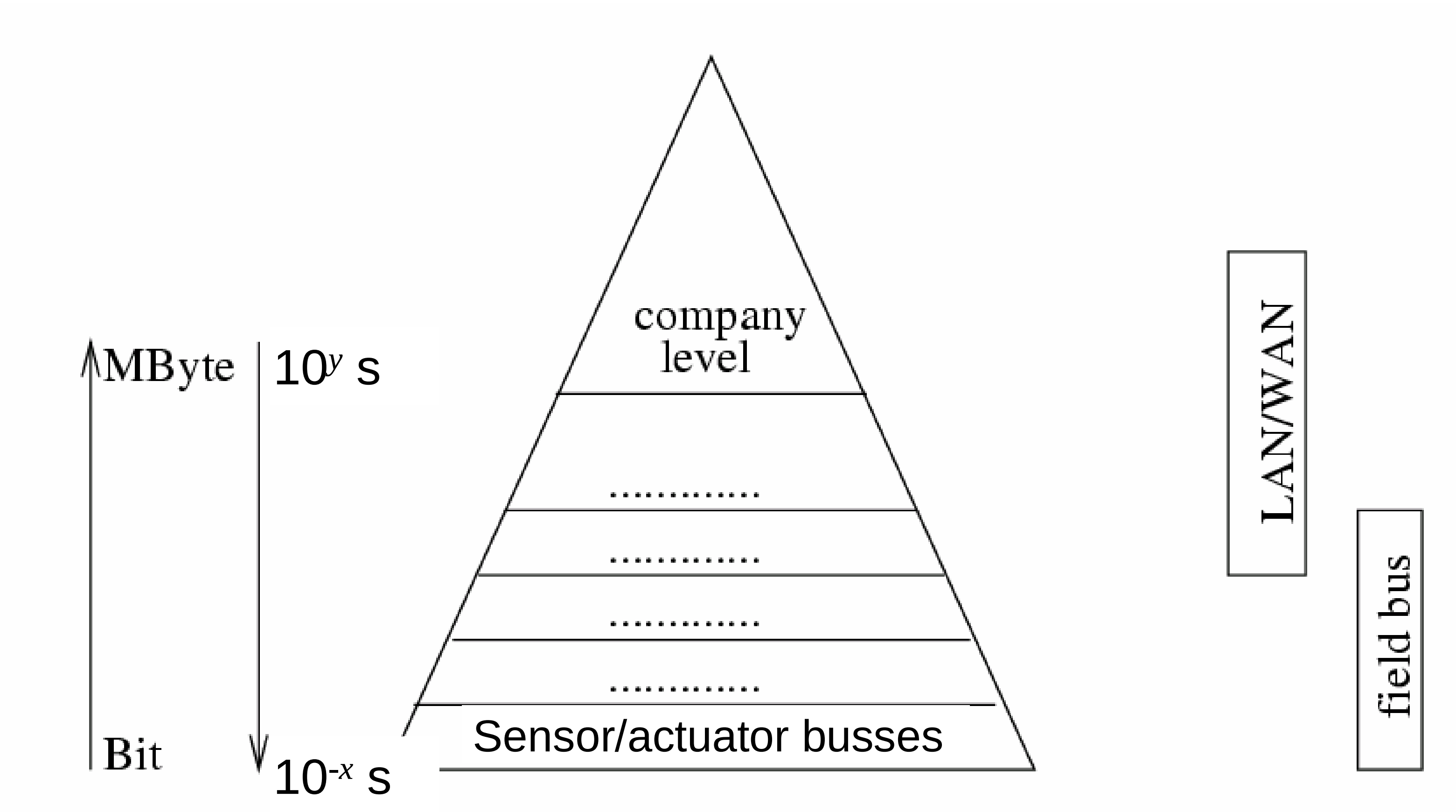
Bus guardian BG protects the system against failing processors, e.g. so-called "babbling idiots"



http://www.ixxat.de/index.php?seite=introduction_flexray_en&root=5873&system_id=5875&com=formular_suche_treffer&markierung=flexray

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.
- Attempts to use Ethernet. Timing predictability an issue.

Wireless communication: Examples

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

Timing predictability of wireless communication?

Energy consumption e.g. of Wimax devices?

☞ chapter 5

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D/A-Converters

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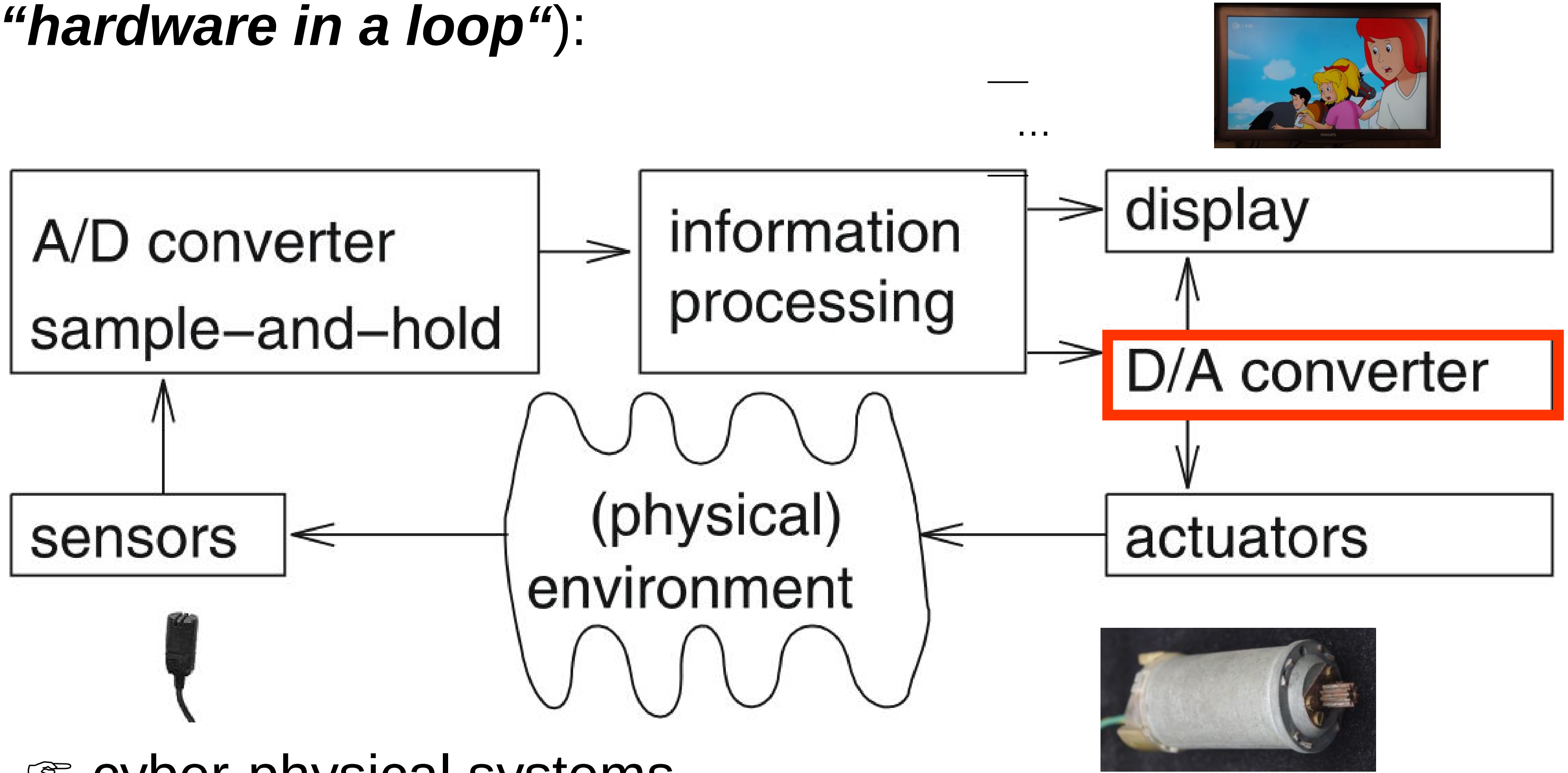
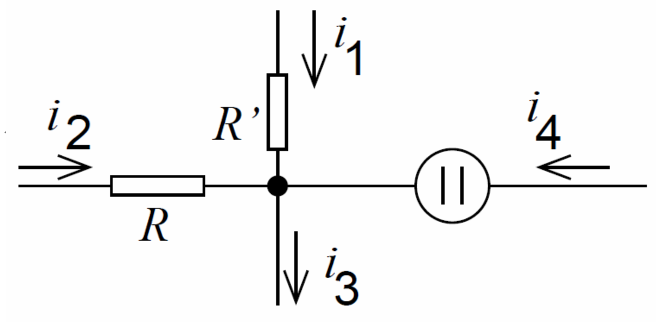


☞ cyber-physical systems

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:

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

$$\sum_k i_k = 0$$

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

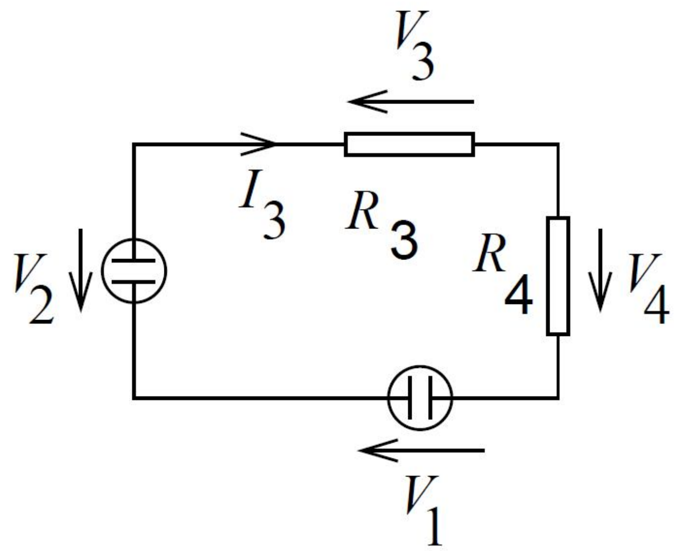
[Jewett and Serway, 2007].

Formally, for any loop in a circuit:

$$\sum_k V_k = 0$$

Count voltages traversed against arrow direction as negative

Example:



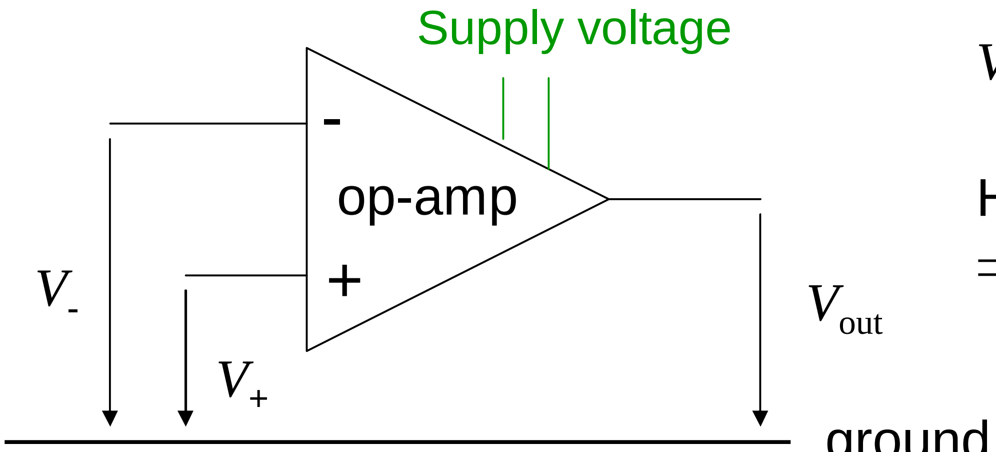
V_1-V_2-V_3+V_4=0

V_3=R_3×I_3 if current counted in the same direction as V_3

V_3=-R_3×I_3 if current counted in the opposite direction as V_3

Operational Amplifiers (Op-Amps)

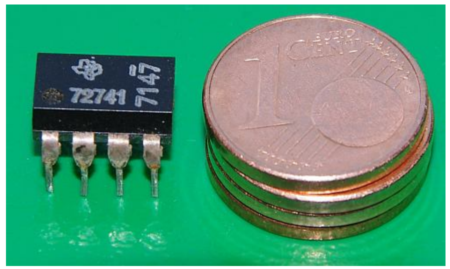
Operational amplifiers (op-amps) are devices amplifying the voltage difference between two input terminals by a large gain factor g



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

High impedance input terminals
$\Rightarrow$ Currents into inputs ≈ 0

Op-amp in a DIL package

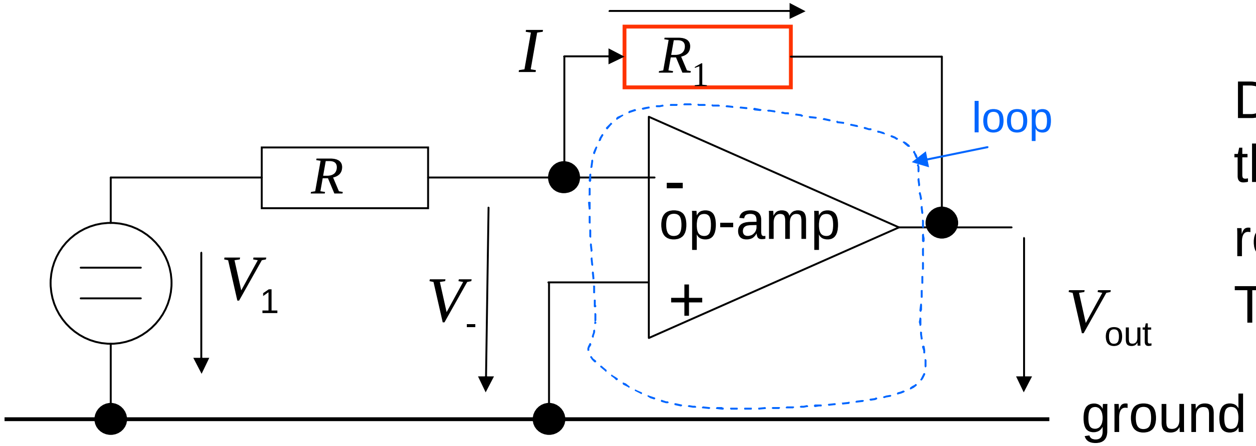


For an **ideal** op-amp: $g \rightarrow \infty$

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

Op-Amps with feedback

In circuits, negative feedback is used to define the actual gain:



Due to the feedback to the *inverted* input, R_1 reduces voltage V_-. To which level?

$V_{out} = - g \cdot V_-$ (op-amp feature)

$I \cdot R_1 + V_{out} - V_- = 0$ (loop rule)

$\Rightarrow I \cdot R_1 + - g \cdot V_- - V_- = 0$

$\Rightarrow (1+g) \cdot V_- = I \cdot R_1$

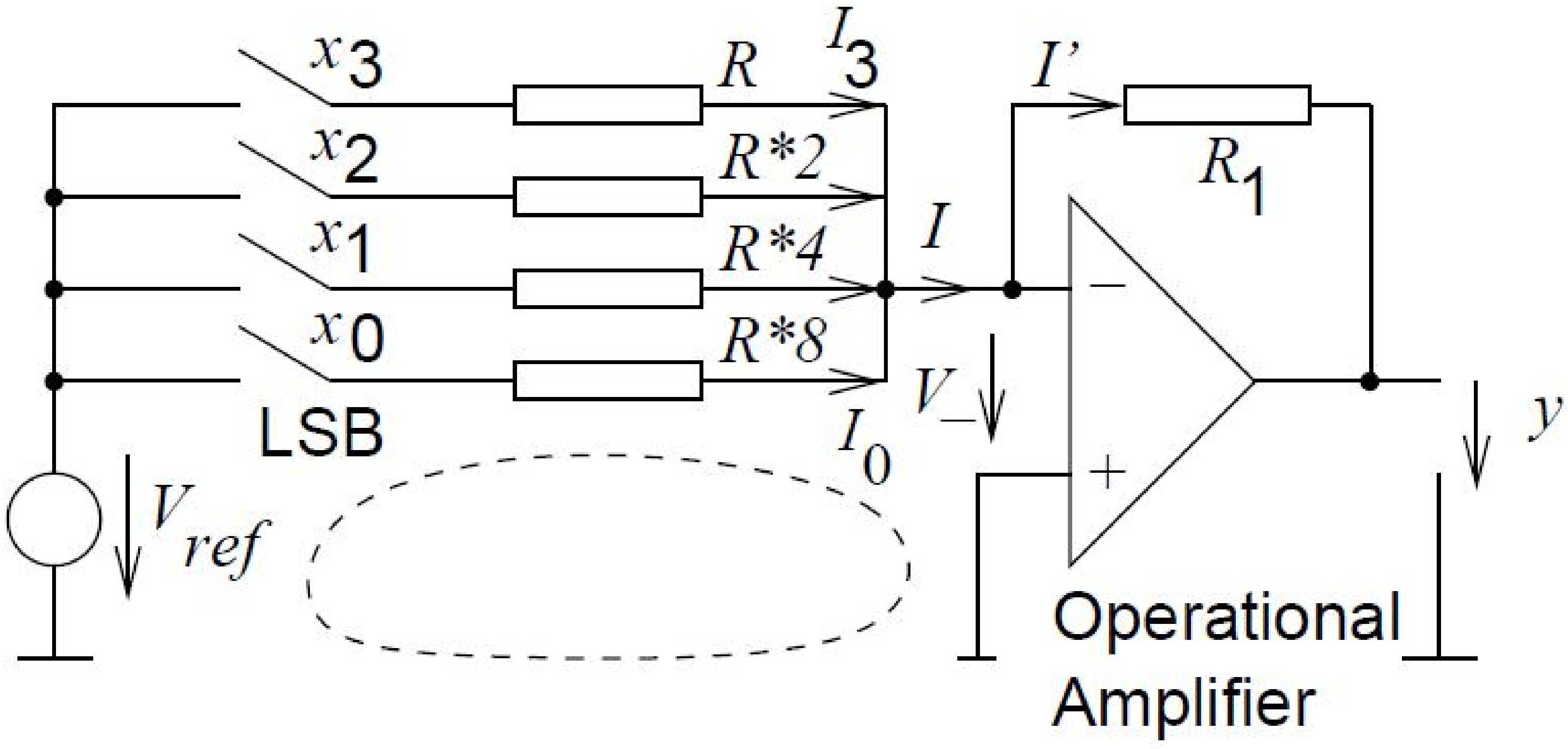
$$\Rightarrow V_- = \frac{I \cdot R_1}{1+g}$$

$$\boxed{V_{-,ideal} = \lim_{g \to \infty} \frac{I \cdot R_1}{1+g} = 0}$$

V_- is called **virtual ground**: the voltage is 0, but the terminal may not be connected to ground

Digital-to-Analog (D/A) Converters

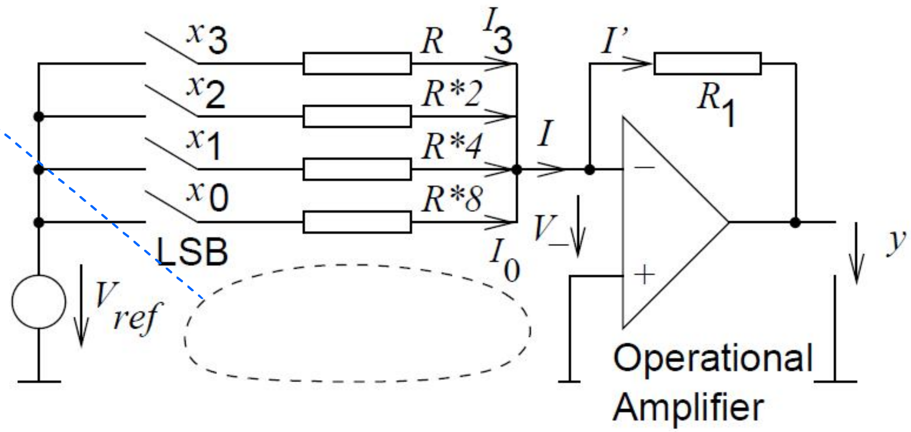
Various types, can be quite simple,
e.g.:



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: $$I = \sum_i I_i$$

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

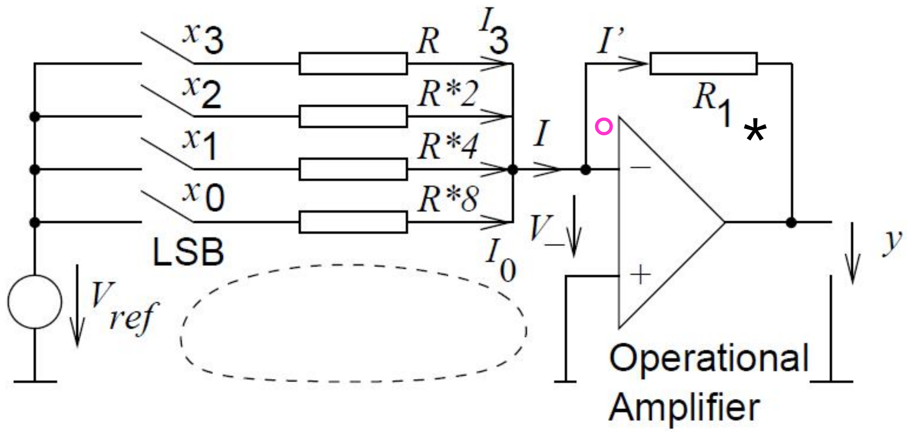
$I \sim nat(x)$, where $nat(x)$: natural number represented by x;

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

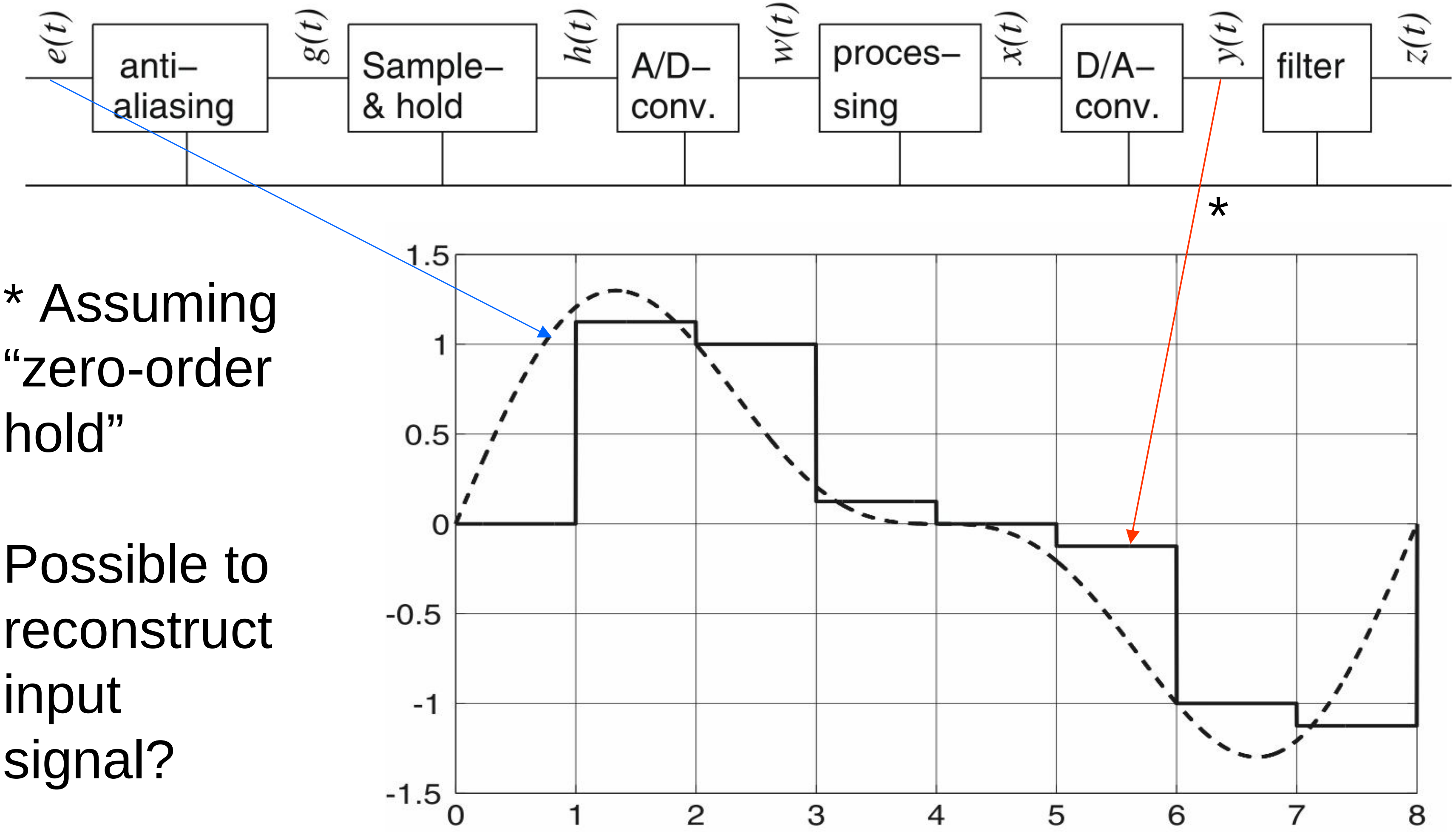
$$I = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^{3} x_i \times 2^i$$

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?

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Sampling Theorem

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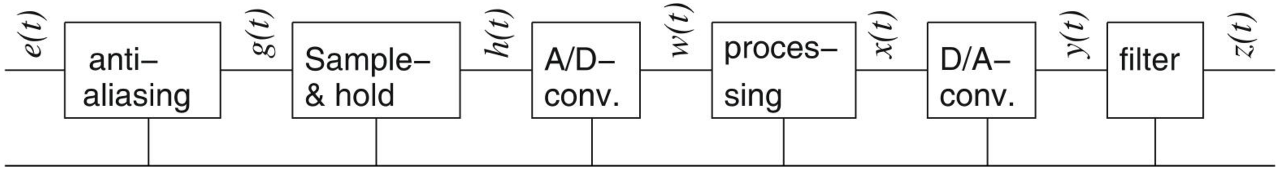
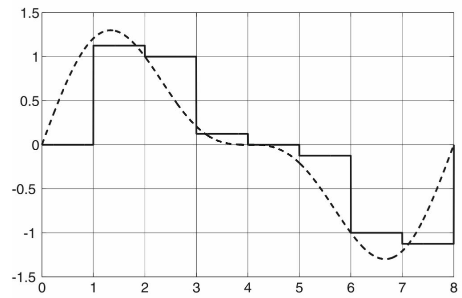
Possible to reconstruct input signal?





- 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:

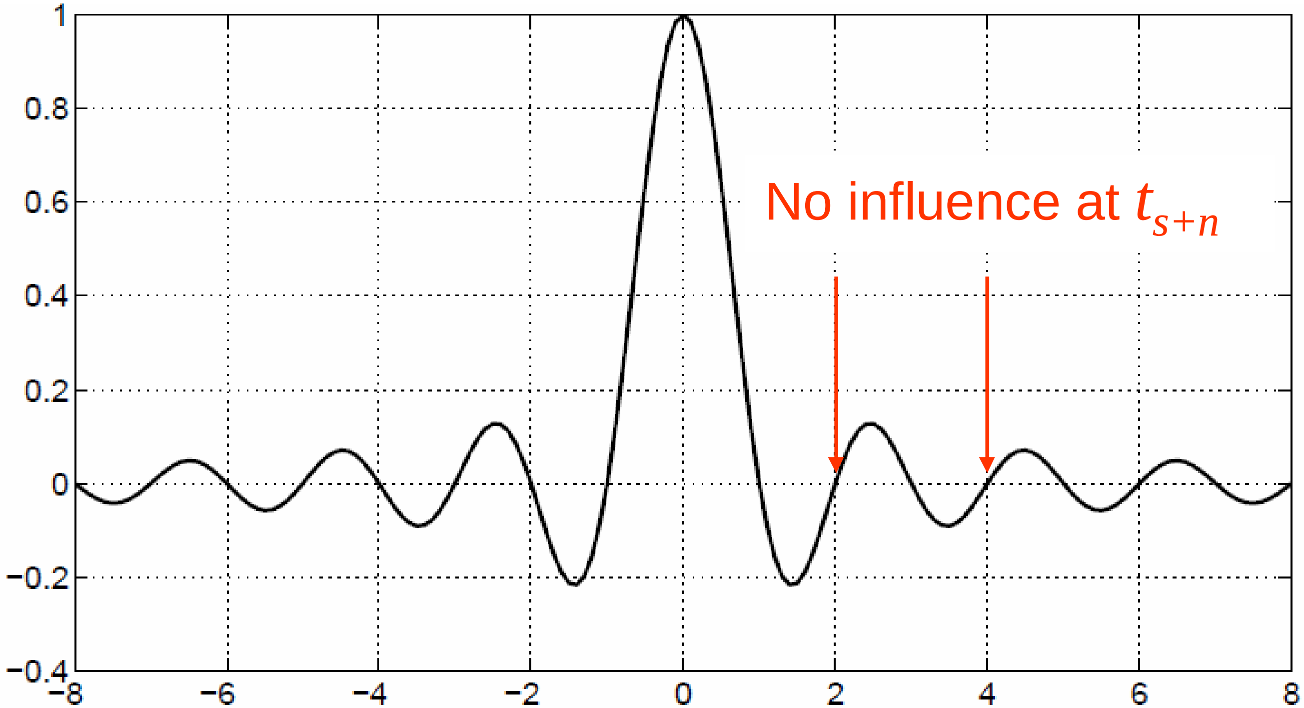
$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) sin \frac{\pi}{p_s}(t - t_s)}{\frac{\pi}{p_s}(t - t_s)}$$

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

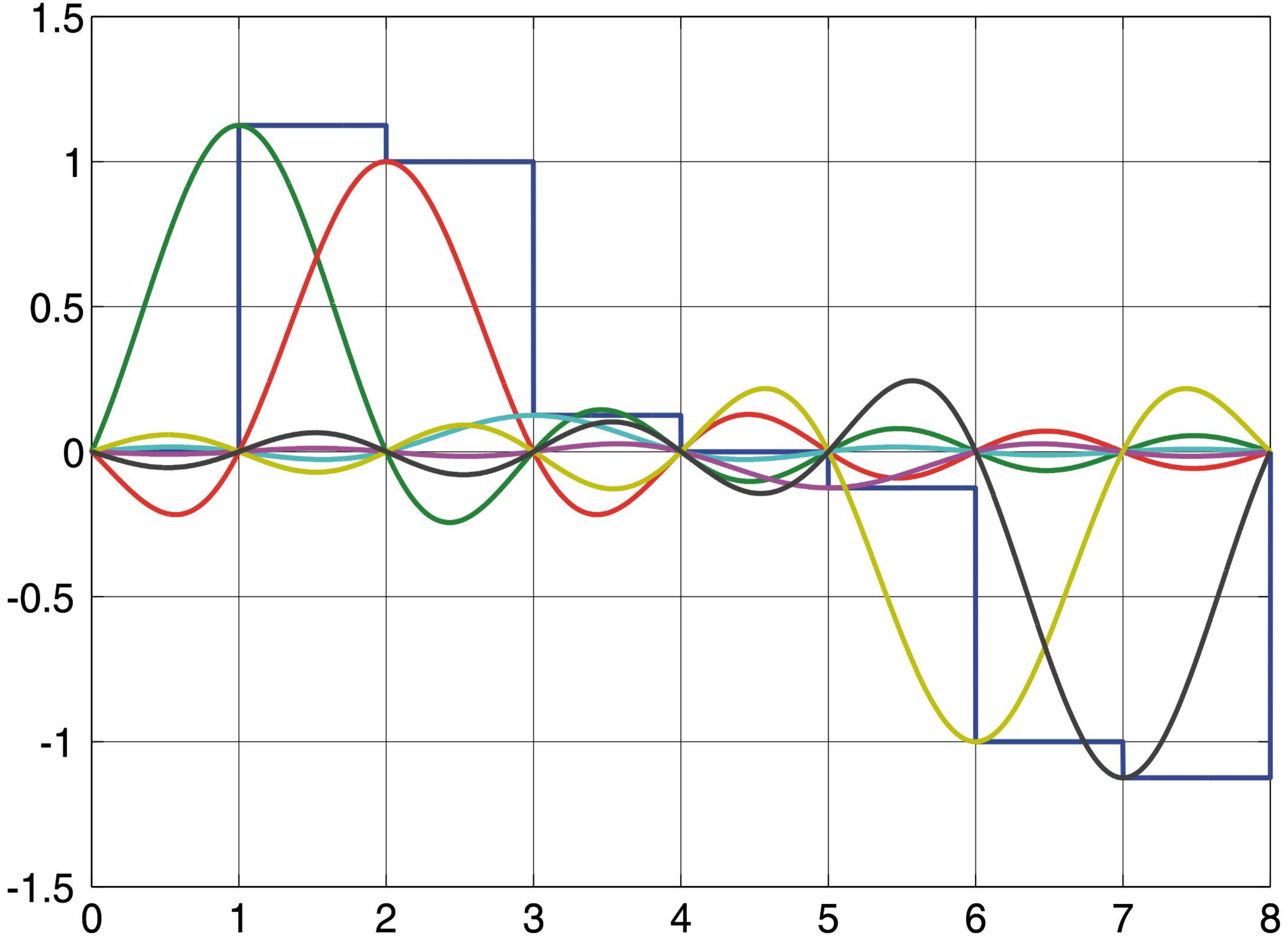
[Oppenheim, Schafer, 2009]

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

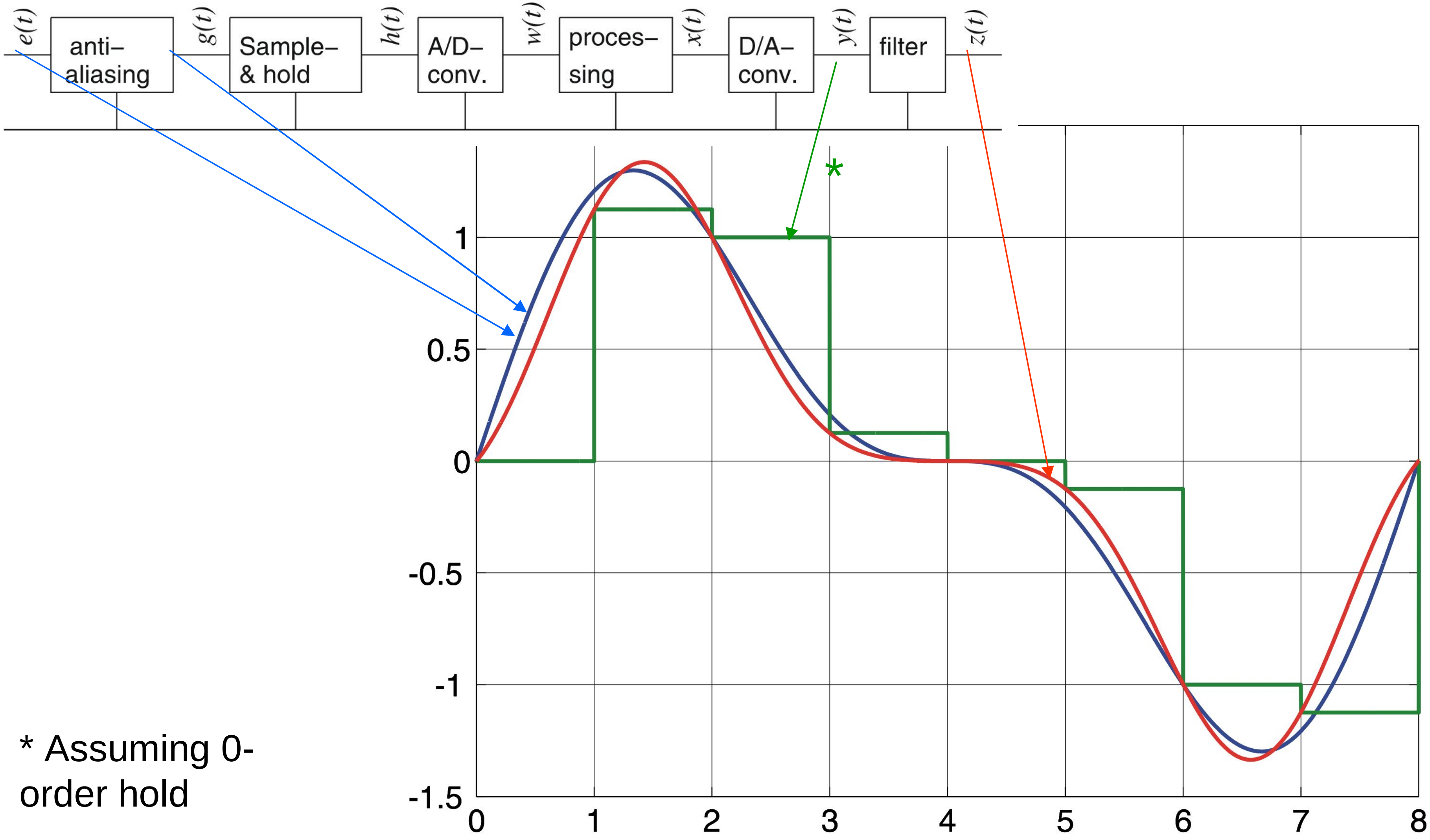
$$sinc(t - t_s) = \frac{sin\left(\frac{\pi}{p_s}(t - t_s)\right)}{\frac{\pi}{p_s}(t - t_s)}$$



Contributions from the various sampling instances



(Attempted) reconstruction of input signal

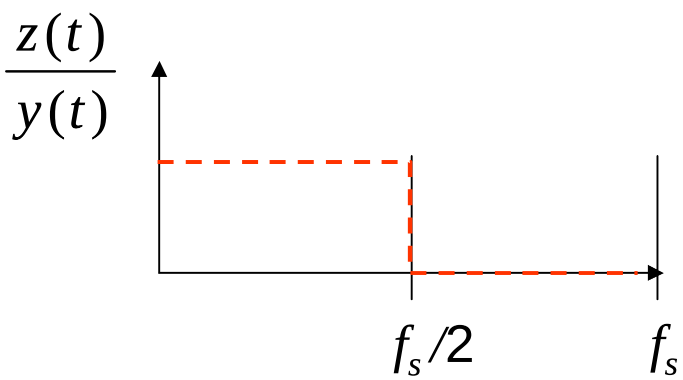


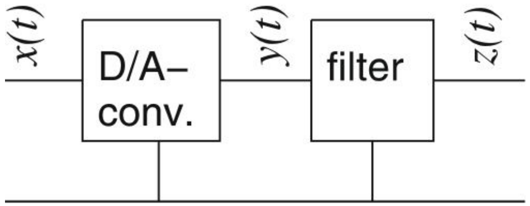
* Assuming 0-order hold

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 $y(t)$

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 ….

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.

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.

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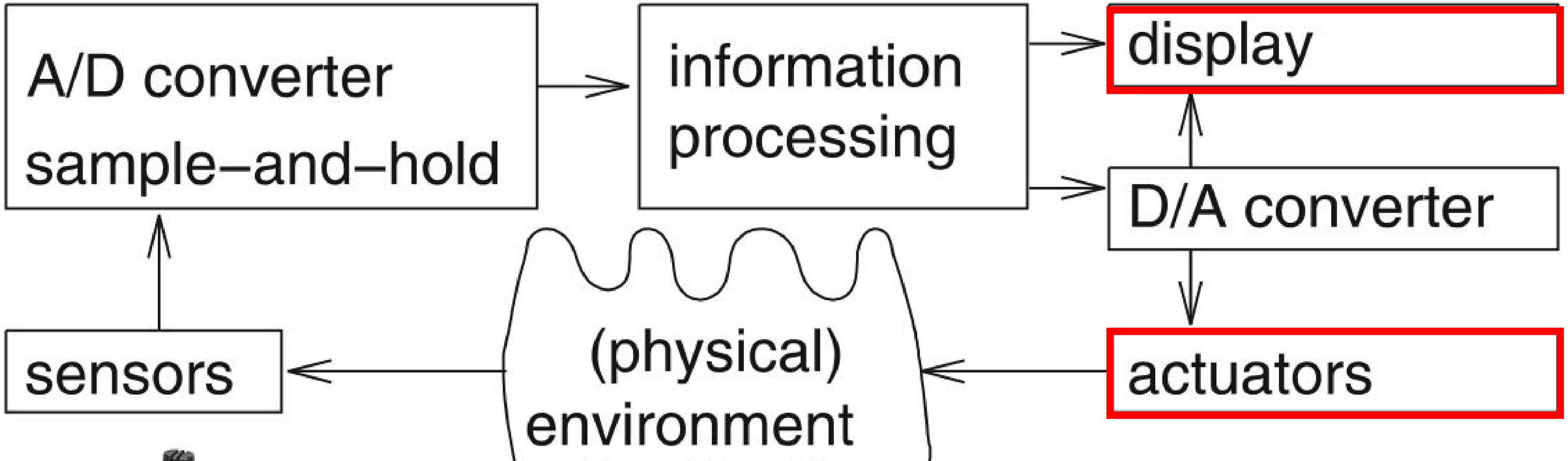

☞ cyber-physical systems

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Actuators

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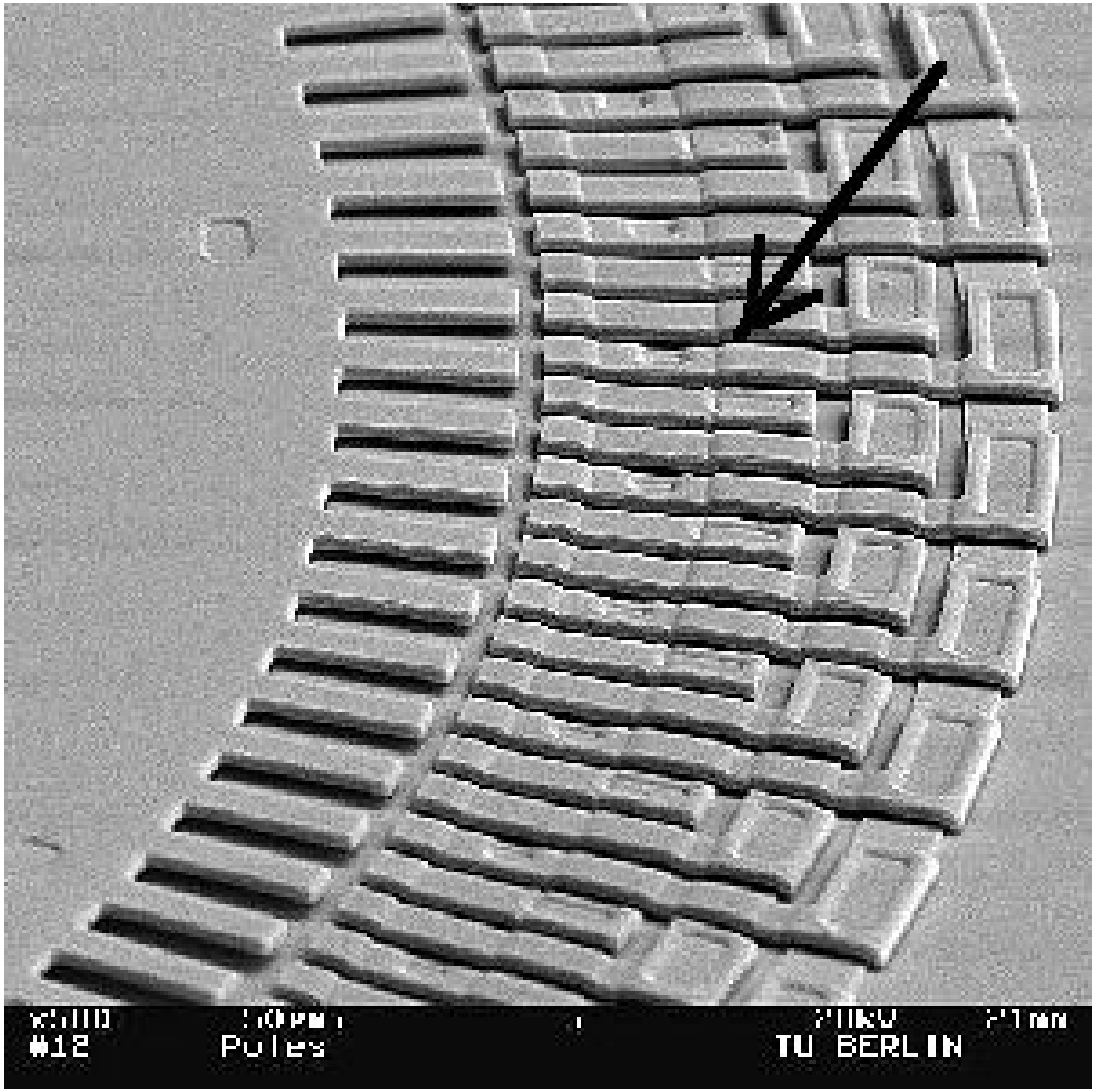
Actuators

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

Motor as an example

Actuators (2)

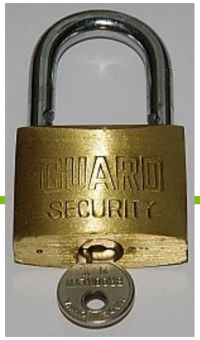


Courtesy and ©: E. Obermeier, MAT, TU Berlin

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.

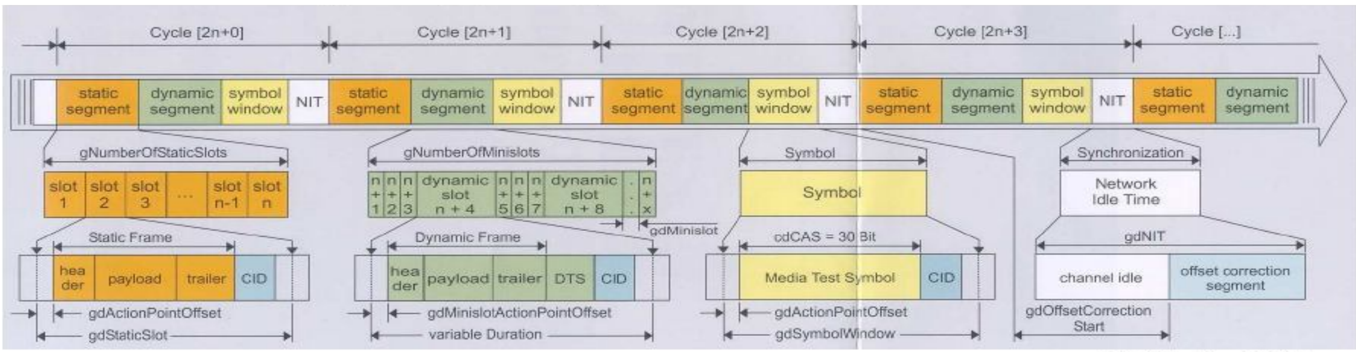
  Special mechanisms for physical protection (shielding, sensor detecting tampering with the modules).
- Logical security, using cryptographic methods needed.
- Smart cards: special case of secure hardware
  - Have to run with a very small amount of energy.
- In general, we have to distinguish between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

Summary

Hardware in a loop

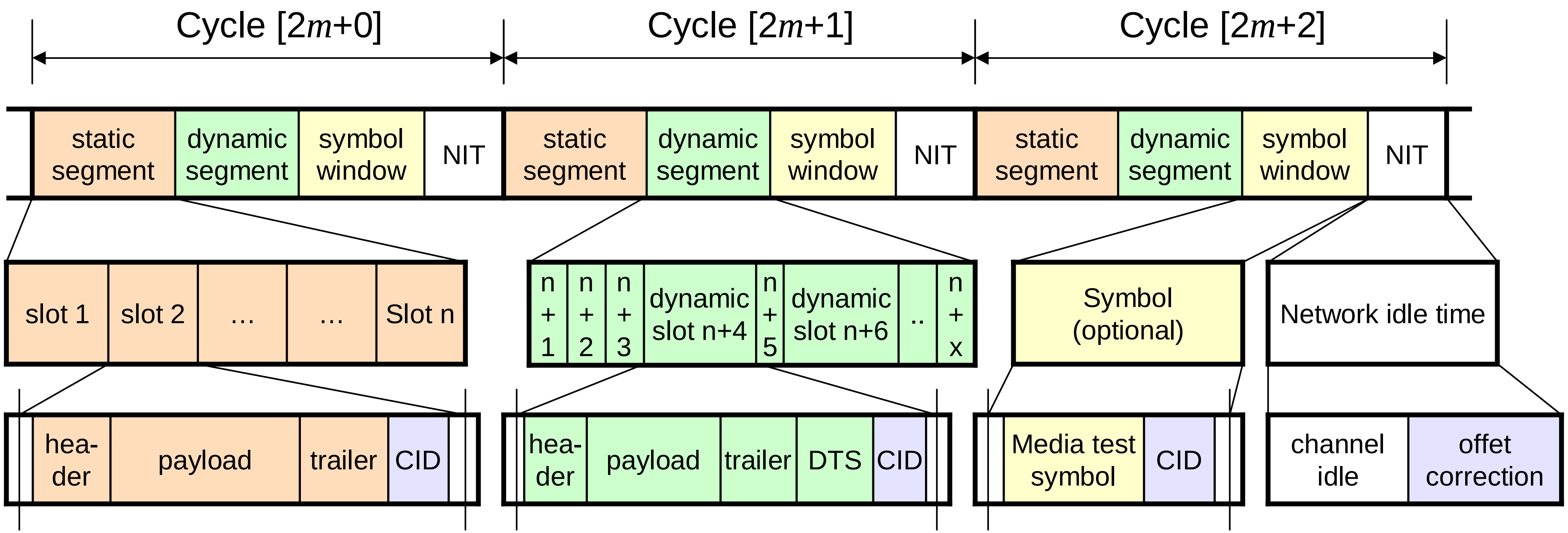
- Sensors
- Discretization
- Information processing
  - Importance of energy efficiency, Special purpose HW very expensive, Energy efficiency of processors, Code size efficiency, Run-time efficiency
  - Reconfigurable Hardware
- Communication
- D/A converters
- Sampling theorem
- Actuators (briefly)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

SPARES



Quelle: Vector Informatik GmbH

Time intervals in Flexray



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Source: Prof. Form, TU Braunschweig, 2007