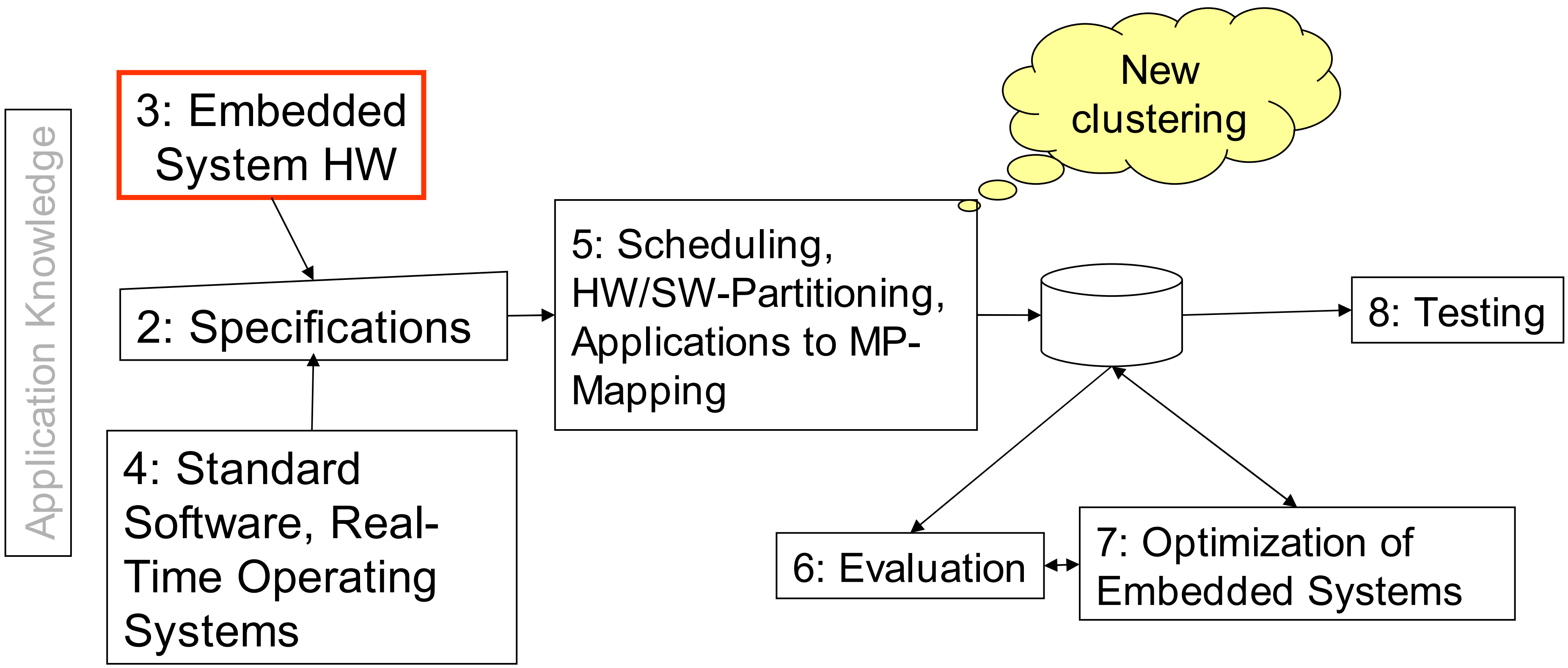
Embedded System Hardware

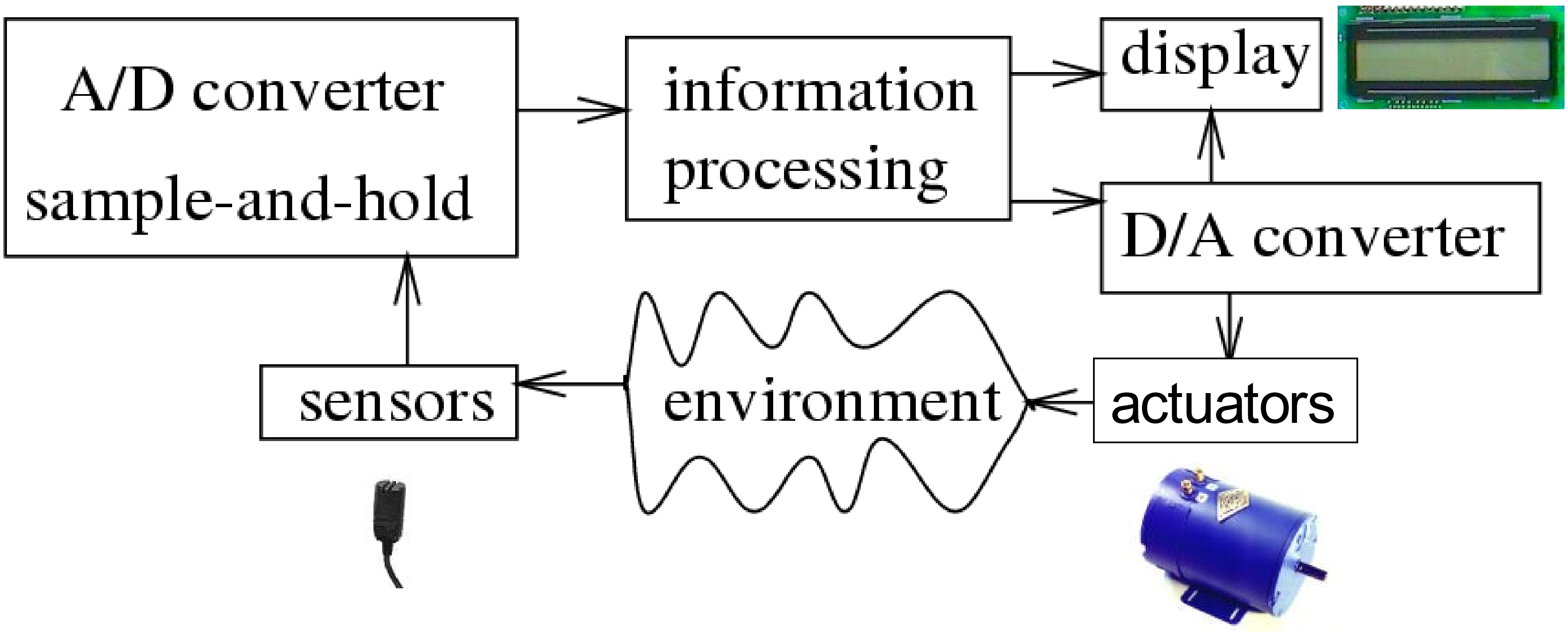
Peter Marwedel
Informatik 12
TU Dortmund
Germany

Structure of this course



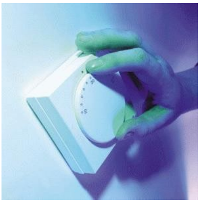
Embedded System Hardware

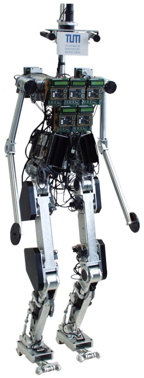
Embedded system hardware is frequently used in a loop („***hardware in a loop***“):



Many examples of such loops

- Heating
- Lights
- Engine control
- Power supply
- …
- Robots





Heating: www.masonsplumbing.co.uk/images/heating.jpg
Robot:: Courtesy and ©: H.Ulbrich, F. Pfeiffer, TU München

Sensors

Processing of physical data starts with capturing this data.

Sensors can be designed for virtually every physical and chemical quantity

- including weight, velocity, acceleration, electrical current, voltage, temperatures etc.
- chemical compounds.

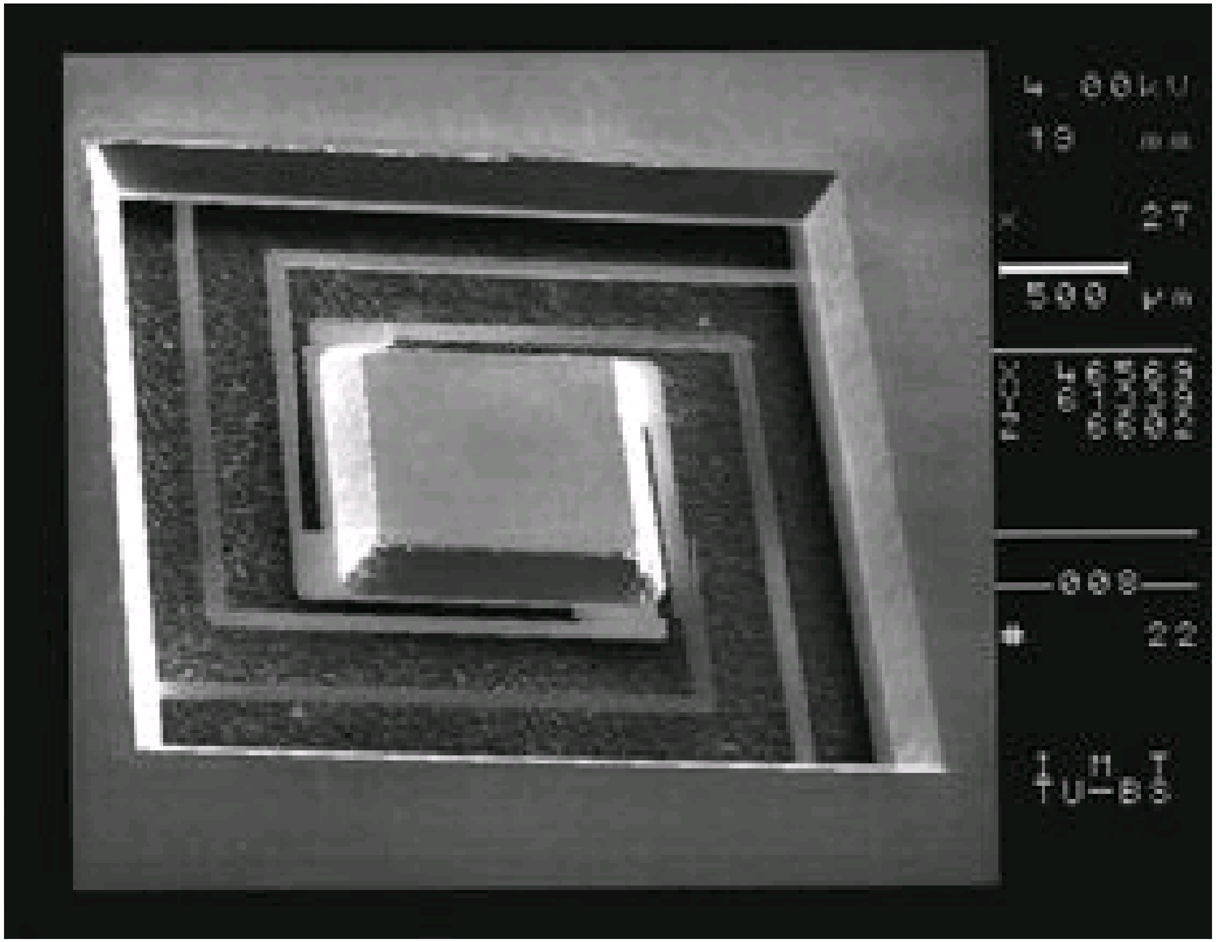
Many physical effects used for constructing sensors.

Examples:

- law of induction (generation of voltages in an electric field),
- light-electric effects.

Huge amount of sensors designed in recent years.

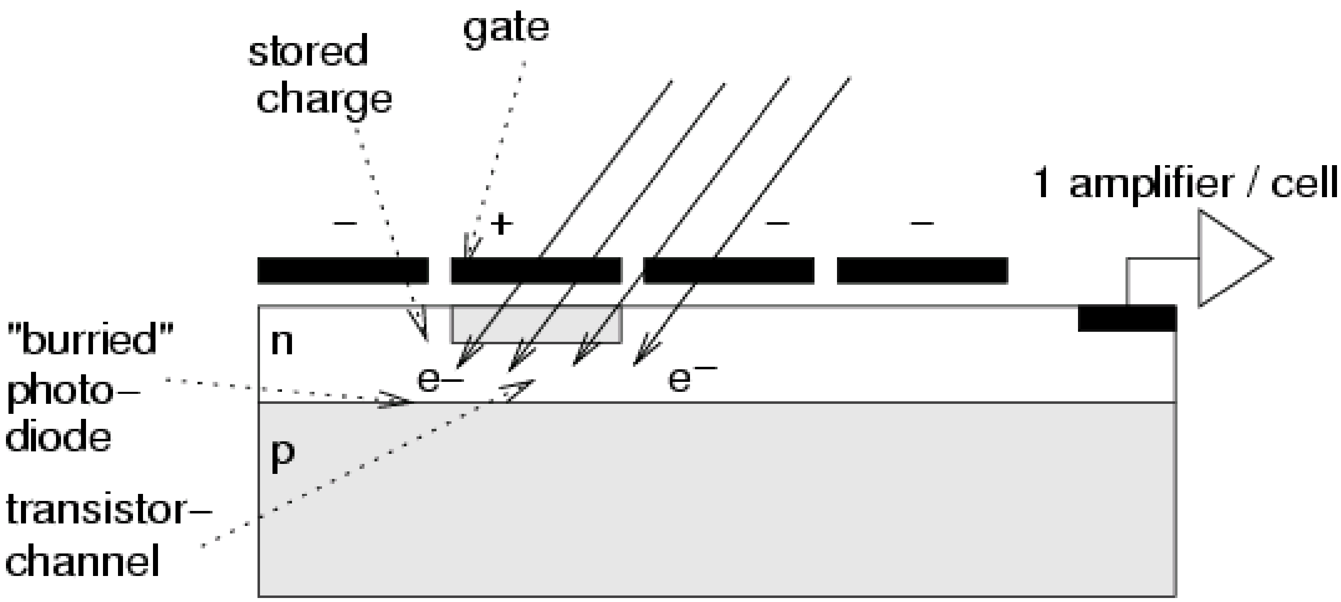
Example: Acceleration Sensor



Courtesy & ©: S. Bütgenbach, TU Braunschweig

Charge-coupled devices (CCD) image sensors

Based on charge transfer to next pixel cell

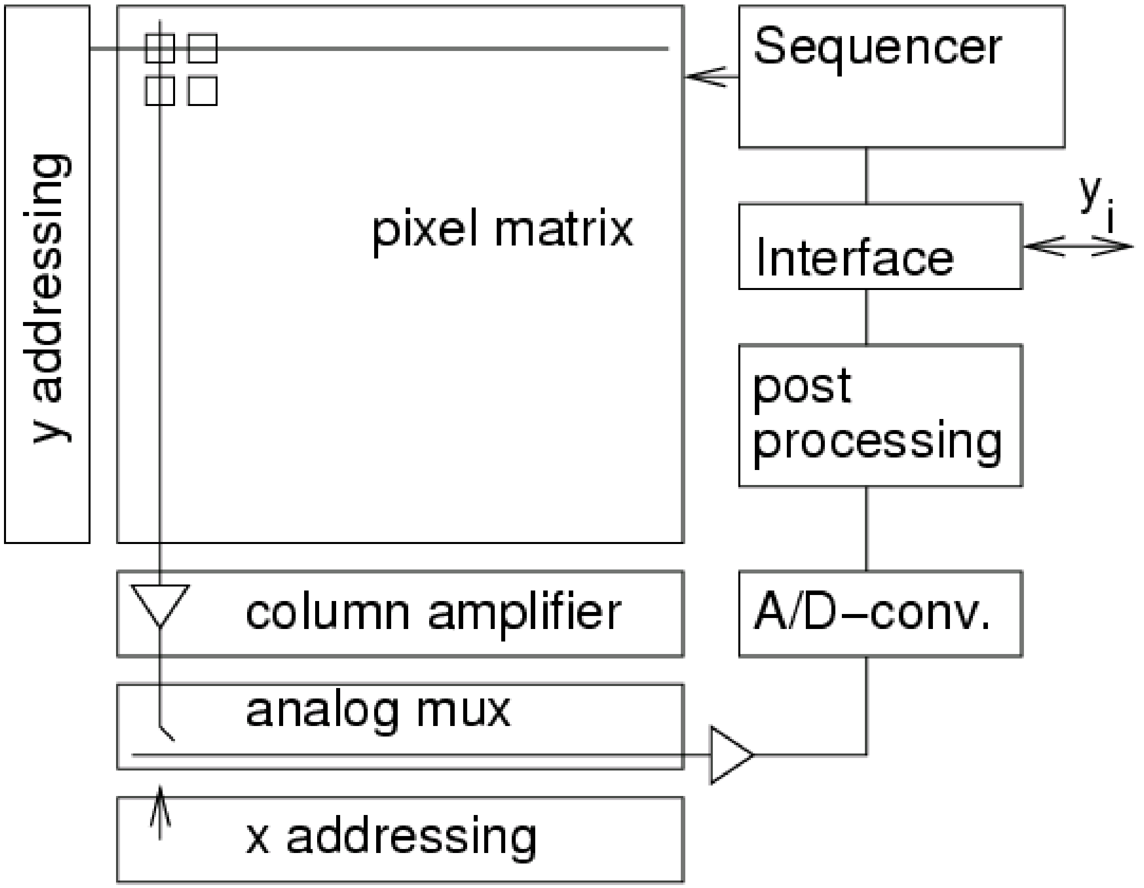


Corresponding to “bucket brigade device” (German: “*Eimerkettenschaltung*”)

http://www.schulen.regensburg.de/hhgs/klassen/2001a/feuerwehr/kette2.jpg

CMOS image sensors

Based on standard production process for CMOS chips, allows integration with other components.



Comparison CCD/CMOS sensors

Property	CCD	CMOS
Signal/noise ratio (SNR)	Excellent	Medium
Dark current	Very low	Medium
Technology optimized for	Optics	VLSI technology
Technology	Special	Standard
Smart sensors?	No, no logic or A/D converters on chip	Logic elements on chip
Access	Serial	Random
Interface	Complex	Simple, single VDD

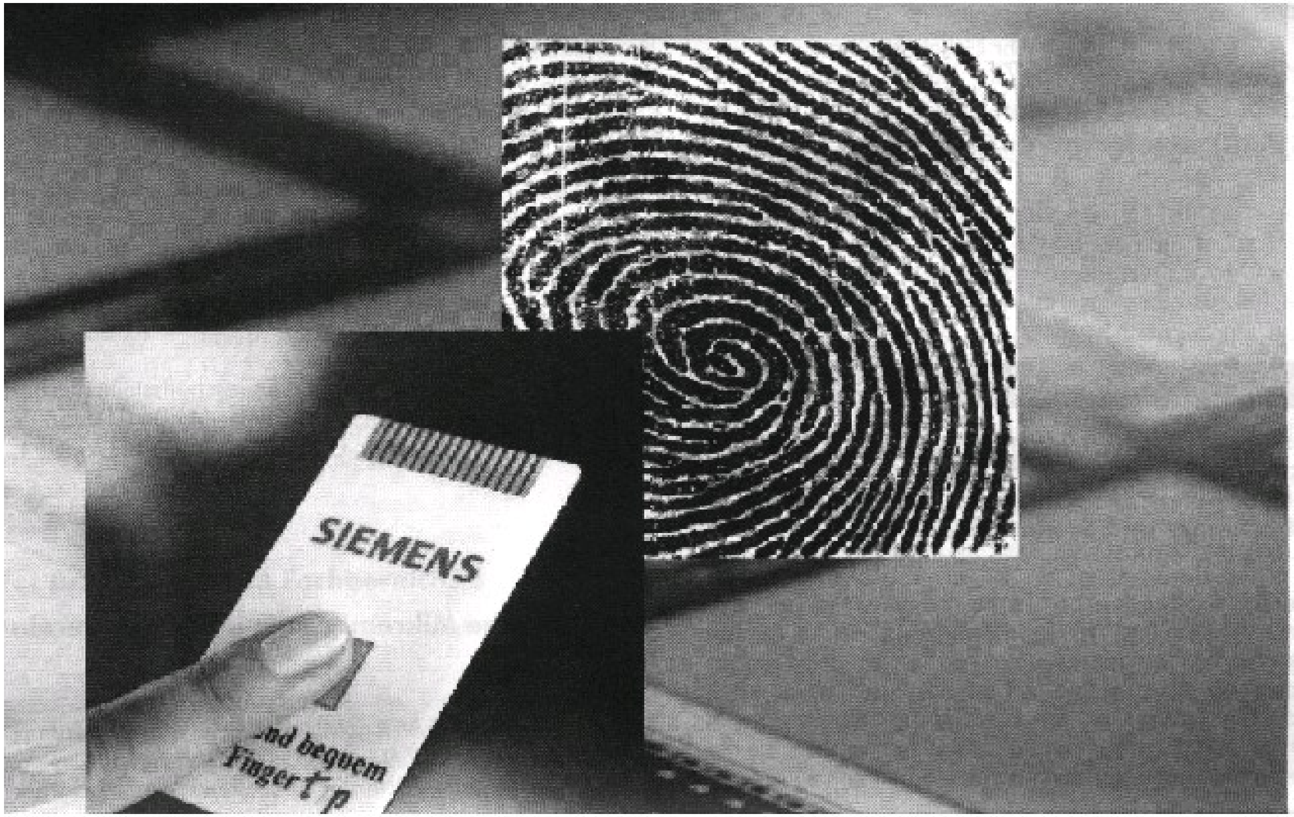
Source: B. Diericks: CMOS image sensor concepts. Photonics West 2000 Short course (Web)

CMOS: low cost devices + digital SLR cameras (due to large size, …)

CCD: medium to high end non-SLR cameras

Example: Biometrical Sensors

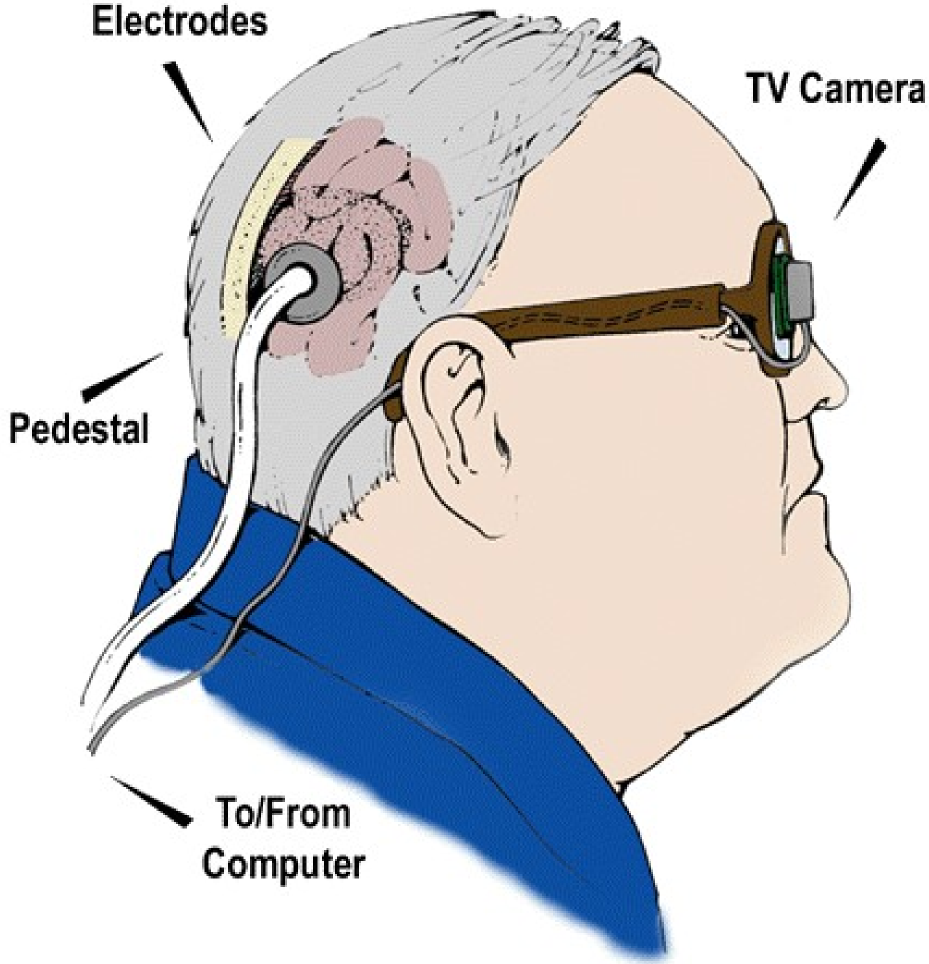
Example: Fingerprint sensor (© Siemens, VDE):



Matrix of 256 x 256 elem. Voltage ~ distance. Resistance also computed. No fooling by photos and wax copies. Carbon dust?

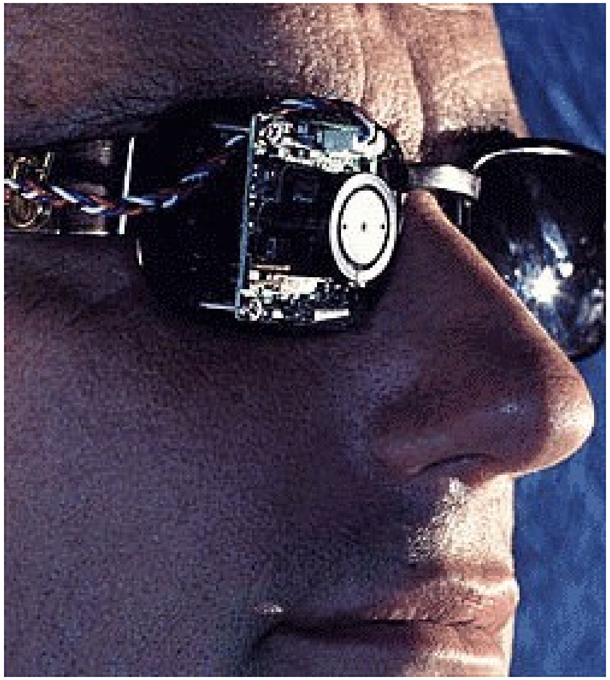
Integrated into ID mouse.

Artificial eyes



© Dobelle Institute
(was at www.dobelle.com)

Artificial eyes (2)



He looks hale, hearty, and healthy — except for the wires. They run from the laptops into the signal processors, then out again and across the table and up into the air, flanking his face like curtains before disappearing into holes drilled through his skull. Since his hair is dark and the wires are black, it's hard to see the actual points of entry. From a distance the wires look like long ponytails.

Show movie from www.dobelle.com (e.g. blind person driving a car)

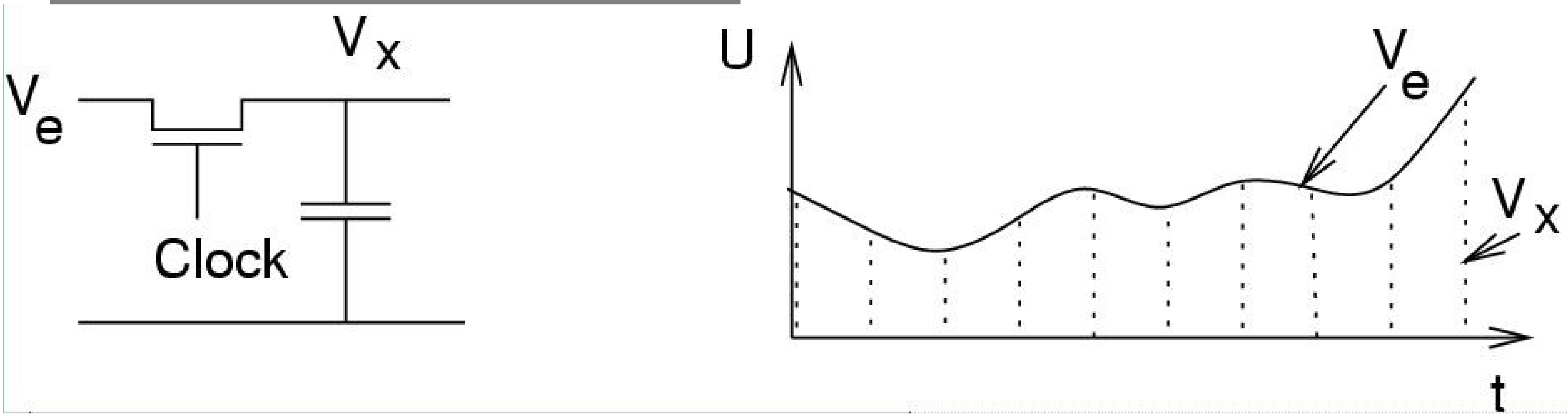
Other sensors

- Rain sensors for wiper control
  („Sensors multiply like rabbits“ [ITT automotive])
- Pressure sensors
- Proximity sensors
- Engine control sensors
- Hall effect sensors

Discretization

Discretization of time

V_e is a mapping $\mathbb{R} \rightarrow \mathbb{R}$



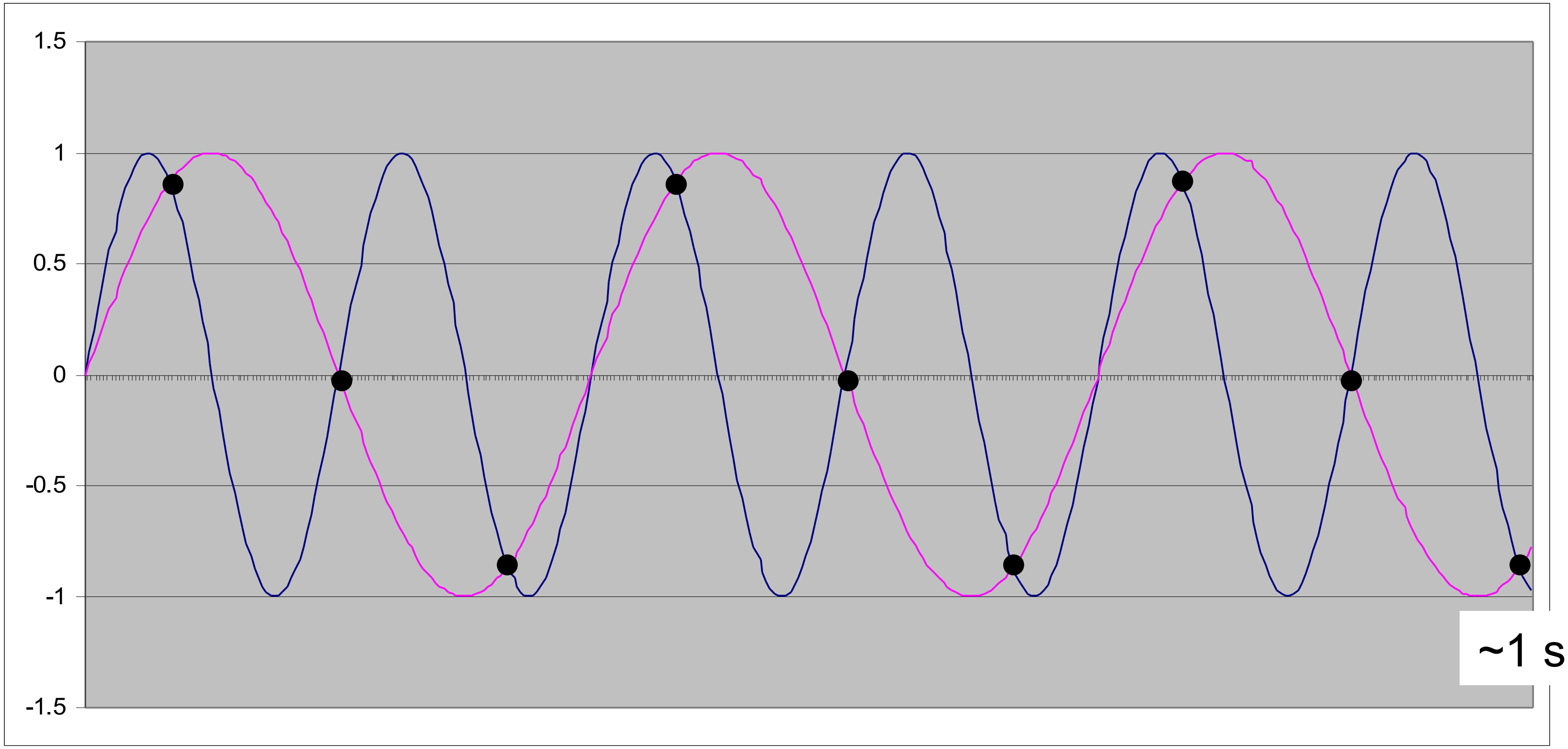
In this course: restriction to digital information processing;
Known digital computers can only process discrete time series. ☞ Discrete time; sample and hold-devices.

Ideally: width of clock pulse -> 0

V_x is a **sequence** of values or a mapping $\mathbb{Z} \rightarrow \mathbb{R}$

Aliasing

Impossible to reconstruct fast signals after slow sampling: multiple fast signals share same sampled sequence;
Example: Signal: 5.6 Hz; Sampling: 9 Hz

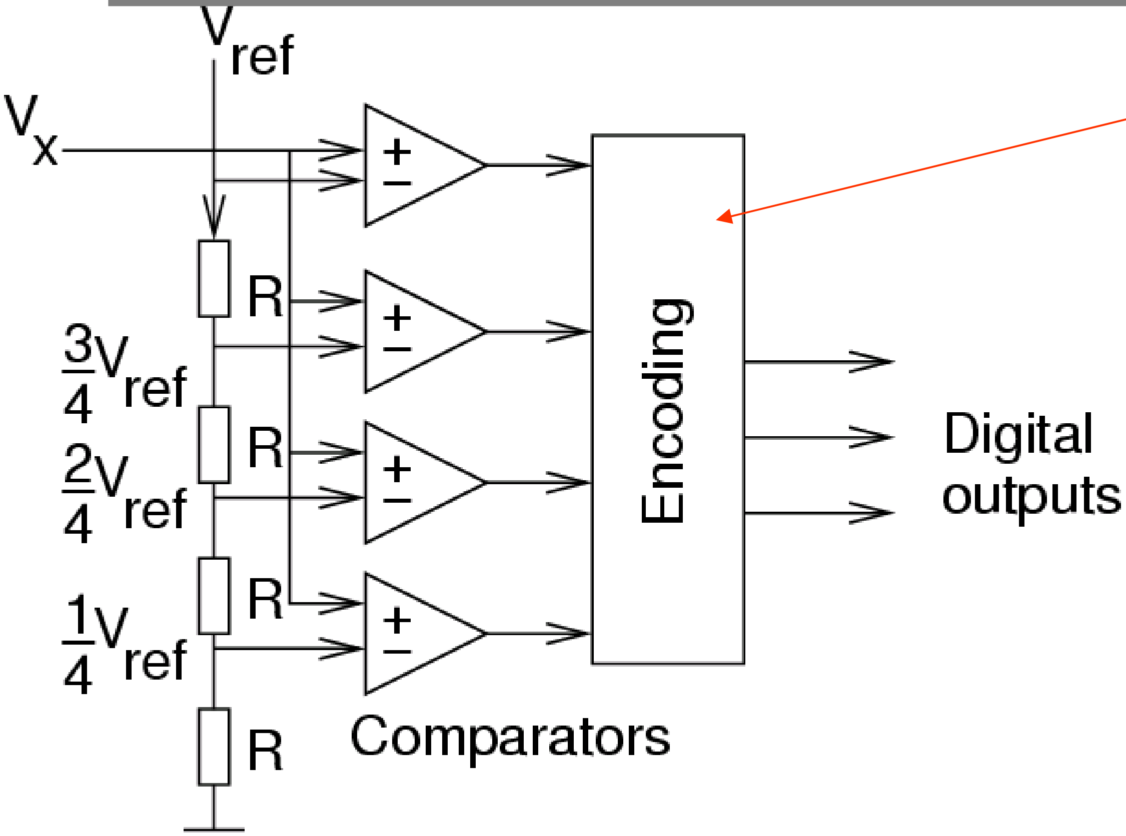


[http://www.cise.ufl.edu/~prabhat/Teaching/cis6930-f04/comp1.ppt]

☞More info at end of chapter.

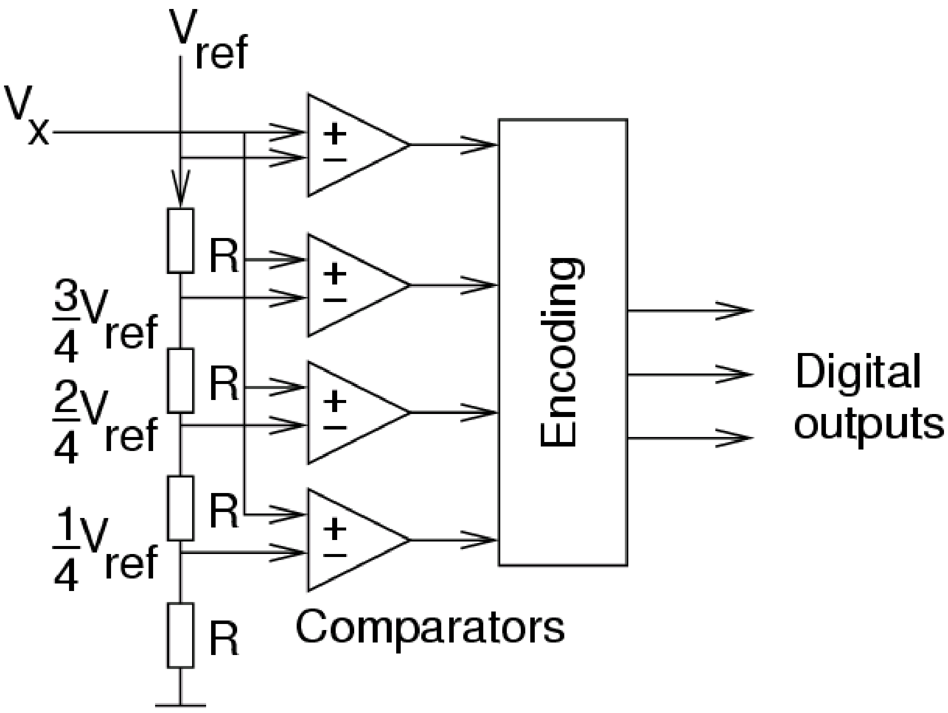
Discretization of values: A/D-converters
1. Flash A/D converter (1)

Digital computers require digital form of physical values
☞A/D-conversion; many methods with different speeds.
Example: 1. Flash A/D converter:



Encodes input number of most significant ‘1’ as an unsigned number, e.g.
“1111” -> “100”,
“0111” -> “011”,
“0011” -> “010”,
“0001” -> “001”,
“0000” -> “000”
(Priority encoder).

Discretization of values: A/D-converters
1. Flash A/D converter (2)



Parallel comparison with reference voltage

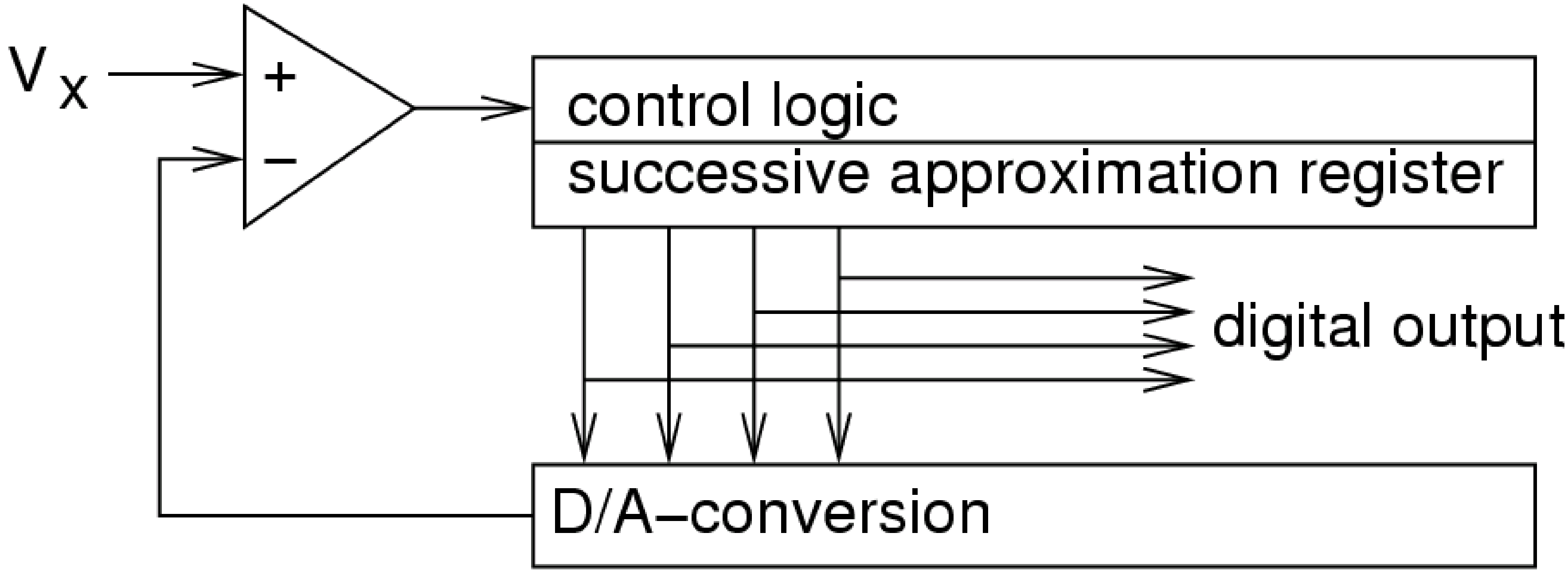
Speed: $O(1)$

Hardware complexity: $O(n)$

with n= # of distinguished voltage levels

Applications: e.g. in video processing

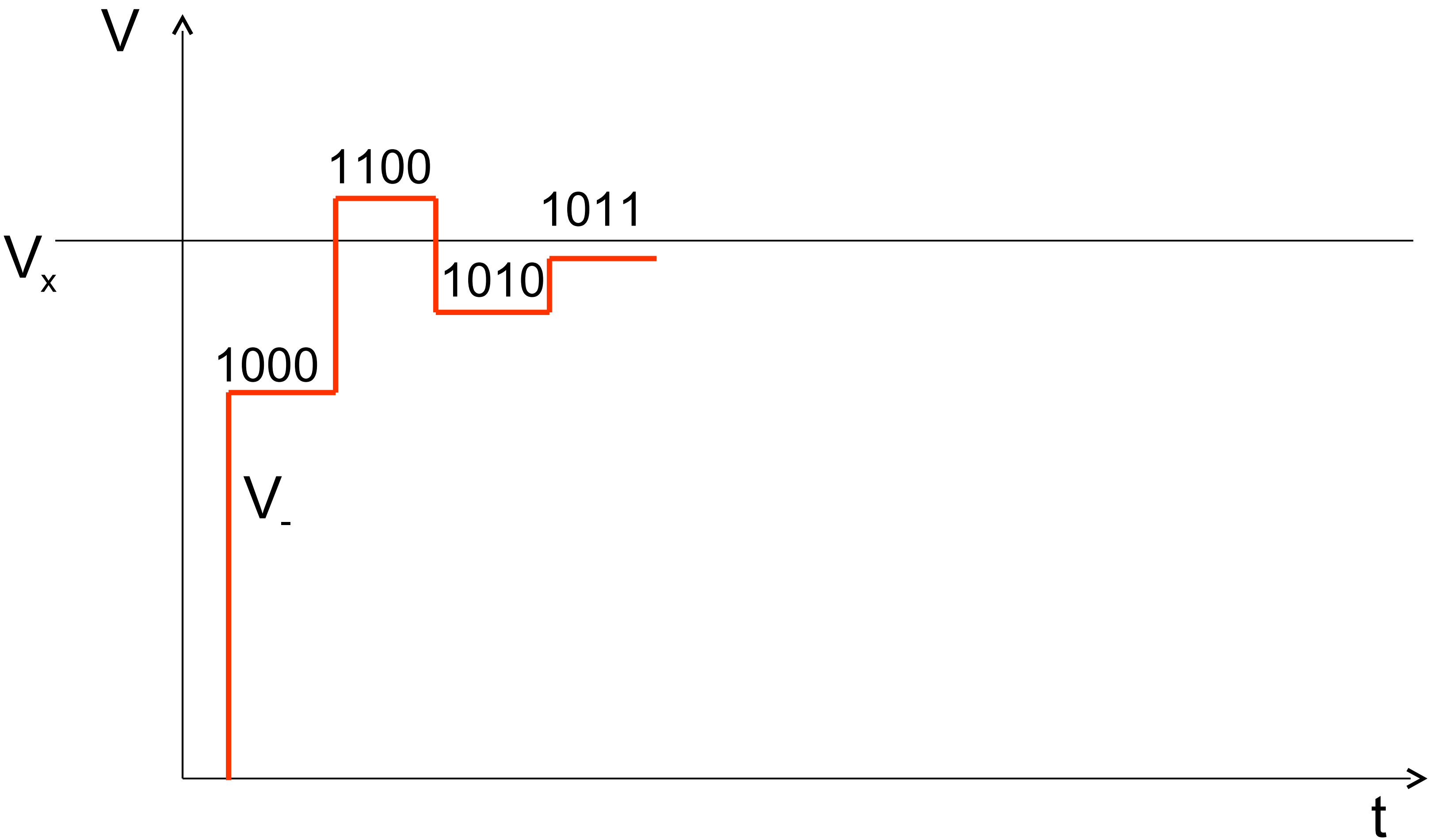
Discretization of values
2. Successive approximation



Key idea: binary search:
Set MSB='1'
if too large: reset MSB
Set MSB-1='1'
if too large: reset MSB-1

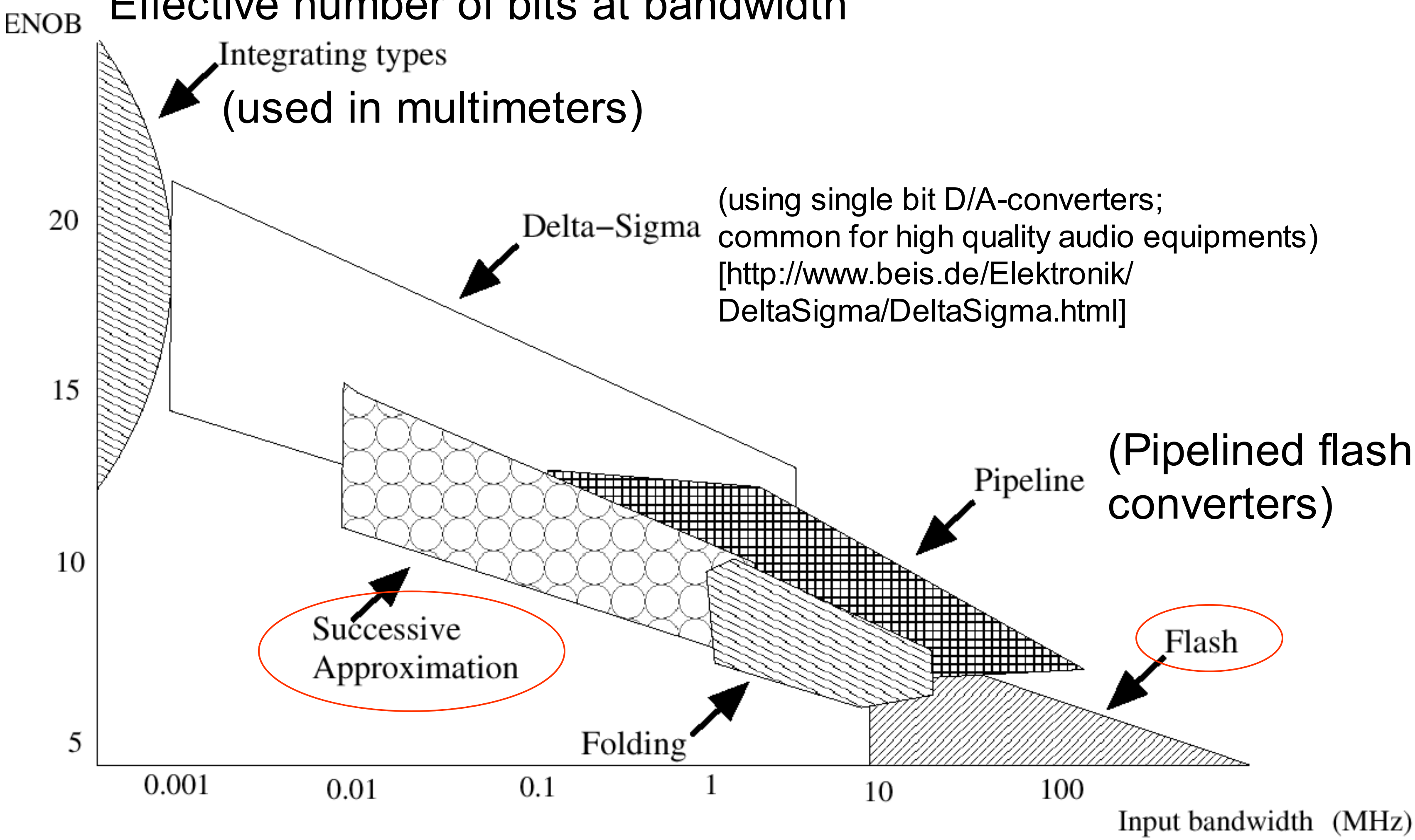
Speed: *O(ld(n))*
Hardware complexity: *O(ld(n))*
with *n*= # of distinguished voltage levels;
slow, but high precision possible.

Successive approximation (2)



Application areas for flash and successive approximation converters

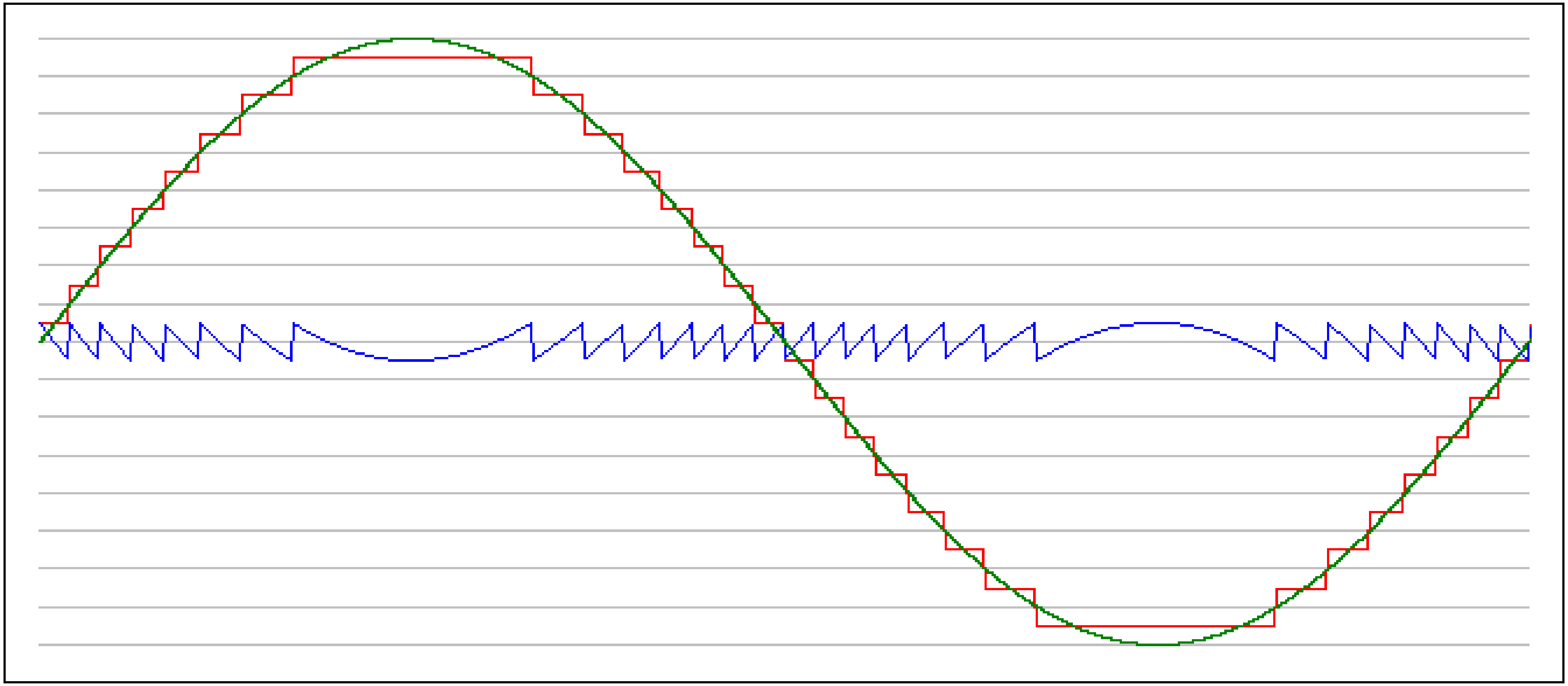
Effective number of bits at bandwidth



[Gielen et al., DAC 2003]

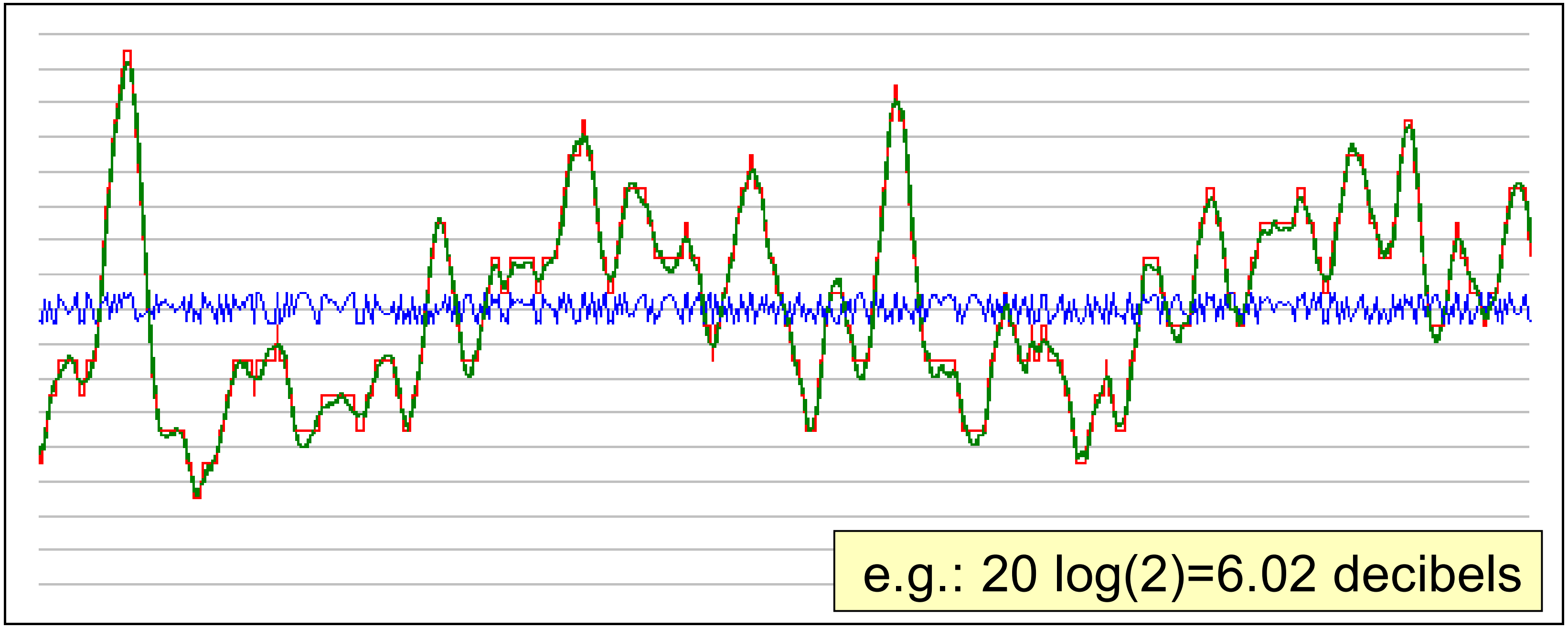
Quantization Noise

N = (approximated - real signal) called **quantization noise**.
Example: quantization noise for sine wave



* [http://www.beis.de/Elektronik/DeltaSigma/DeltaSigma.html]

Quantization noise for audio signal



$$\text{signal to noise ratio (SNR) [db]} = 20 \log\left(\frac{\text{effective signal voltage}}{\text{effective noise voltage}}\right)$$

Signal to noise for ideal n-bit converter : n * 6.02 + 1.76 [dB]

e.g. 98.1 db for 16-bit converter, ~ 160 db for 24-bit converter

Additional noise for non-ideal converters

Source: [http://www.beis.de/Elektronik/DeltaSigma/DeltaSigma.html]

Information Processing

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Germany

Embedded System Hardware

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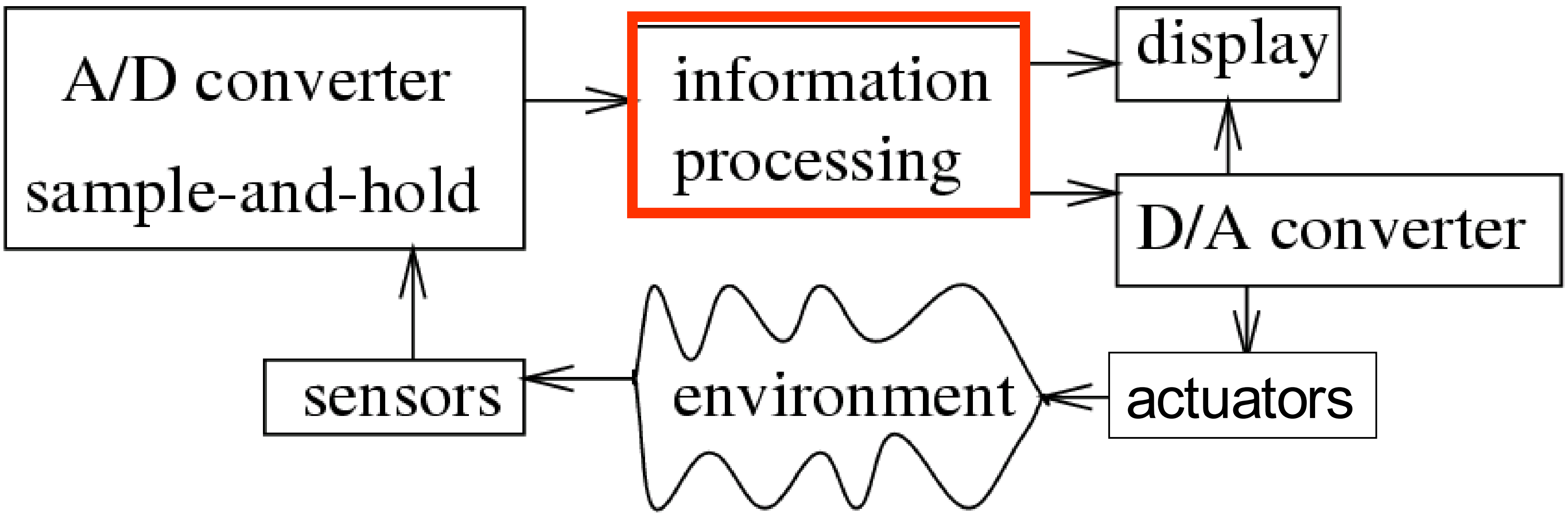
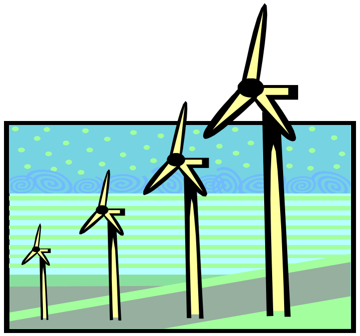


Processing units

Need for efficiency (power + energy):

Why worry about energy and power?

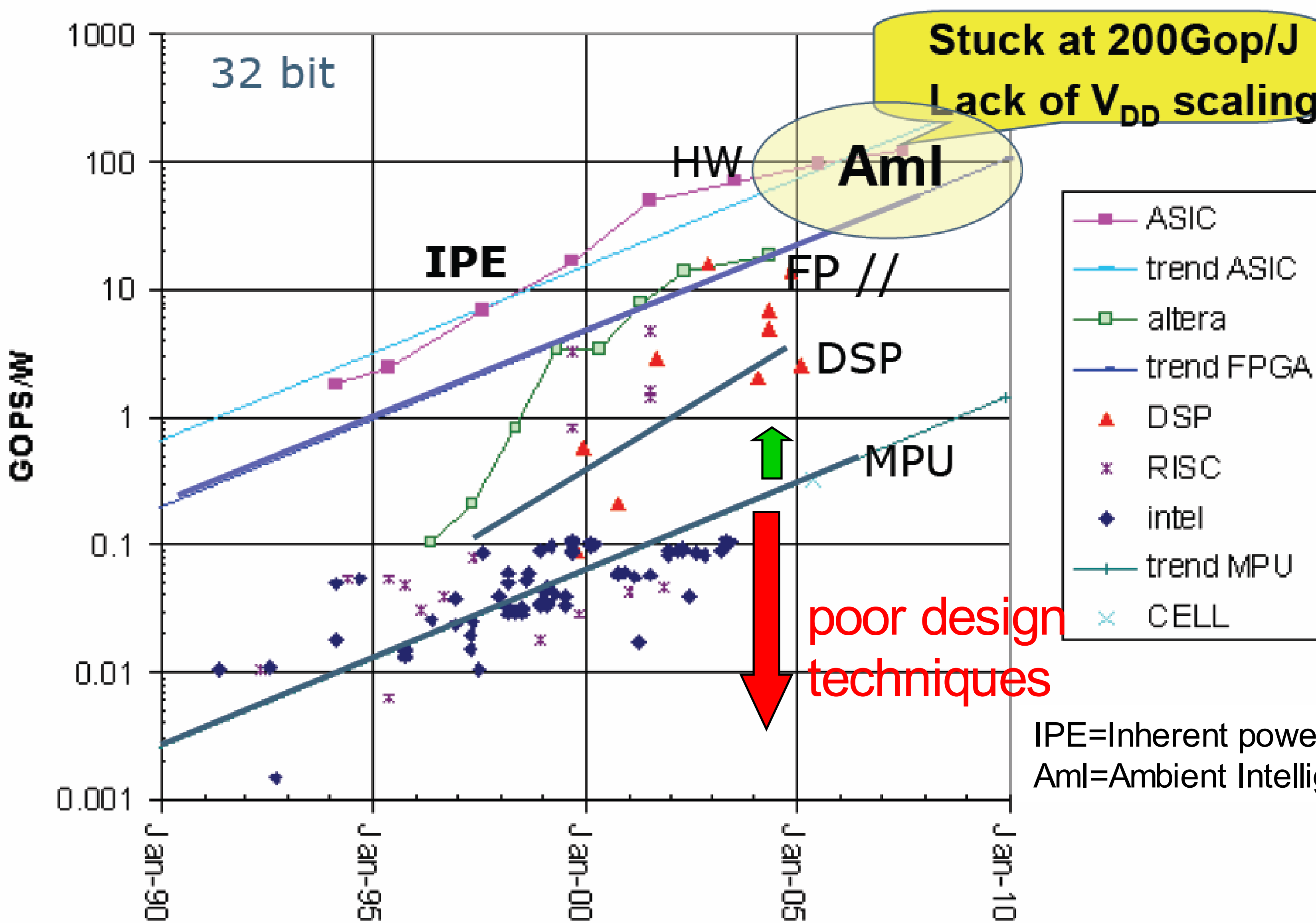


„Power is considered as the most important constraint in embedded systems"
[in: L. Eggermont (ed): Embedded Systems Roadmap 2002, STW]

Energy consumption by IT is the key concern of green computing initiatives (embedded computing leading the way)

http://www.esa.int/images/earth,4.jpg

Importance of Energy Efficiency



Courtesy: Philips
© Hugo De Man, IMEC, 2007

IPE=Inherent power efficiency
AmI=Ambient Intelligence

Efficient software design needed, otherwise, the price for software flexibility cannot be paid.

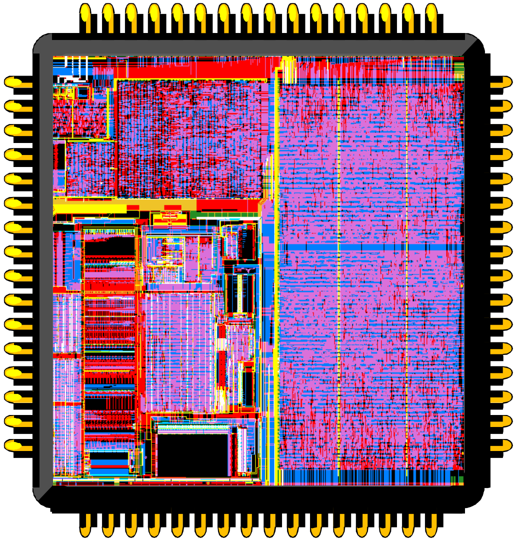
Application Specific Circuits (ASICS) or Full Custom Circuits

Custom-designed circuits necessary

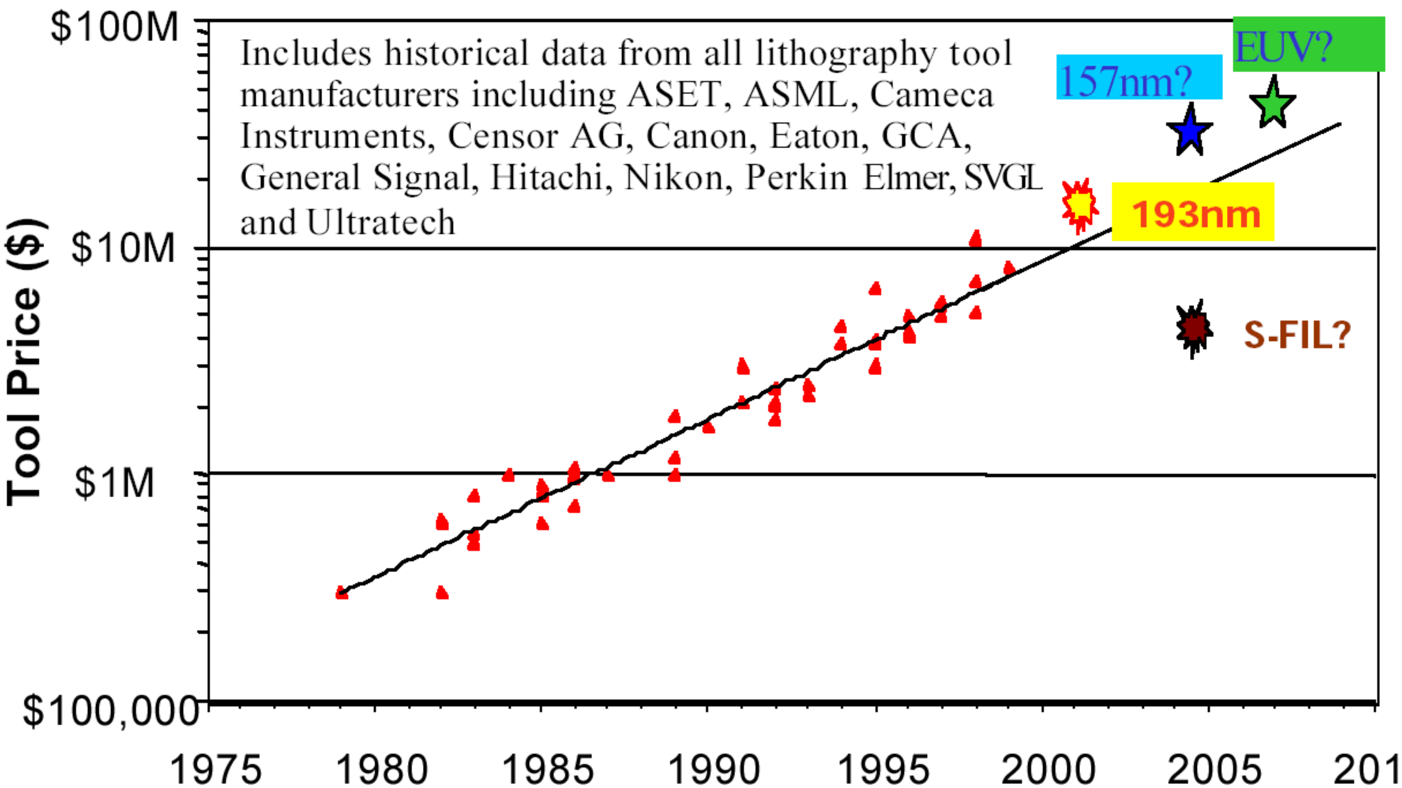
- if ultimate speed or
- energy efficiency is the goal and
- large numbers can be sold.

Approach suffers from

- long design times,
- lack of flexibility (changing standards) and
- high costs (e.g. Mill. $ mask costs).



Mask cost for specialized HW becomes very expensive



☞Trend towards implementation in Software

HW synthesis not covered in this course.

[http://www.molecularimprints.com/Technology/tech_articles/MII_COO_NIST_2001.PDF9]

Microcontrollers
- MHS 80C51 as an example -

- 8-bit CPU optimised for control applications
- Extensive Boolean processing capabilities
- 64 k Program Memory address space
- 64 k Data Memory address space
- 4 k bytes of on chip Program Memory
- 128 bytes of on chip data RAM
- 32 bi-directional and individually addressable I/O lines
- Two 16-bit timers/counters
- Full duplex UART
- 6 sources/5-vector interrupt structure with 2 priority levels
- On chip clock oscillators
- Very popular CPU with many different variations

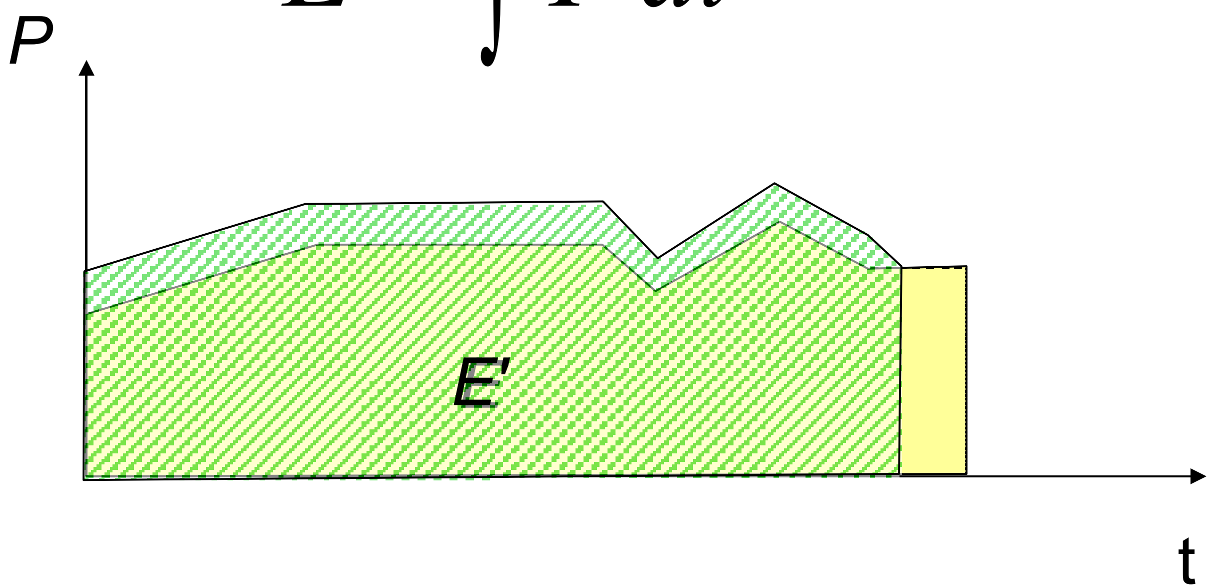
Features for Embedded Systems

Key requirements for processors

1. **Energy/power-efficiency**

Power and energy are related to each other

$$E = \int P\,dt$$



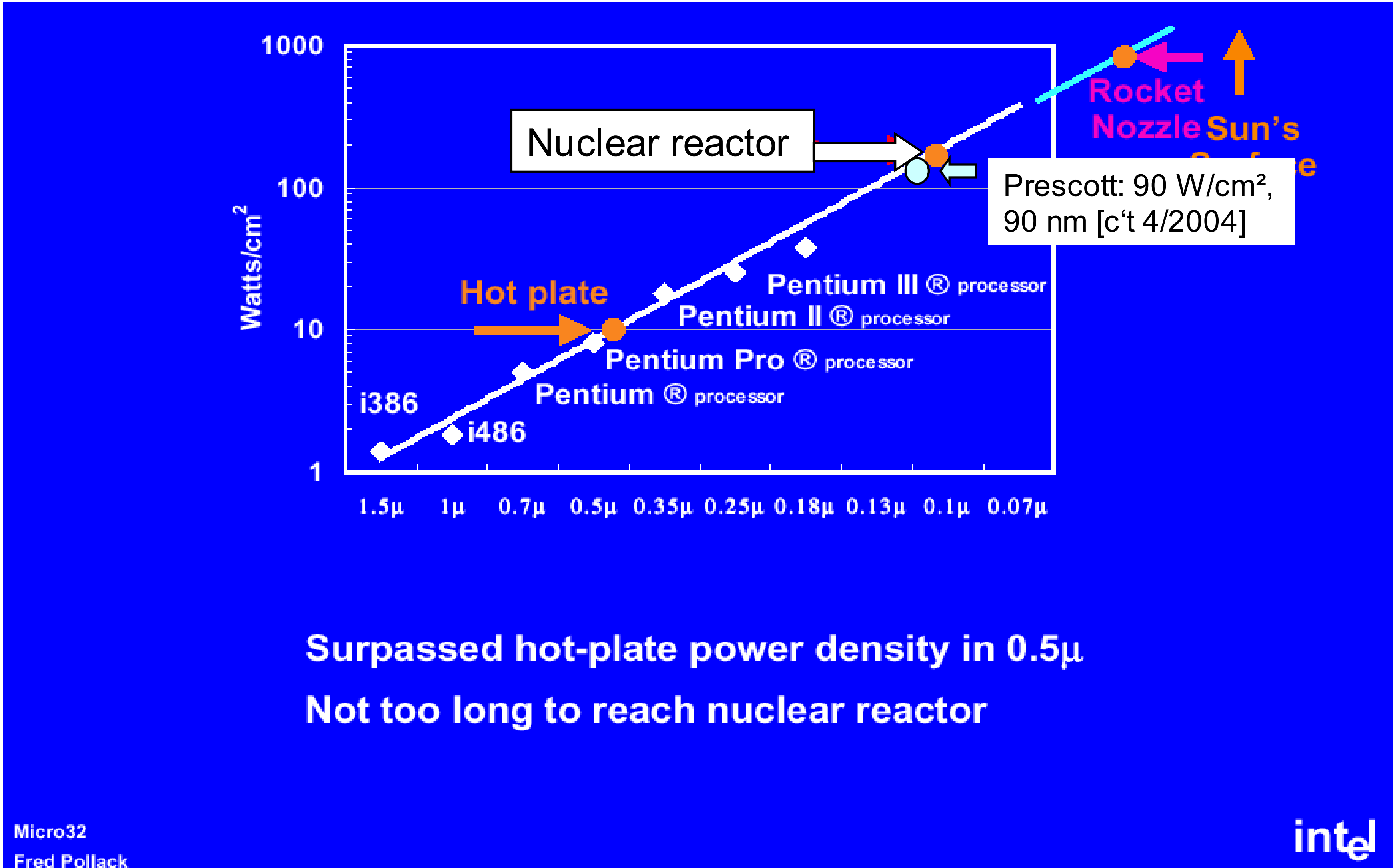
In many cases, faster execution also means less energy, but the opposite may be true if power has to be increased to allow faster execution.

Low Power vs. Low Energy Consumption

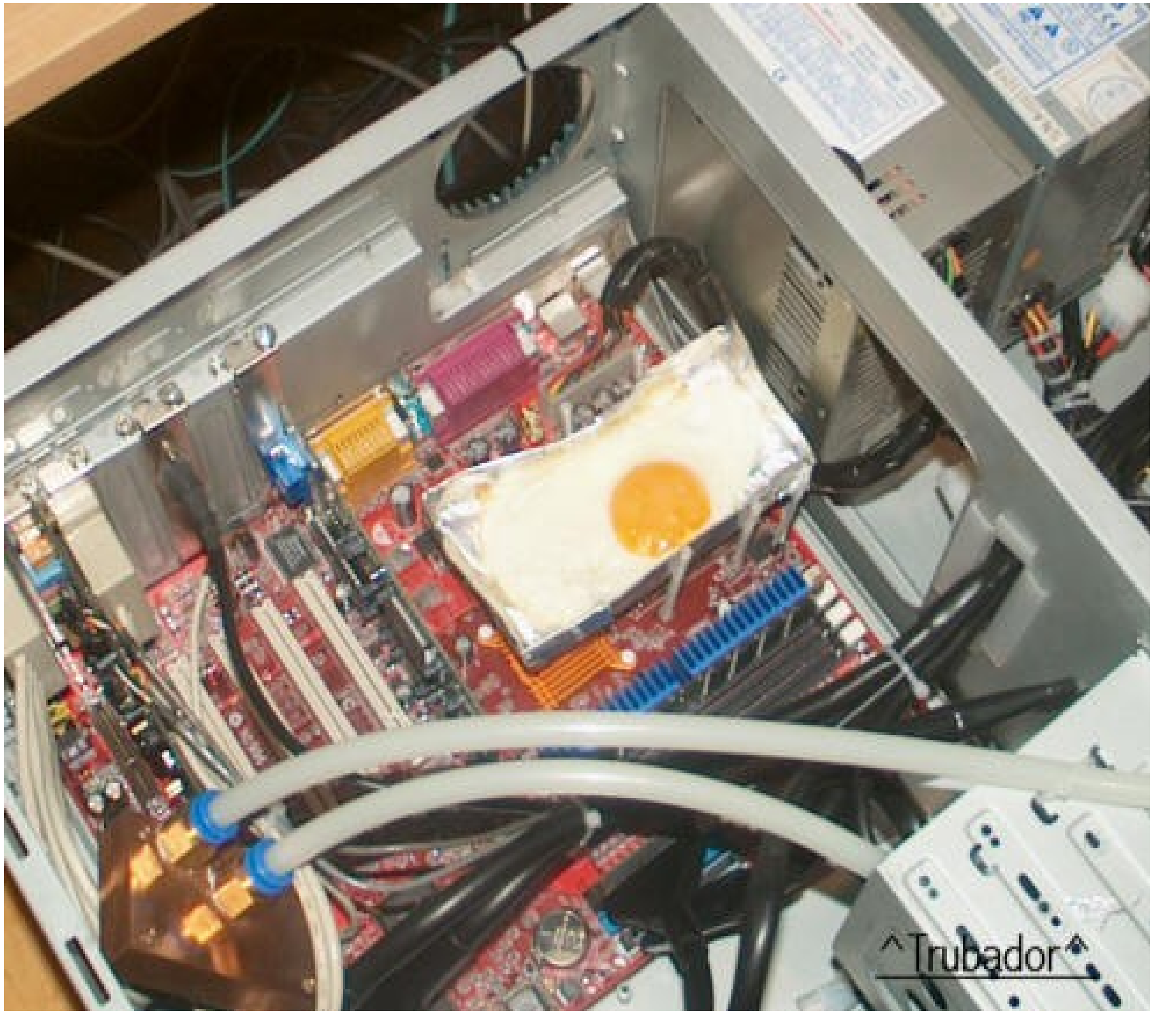
- Minimizing the **power consumption** is important for
  - the design of the power supply
  - the design of voltage regulators
  - the dimensioning of interconnect
  - short term cooling

- Minimizing the **energy consumption** is important due to
  - restricted availability of energy (mobile systems)
    - limited battery capacities (only slowly improving)
    - very high costs of energy (solar panels, in space)
  - cooling
    - high costs
    - limited space
  - dependability
  - long lifetimes, low temperatures

Power density continues to get worse

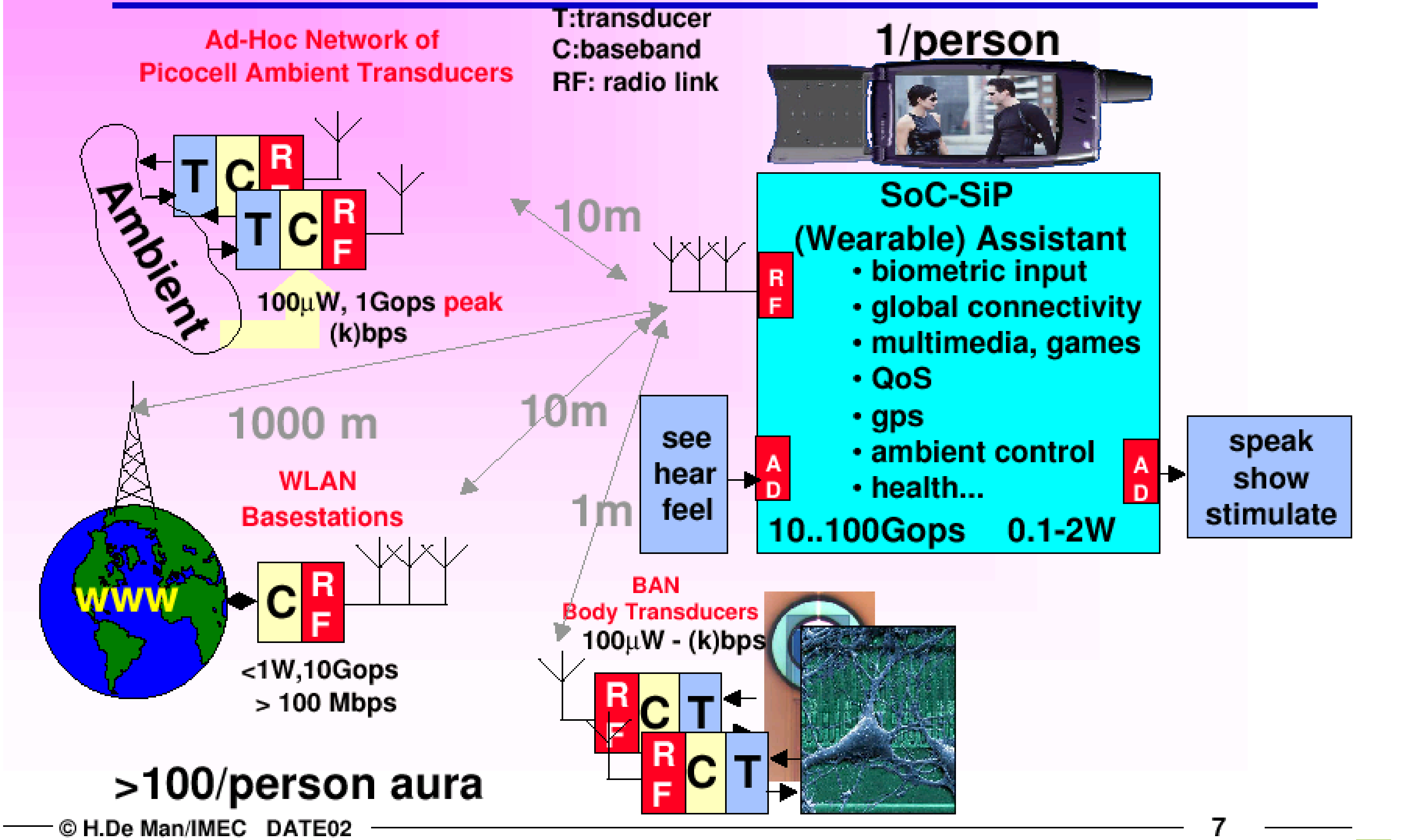


Surpassed hot (kitchen) plate …? Why not use it?



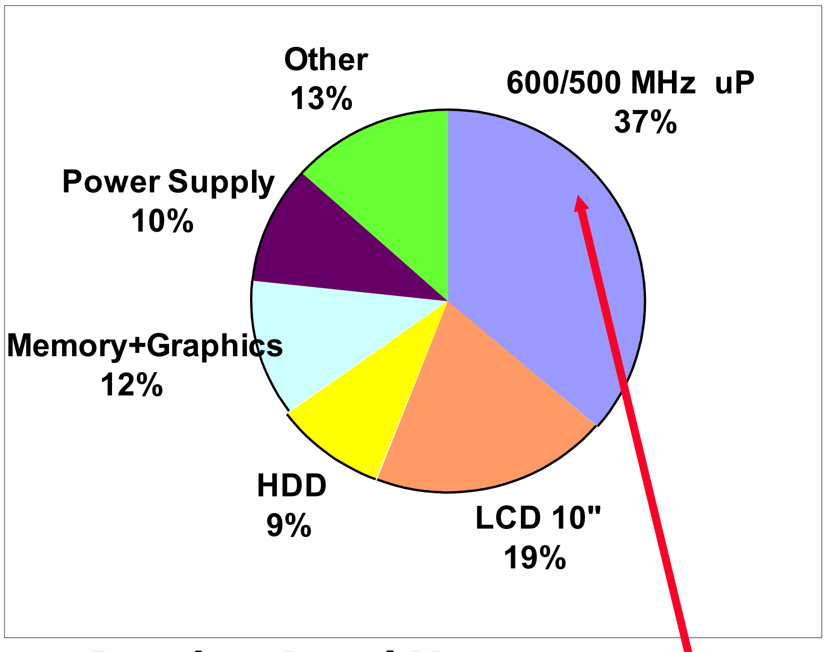
http://www.phys.ncku.edu.tw/~htsu/humor/fry_egg.html

Ambient Intelligence Global System



Need to consider CPU & System Power

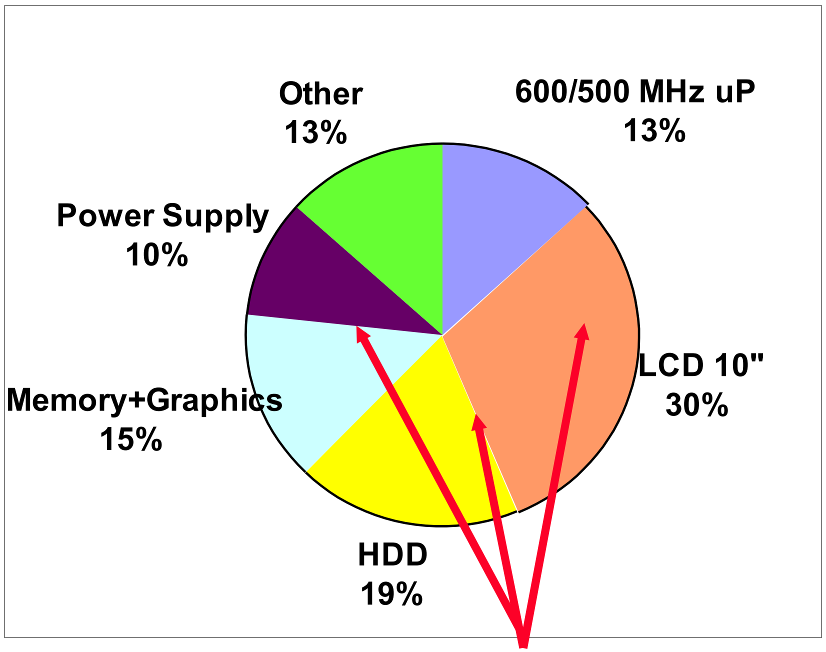
Mobile PC (notebook)
Thermal Design (TDP) System Power



Note: Based on Actual Measurements

CPU Dominates Thermal Design Power

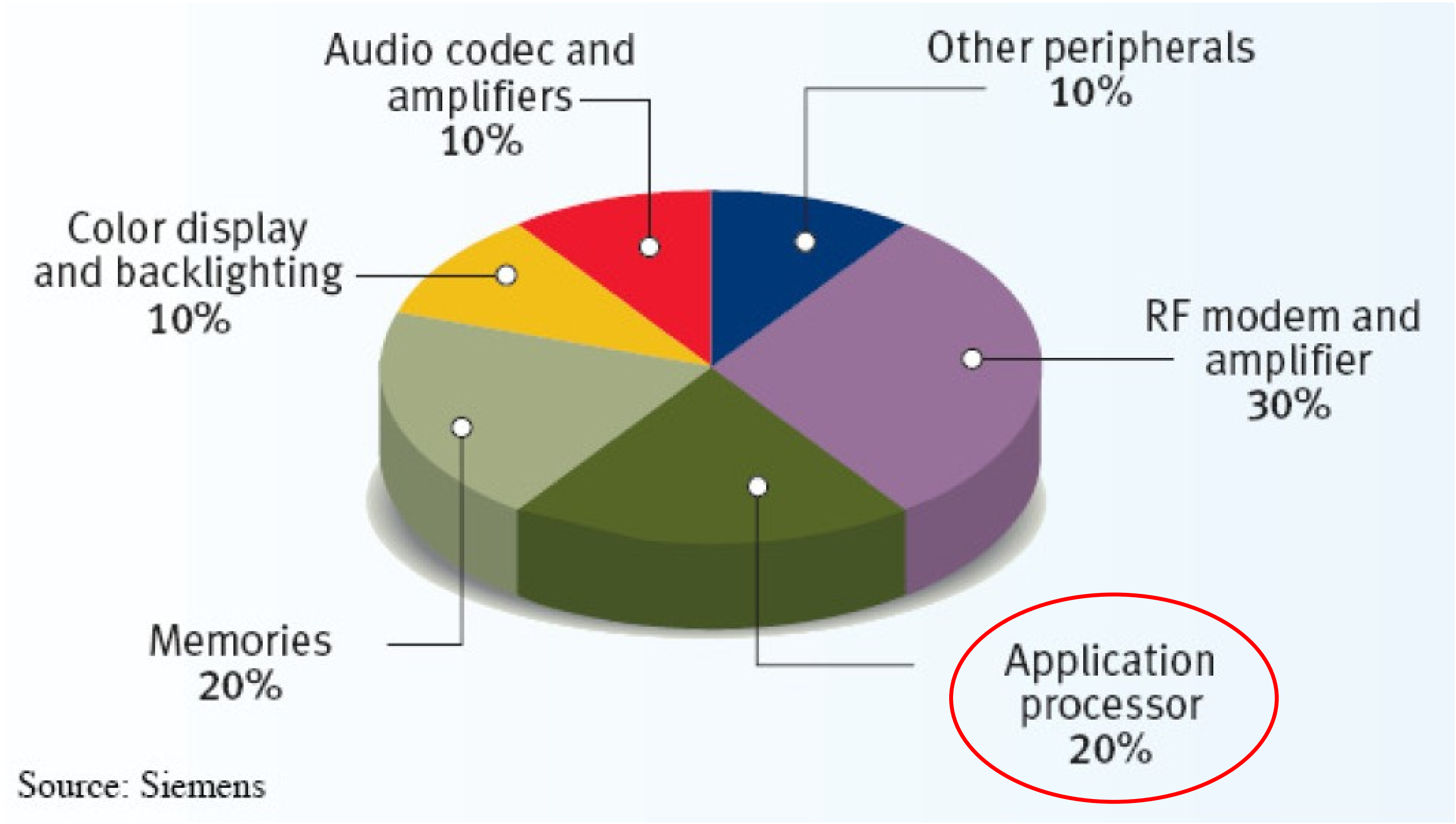
Mobile PC (notebook)
Average System Power



Multiple Platform Components Comprise Average Power

[Courtesy: N. Dutt; Source: V. Tiwari]

Energy consumption in mobile devices

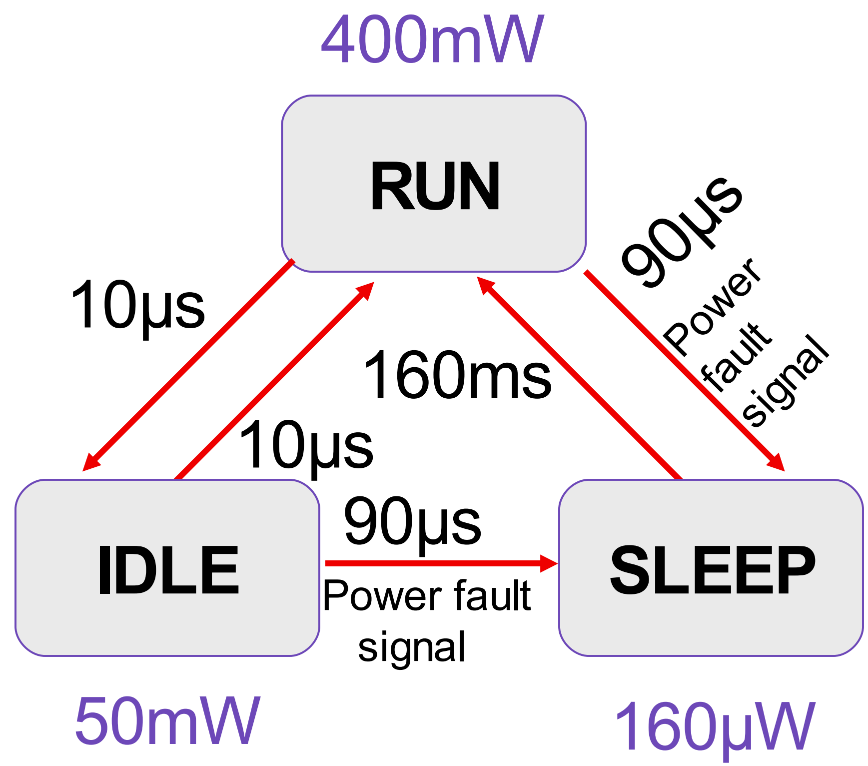


[O. Vargas (Infineon Technologies): Minimum power consumption in mobile-phone memory subsystems; Pennwell Portable Design - September 2005;] Thanks to Thorsten Koch (Nokia/ Univ. Dortmund) for providing this source.

Dynamic power management (DPM)

Example: STRONGARM SA1100

RUN: operational
IDLE: a sw routine may stop the CPU when not in use, while monitoring interrupts
SLEEP: Shutdown of on-chip activity



Fundamentals of dynamic voltage scaling (DVS)

Power consumption of CMOS circuits (ignoring leakage):

$P = \alpha \; C_L V_{dd}^2 \; f$ with

α : switching activity

C_L : load capacitance

V_{dd} : supply voltage

f : clock frequency

Delay for CMOS circuits:

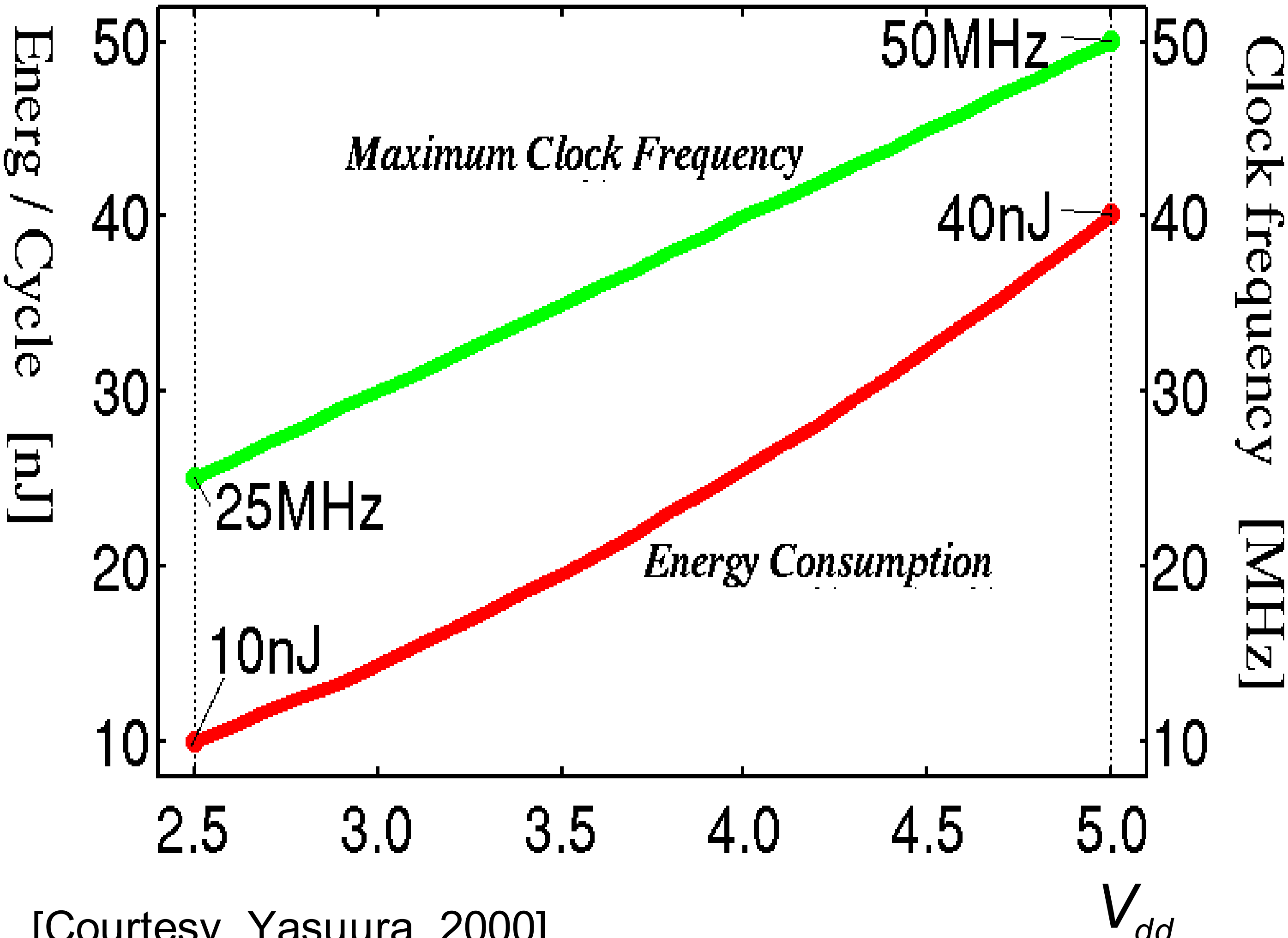
$$\tau = k C_L \frac{V_{dd}}{(V_{dd} - V_t)^2}$$ with

V_t : threshhold voltage

($V_t <$ than V_{dd})

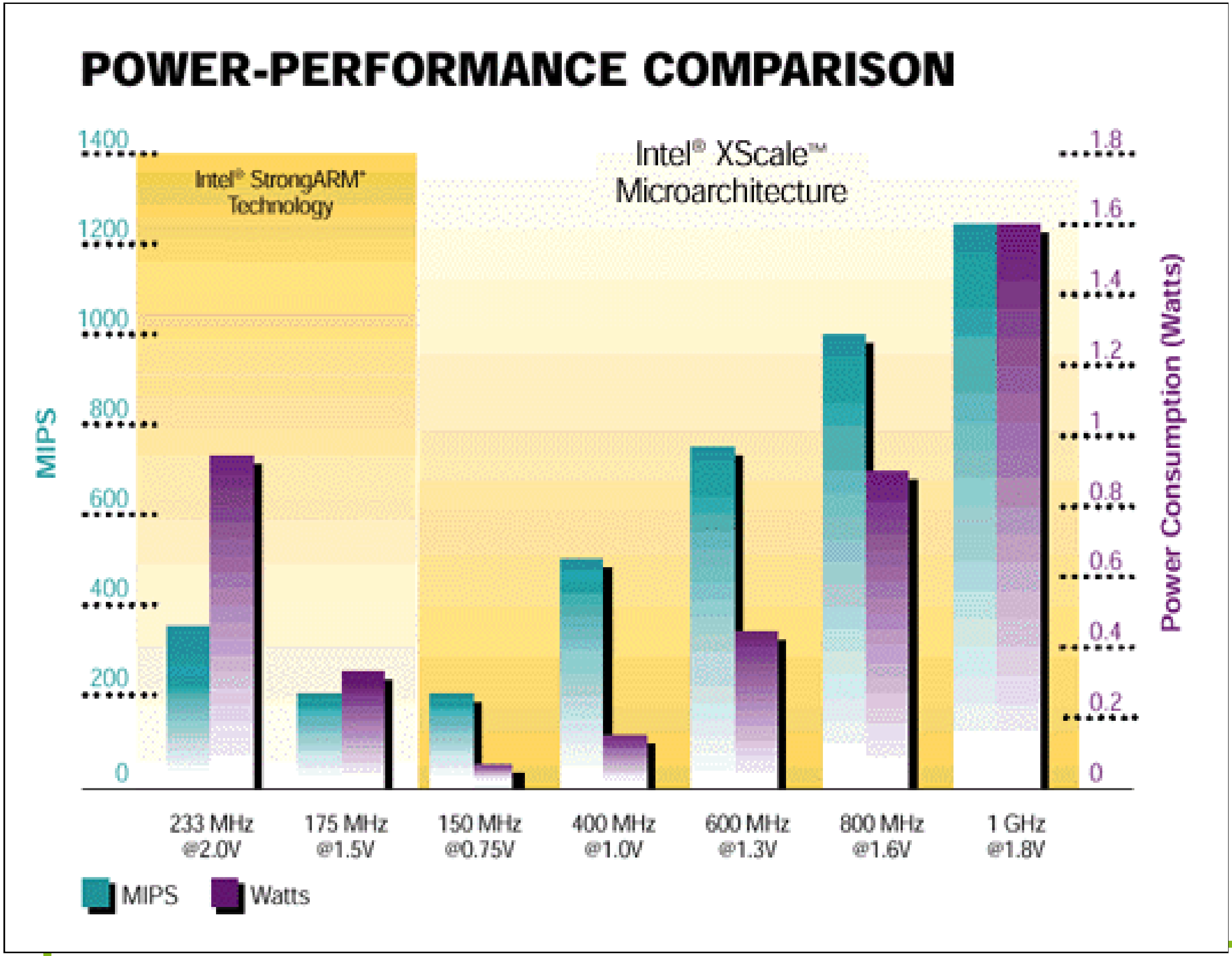
☞Decreasing V_{dd} reduces P quadratically,
while the run-time of algorithms is only linearly increased
$E=P \times t$ decreases linearly
(ignoring the effects of the memory system and V_t)

Voltage scaling: Example



[Courtesy, Yasuura, 2000]

Variable-voltage/frequency example: INTEL Xscale



OS should schedule distribution of the energy budget.

From Intel's Web Site

Summary

Hardware in a loop

- Sensors
- Discretization
  - Sample-and-hold circuits
  - A/D-converters
- Information processing
  - Importance of energy efficiency
  - Special purpose HW very expensive
  - Energy efficiency of processors
  - ..
- D/A converters
- Actuators