technische universität
dortmund

fakultät für informatik
informatik 12

# (Introduction to)
# Embedded Systems

Peter Marwedel
TU Dortmund,
Informatik 12


Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

preface

2010/09/20

# Motivation for Course (1)

According to forecasts, future of IT characterized by terms such as

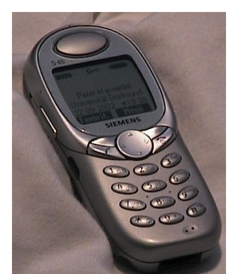
- Disappearing computer,
- Ubiquitous computing,
- Pervasive computing,
- Ambient intelligence,
- Post-PC era,
- Cyber-physical systems.

Basic technologies:

- *Embedded Systems*
- Communication technologies





# Motivation for Course (2)

“Information technology (IT) is on the verge of another revolution. …..

networked systems of embedded computers ... have the potential to change radically the way people interact with their environment by linking together a range of devices and sensors that will allow information to be collected, shared, and processed in unprecedented ways. ...

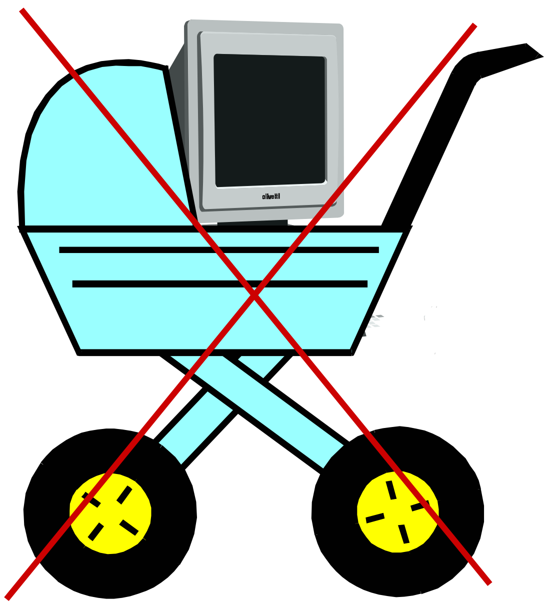
The use … throughout society could well dwarf previous milestones in the information revolution.”

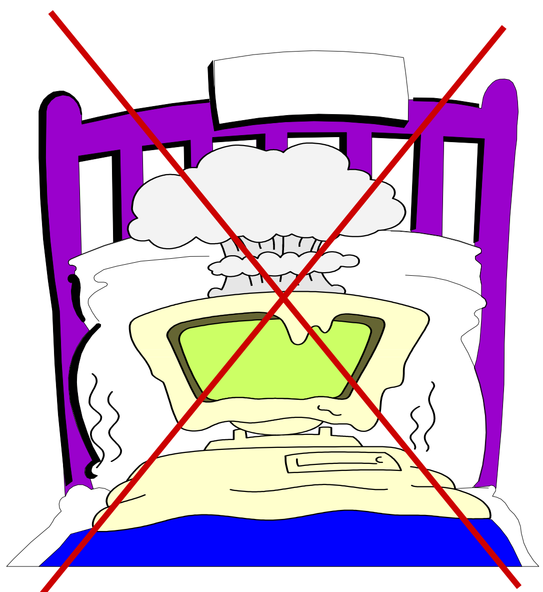
*National Research Council Report (US)*
*Embedded Everywhere, 2001*

# Motivation for Course (3)

☞ **The future is embedded, embedded is the future**

# What is an embedded system?





# Embedded Systems & Cyber-Physical Systems

“Dortmund“ Definition: [Peter Marwedel]

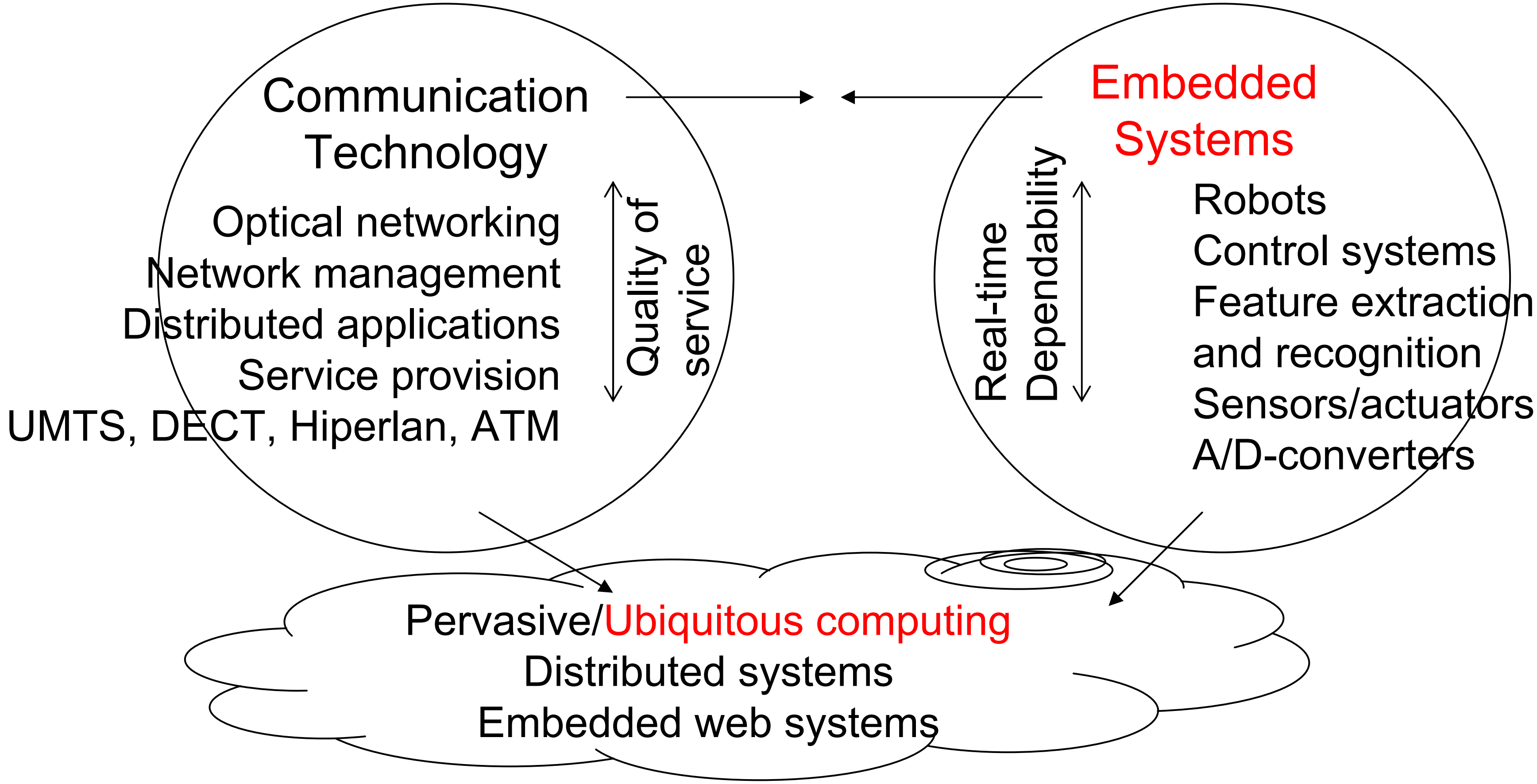
**Embedded systems are information processing systems embedded into a larger product**

Berkeley: [Edward A. Lee]*:*
**Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.**

☞ **Definition**: **Cyber-Physical (cy-phy) Systems** (CPS) are integrations of computation with physical processes [Edward Lee, 2006].

# Extending the motivation: Embedded systems and ubiquitous computing

Ubiquitous computing: Information anytime, anywhere.
Embedded systems provide fundamental technology.



# Growing importance of embedded systems (1)

- *the global mobile entertainment industry is now worth some $32 bln…predicting average revenue growth of 28% for 2010* [www.itfacts.biz, July 8th, 2009]
- *…, the market for remote home health monitoring is expected to generate $225 mln revenue in 2011, up from less than $70 mln in 2006, according to Parks Associates. .* [www.itfacts.biz, Sep. 4th, 2007]
- *According to IDC the identity and access management (IAM) market in Australia and New Zealand (ANZ) … is expected to increase at a compound annual growth rate (CAGR) of 13.1% to reach $189.3 mln by 2012* [www.itfacts.biz, July 26th, 2008]*.*
- Accessing the Internet via a mobile device up by 82% in the US, by 49% in Europe, from May 2007 to May 2008 [www.itfacts.biz, July 29th, 2008]

# Growing importance of embedded systems (2)

- .. *but embedded chips form the backbone of the electronics driven world in which we live ... they are part of almost everything that runs on electricity* [Ryan, EEDesign, 1995]
- Creation of the ARTEMIS Joint Undertaking in Europe
- Funding of CPS research in the US
- Foundation for the "post PC era"
- ES hardly discussed in other CS courses
- ES important for TU Dortmund
- ES important for Europe
- Scope: sets context for specialized courses

Importance of education

# Application areas and examples

# Automotive electronics

Functions by embedded processing:

- ABS: Anti-lock braking systems
- ESP: Electronic stability control
- Airbags
- Efficient automatic gearboxes
- Theft prevention with smart keys
- Blind-angle alert systems
- ... etc ...

Multiple networks

- Body, engine, telematics, media, safety, ...

Multiple networked processors

- Up to 100

© Jakob Engblom

# Avionics

- Flight control systems,
- anti-collision systems,
- pilot information systems,
- power supply system,
- flap control system,
- entertainment system,
- …


Dependability is of outmost importance.

# Railways

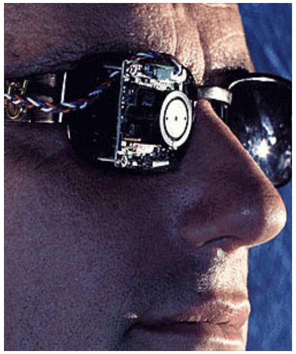
- Safety features contribute significantly to the total value of trains, and dependability is extremely important

# Telecommunication

- Mobile phones have been one of the fastest growing markets in the recent years,
- Geo-positioning systems,
- Fast Internet connections,
- Closed systems for police, ambulances, rescue staff.

# Medical systems

- For example:
  - Artificial eye: several approaches, e.g.:
    - Camera attached to glasses; computer worn at belt; output directly connected to the brain, "pioneering work by William Dobelle". Previously at [www.dobelle.com]



- Translation into sound; claiming much better resolution. [http://www.seeingwithsound.com/etumble.htm]

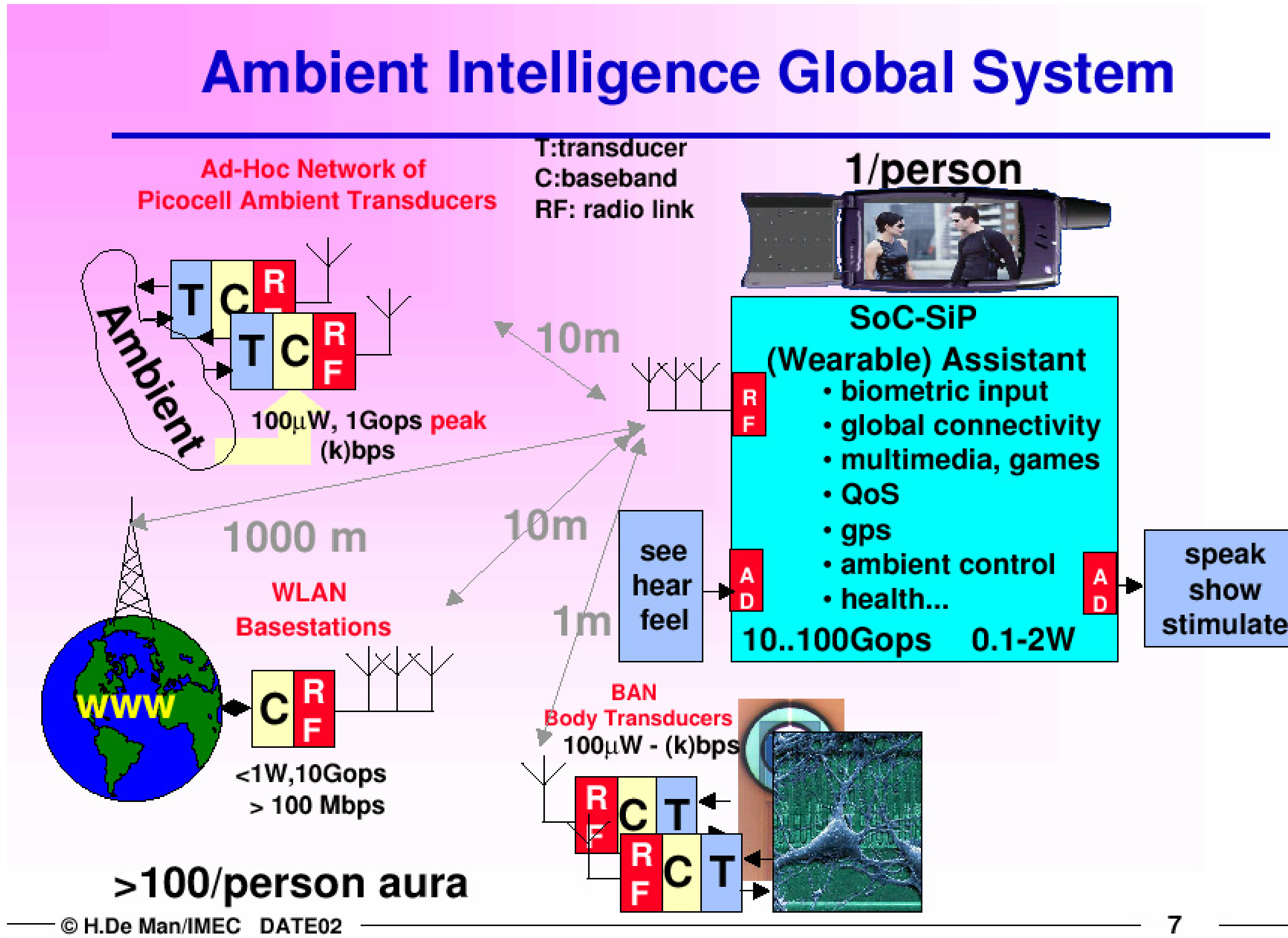
# Authentication systems

- Finger print sensors
- Access control
- Airport security systems
- Smartpen®
- Smart cards
- ….

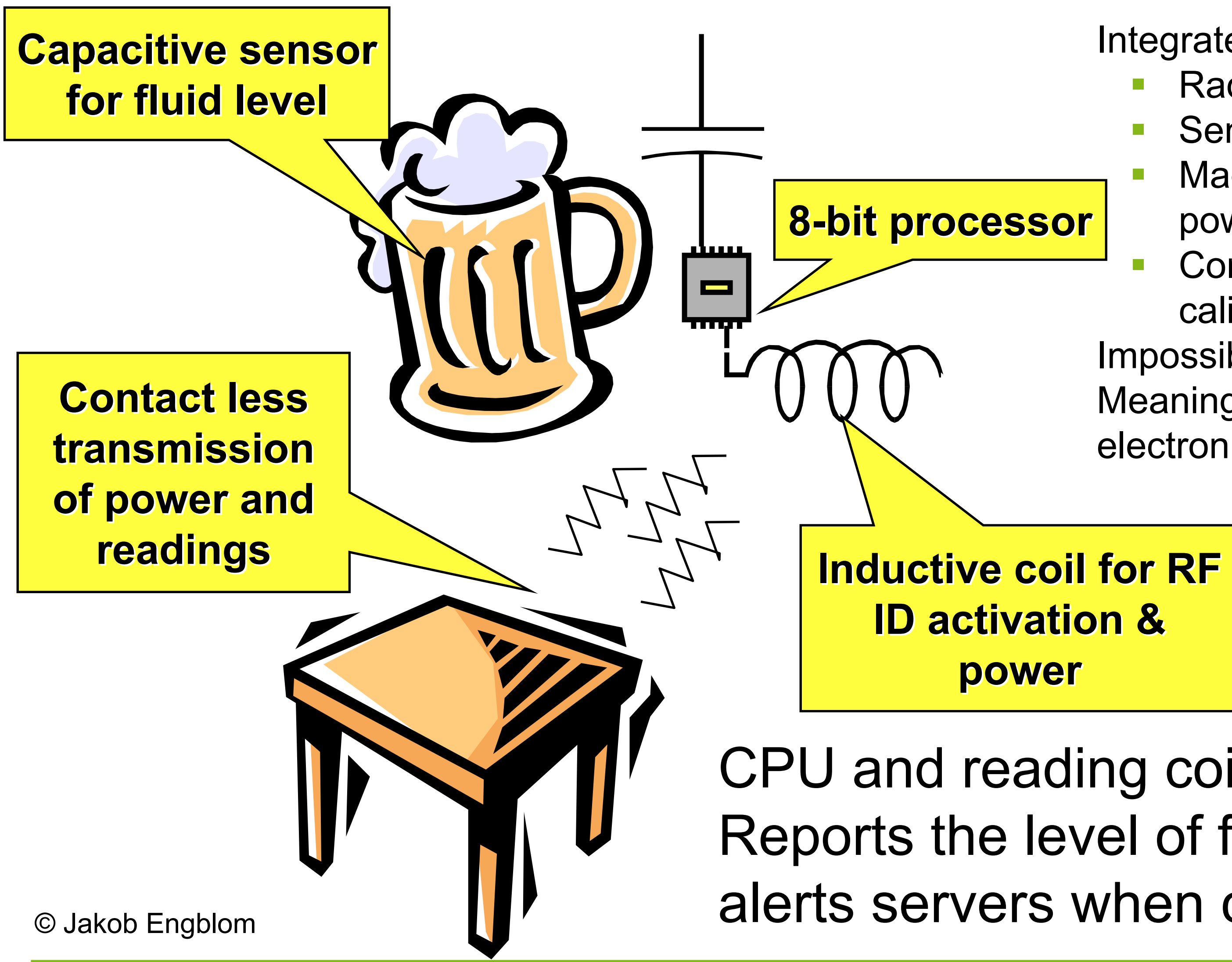
[tomsguide.com]

# Consumer electronics

Examples



# Smart Beer Glass




Integrates several technologies:

- Radio transmissions
- Sensor technology
- Magnetic inductance for power
- Computer used for calibration

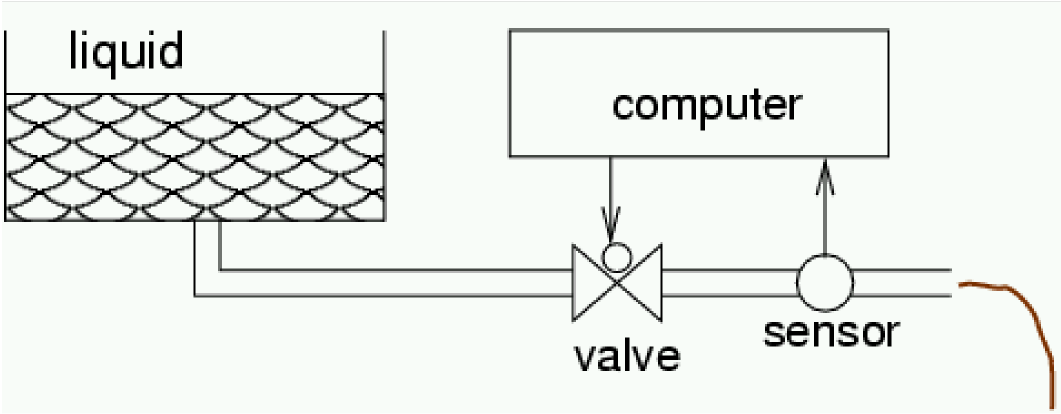
Impossible without the computer

Meaningless without the electronics

CPU and reading coil in the table. Reports the level of fluid in the glass, alerts servers when close to empty

# Industrial automation

Examples




# Forestry Machines

Networked computer system

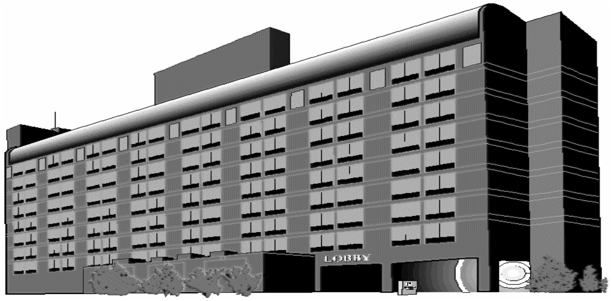
- Controlling arms & tools
- Navigating the forest
- Recording the trees harvested
- Crucial to efficient work

"Tough enough to be out in the woods"

# Smart buildings

Examples

- Integrated cooling, lightning, room reservation, emergency handling, communication
- Goal: “Zero-energy building”
- Expected contribution to fight against global warming



Show movie http://www.date-conference.com/conference/2003/keynotes/index.htm

# Logistics

Applications of embedded/cyber-physical system

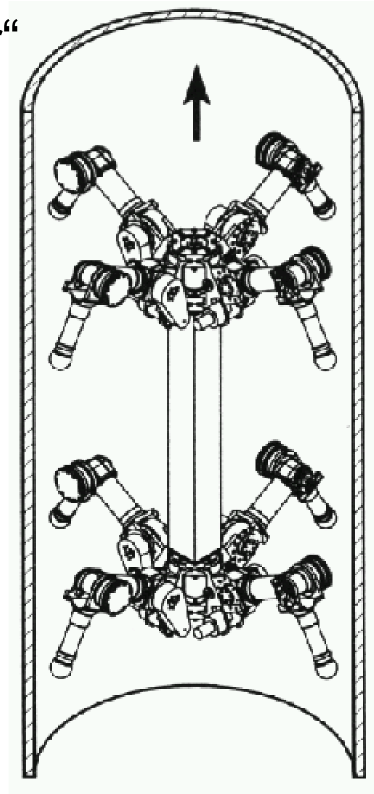
technology to logistics:

- Radio frequency identification (RFID) technology provides easy identification of each and every object, worldwide.
- Mobile communication allows unprecedented interaction.
- The need of meeting real-time constraints and scheduling are linking embedded systems and logistics.
- The same is true of energy minimization issues

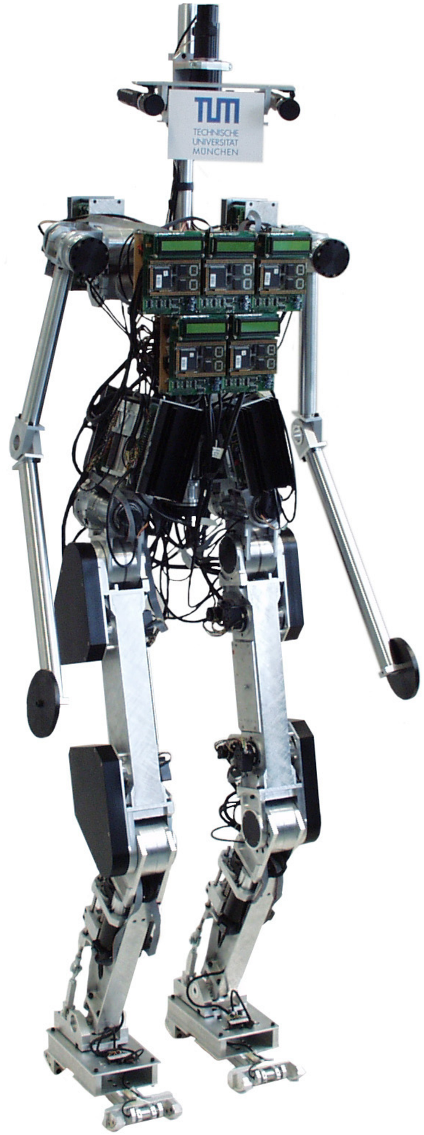
# Robotics

## Examples

- “Pipe-climber“



- Robot “Johnnie“ (Courtesy and ©: H.Ulbrich, F. Pfeiffer, TU München)







Show movie of 2-legged robot(s)

# Robotics (2)

Lego mindstorms robotics kit

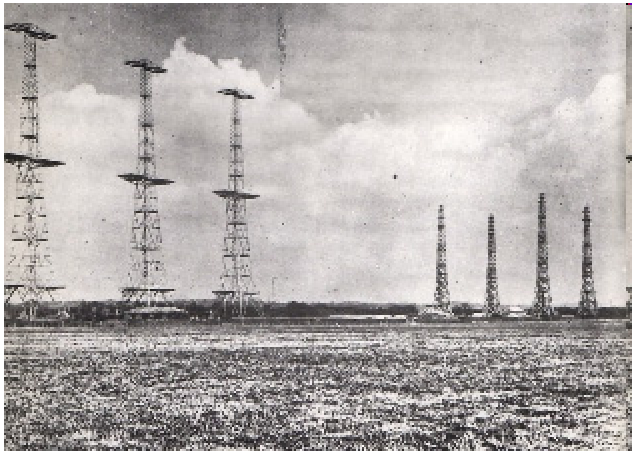
- Standard controller
  - 8-bit processor
  - 64 kB of memory
- Electronics to interface to motors and sensors

Good way to learn embedded systems

# Military applications

Example:

- Military radar



http://www.worthingherald.co.uk/CustomPages/CustomPage.aspx?SectionID=14271

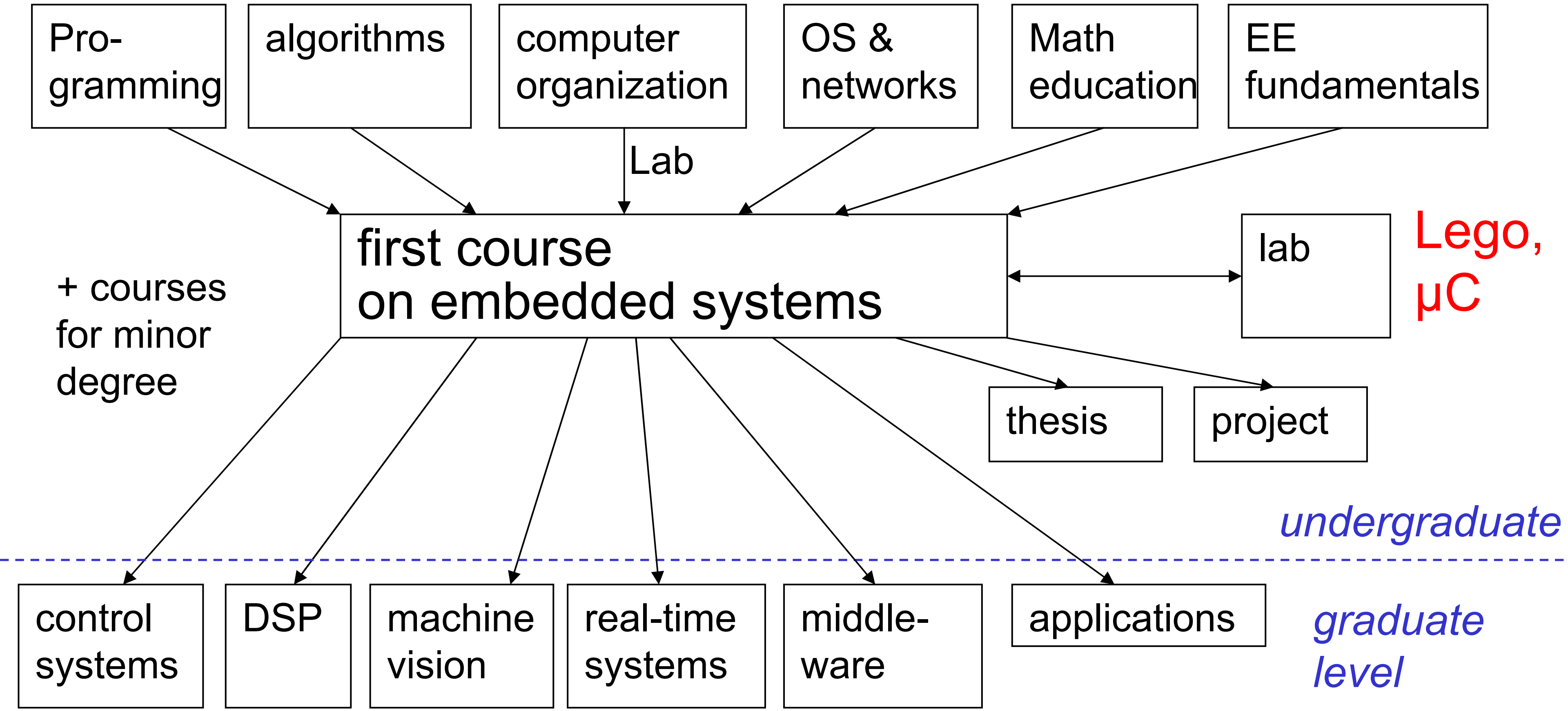
# Educational concept




From the preface of the book

# Concept of ES Education at Dortmund

- Integrated as a specialization into CS curriculum



# Structure of the CS curriculum at Dortmund
# - 4.5 year diploma program -

| Term | | | | |
|---|---|---|---|---|
| 1 | Computer organization | | Programming & semantics | Math education |
| 2 | Circuits & communication | OS | Algorithms | |
| 3 | HW lab | Networks | SW lab | |
| 4 | | Databases | … | |
| 5 | Embedded systems fundamentals | Software engineering | … | |
| 6 | Advanced topic in ES | … | … | |
| 7 | Project group | … | | |
| 8 | | … | … | |
| 9 | Thesis | | | |

All dependences met

# Structure of the CS curriculum at Dortmund - 3 year bachelor program -

| Term | | | | |
|---|---|---|---|---|
| 1 | Computer organization | | Programming & semantics | Math education |
| 2 | Circuits & communication | OS | Algorithms | |
| 3 | HW lab | Networks | SW lab | |
| 4 | | Databases | … | |
| 5 | Embedded systems fundamentals | Software engineering | … | |
| 6 | Bachelor project + Thesis | … | … | |

All dependences met

# Broad scope avoids problems with narrow perspectives reported in ARTIST curriculum guidelines

“The lack of maturity of the domain results in a large variety of industrial practices, often due to cultural habits”

“curricula … concentrate on one technique and do not present a sufficiently wide perspective.”

“As a result, industry has difficulty finding adequately trained engineers, fully aware of design choices.”

Source: ARTIST network of excellence:
Guidelines for a Graduate Curriculum on Embedded Software and Systems,
http://www.artist-embedded.org/Education/Education.pdf, 2003

# Scope consistent with ARTIST guidelines

"The development of ES cannot ignore the underlying HW characteristics. Timing, memory usage, power consumption, and physical failures are important."

$\int P \, dt$

"It seems that fundamental bases are really difficult to acquire during continuous training if they haven't been initially learned, and we must focus on them."

# Textbook(s)

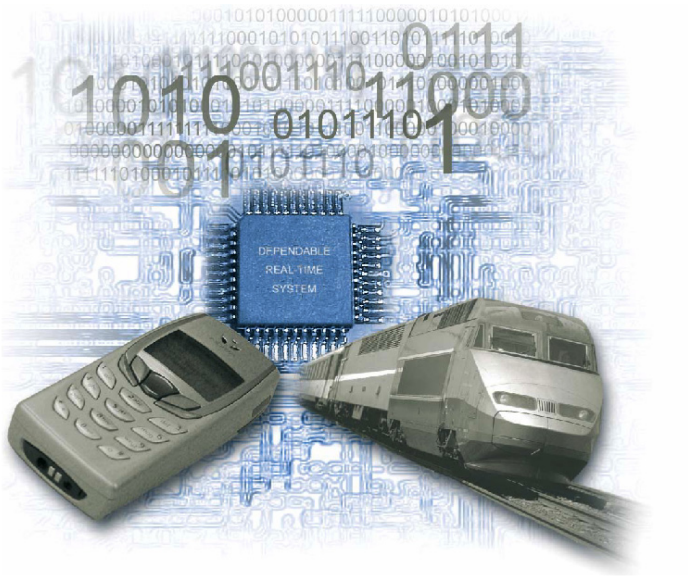

Several Editions:

- 1st English edition
  - Original hardcover version, Kluwer, 2003, >100 $/€
  - Reprint, lighter cover borders;
  - Reprint, soft cover, corrections, Springer, 2006, 37-39€
- 2nd English edition, 2010
- 1st German edition 29€
  - March 2007
  - Reprint, 2008
- Chinese edition, April 2007, only preface in Chinese, not for sale outside China
- Plans for Russian, Portuguese, Macedonian and Greek edition

# Slides

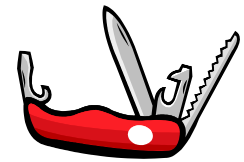
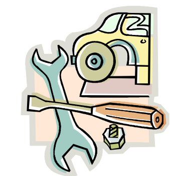
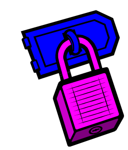
- Slides are available at: http://ls12-www.cs.tu-dortmund.de/en/teaching/courses/index.html
- Master format: Powerpoint (XP);
- Derived format: PDF

# Common characteristics




Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

# Dependability

- ES Must be **dependable**, 
  - **Reliability *R(t)* =** probability of system working correctly provided that is was working at $t$=0 
  - **Maintainability *M(d)* =** probability of system working correctly $d$ time units after error occurred. 
  - **Availability *A*(*t*)**: probability of system working at time $t$
  - **Safety**: no harm to be caused 
  - **Security**: confidential and authentic communication 

Even perfectly designed systems can fail if the assumptions about the workload and possible errors turn out to be wrong.

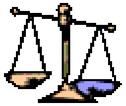
Making the system dependable must not be an after-thought, it must be considered from the very beginning

# Efficiency

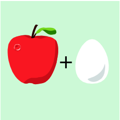
- ES must be **efficient**
  - Code-size efficient (especially for systems on a chip)

  - Run-time efficient

  - Weight efficient

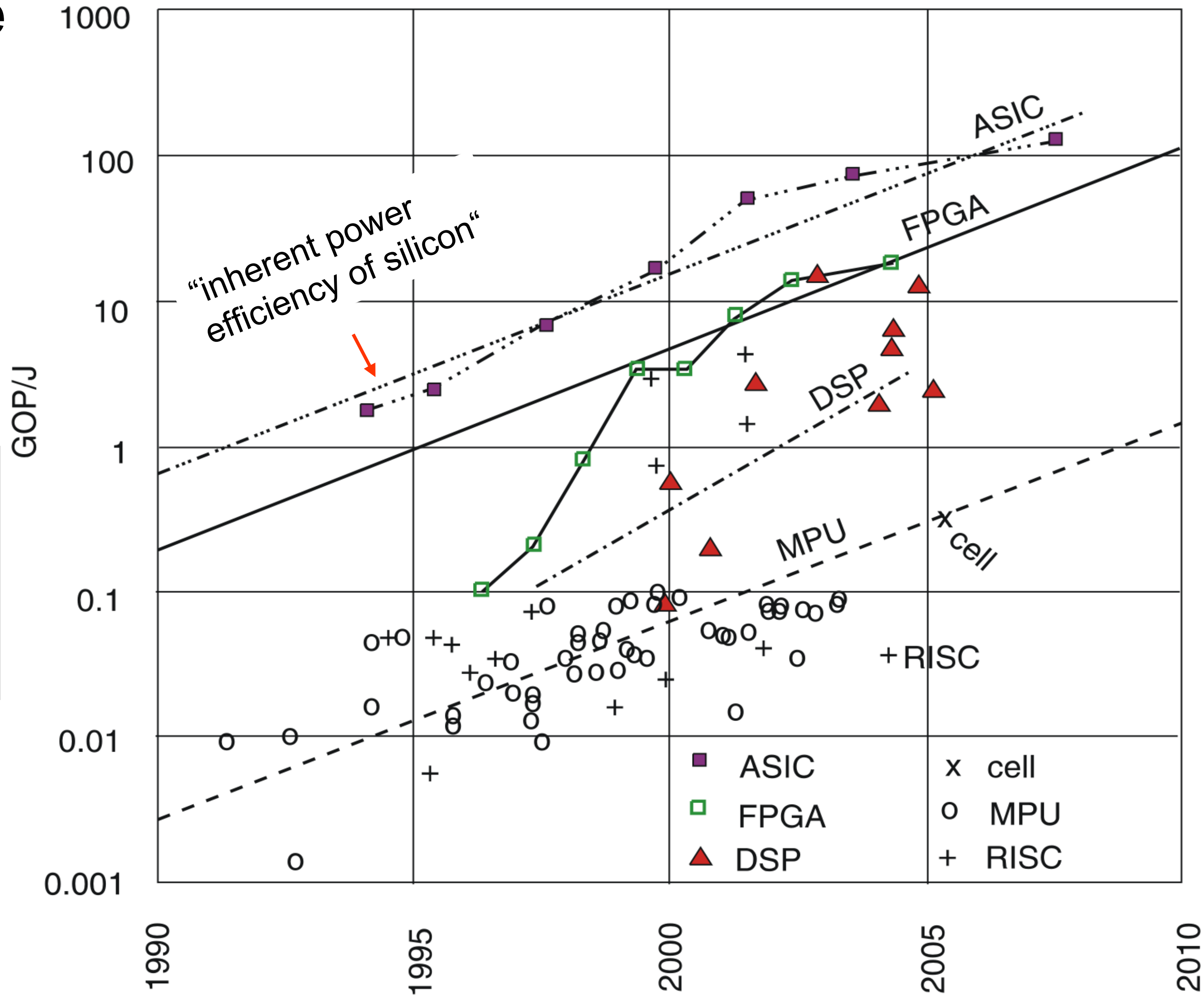


  - Cost efficient



  - Energy efficient

# Importance of Energy Efficiency

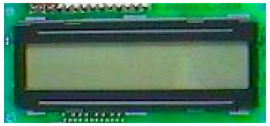


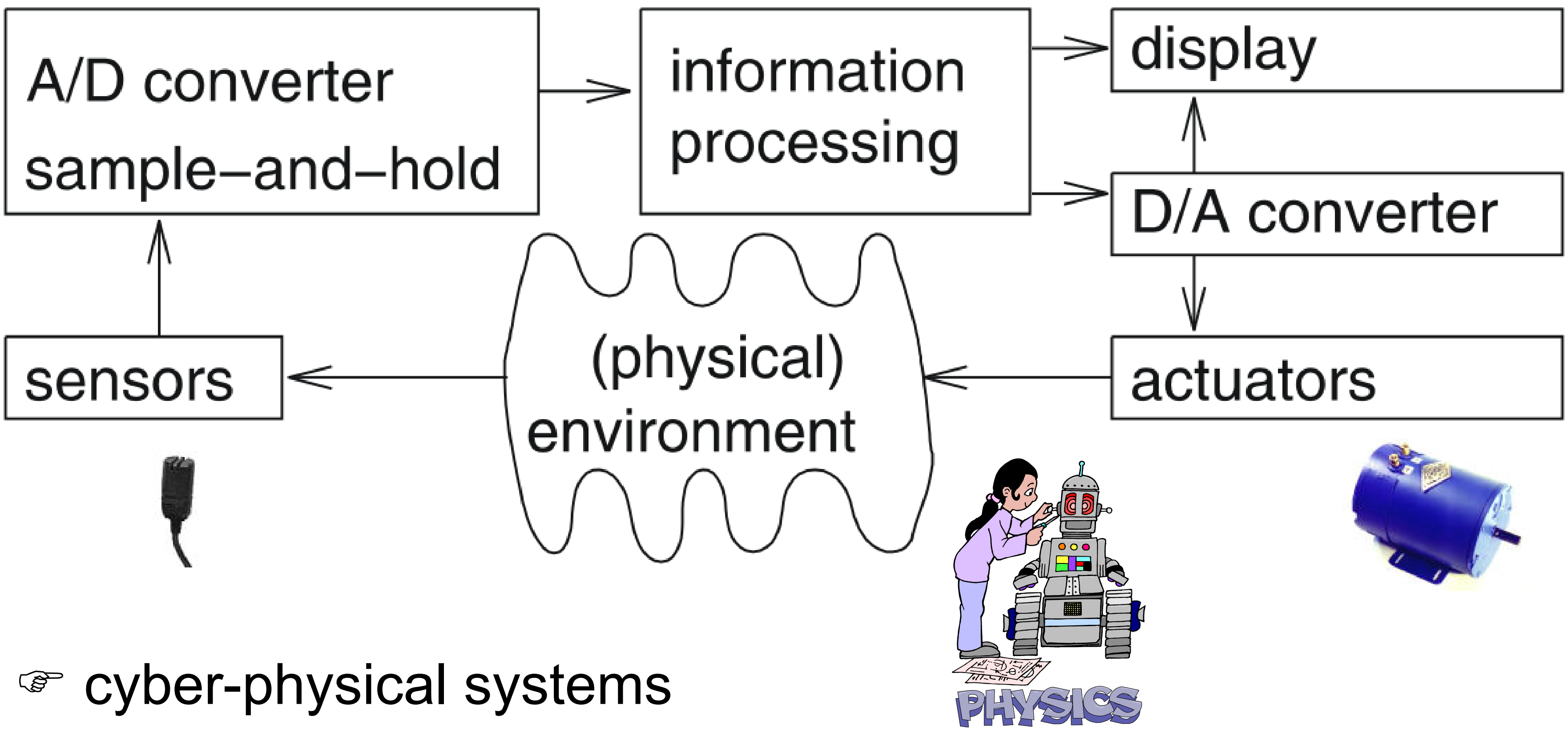

Efficient software design needed, otherwise, the price for software flexibility cannot be paid.

© Hugo De Man, IMEC, Philips, 2007

# Embedded System Hardware

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






☞ cyber-physical systems

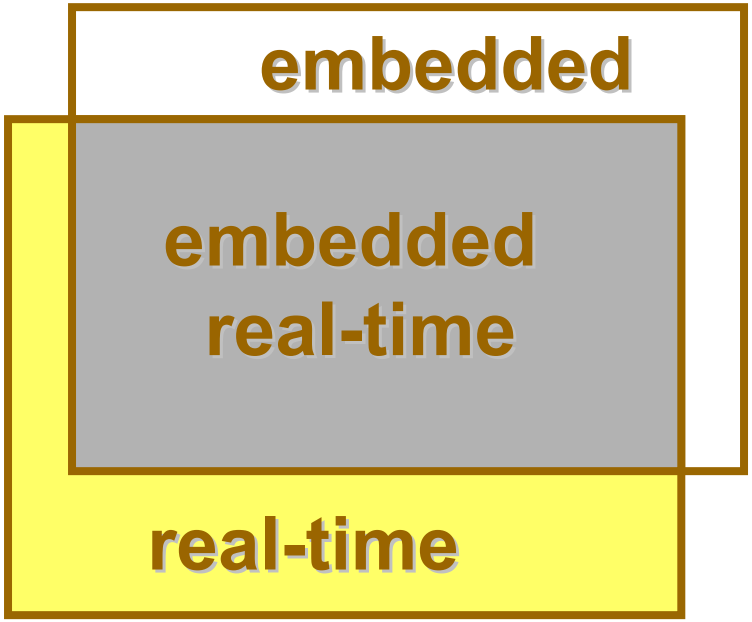
# Real-time constraints

- Many ES must meet **real-time constraints**
  - A real-time system must react to stimuli from the controlled object (or the operator) within the time interval **dictated** by the environment.
  - For real-time systems, right answers arriving too late are wrong.
  - **"A real-time constraint is called hard, if not meeting that constraint could result in a catastrophe"** [Kopetz, 1997].
  - All other time-constraints are called **soft**.
  - A guaranteed system response has to be explained without statistical arguments

# Real-Time Systems

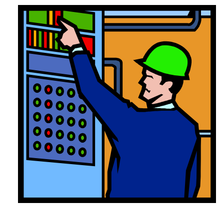
Embedded and Real-Time Synonymous?

- Most embedded systems are real-time
- Most real-time systems are embedded



# Reactive & hybrid systems

- Typically, ES are **reactive systems**:
  **“A reactive system is one which is in continual interaction with is environment and executes at a pace determined by that environment“**
  [Bergé, 1995]
  Behavior depends on input **and current state.**
  ☞ automata model appropriate,
  model of computable functions inappropriate.



- **Hybrid systems**
  (analog + digital parts).

# Dedicated systems

- **Dedicated** towards a certain **application**
  Knowledge about behavior at design time can  be used to minimize resources and to maximize robustness
- **Dedicated user interface**
  (no mouse, keyboard and screen)

# Underrepresented in teaching

- ES are **underrepresented in teaching** and public discussions:
  "*Embedded chips aren't hyped in TV and magazine ads ...*" [Mary Ryan, EEDesign, 1995]

Not every ES has all of the above characteristics.

**Def.**: **Information processing systems having most of the above characteristics are called embedded systems.**

Course on embedded systems makes sense because of the number of common characteristics.

# Summary

- A look at the future of IT
- Definition: embedded & cyber-physical (cy-phy) systems
- Growing importance of embedded & cy-phy systems
- Application areas
- Examples
- Curriculum
- Characteristics