Eingebettete Systeme/
Embedded Systems

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Informatik 12

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2008/10/10

Motivation for Course (1)

According to forecasts 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.”

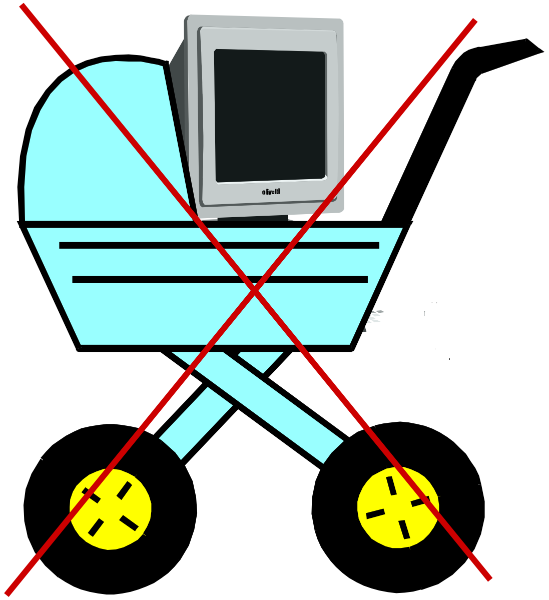
National Research Council Report (US)
Embedded Everywhere

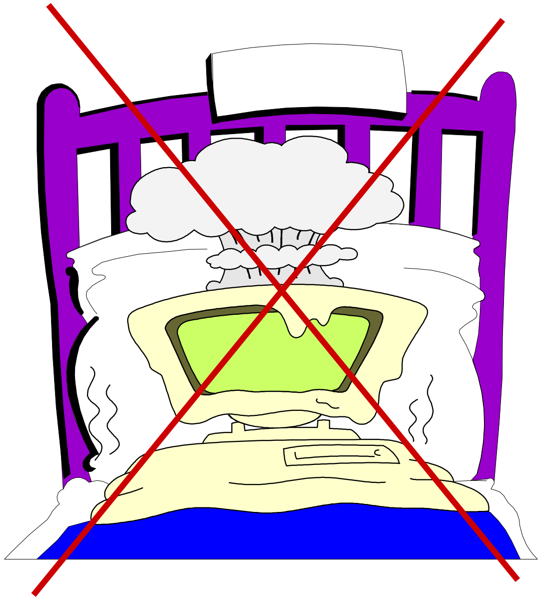
Source. Ed Lee, UC Berkeley, ARTEMIS Embedded Systems Conference, Graz, 5/2006]

Motivation for Course (3)

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

What is an embedded system?





Embedded Systems

“Dortmund“ Definition: [Peter Marwedel]

Information processing systems embedded into a larger product

Main reason for buying is **not** information processing

Berkeley Modell: [Ed Lee]*:*

Embedded software is software integrated with physical* processes. The technical problem is managing time and concurrency in computational systems.

* ☞ “cyber-physical systems”

Growing importance of embedded systems (1)

- *Spending on GPS units exceeded $100 mln during Thanksgiving week, up 237% from 2006 … More people bought GPS units than bought PCs, NPD found.* [www.itfacts.biz, Dec. 6th, 2007]
- *…, 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)

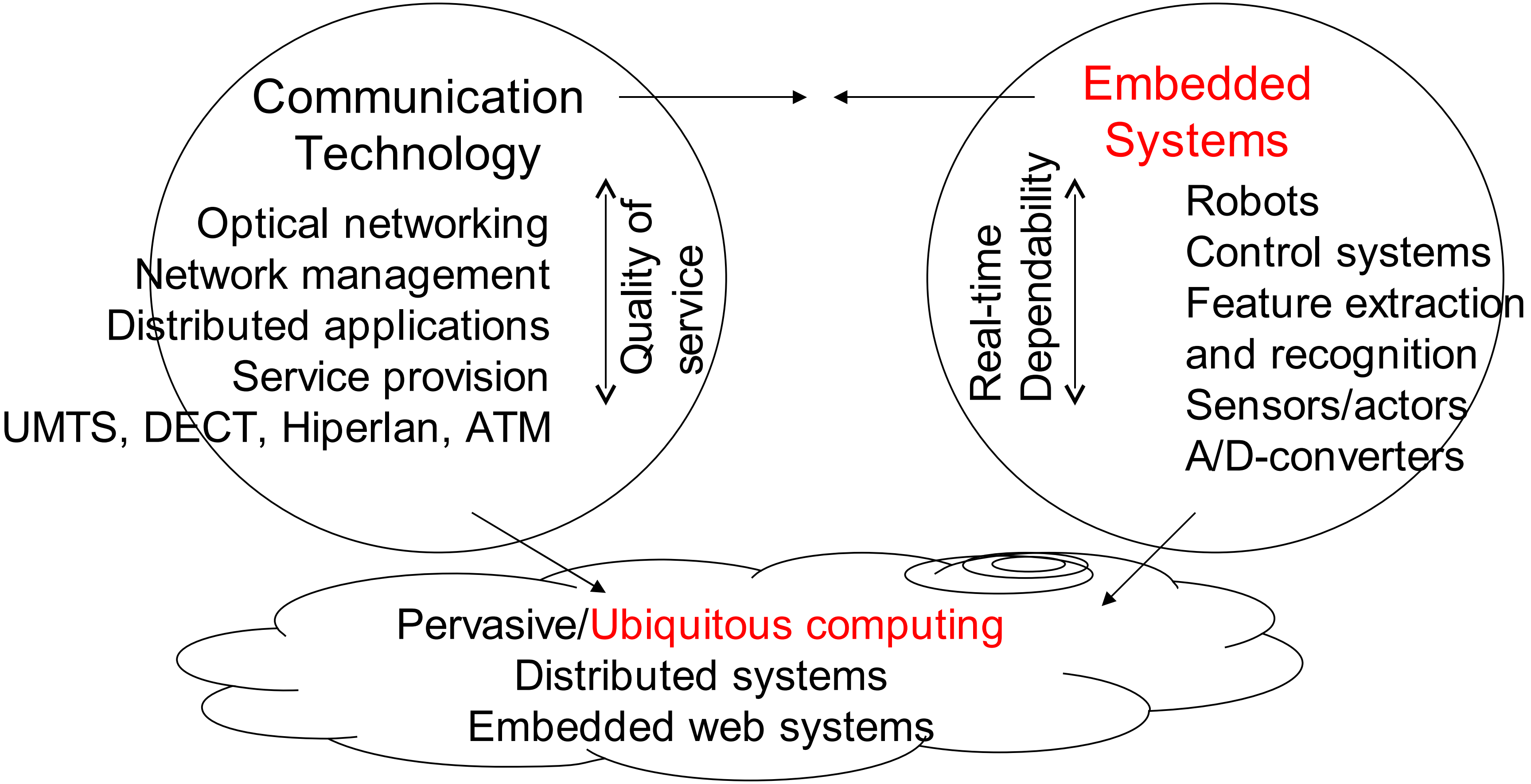
- *.. but embedded chips form the backbone of the electronics driven world in which we live ... they are part of almost everything that runs on electricity* [Mary Ryan, EEDesign, 1995]
- The future is embedded, Embedded is the future!

- Foundation for the "post PC era"
- ES hardly discussed in other CS courses
- ES important for Technical University
- ES important for Europe
- Scope: sets context for specialized courses

Importance of education

Embedded systems
and ubiquitous computing

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



Communication Technology

Optical networking
Network management
Distributed applications
Service provision
UMTS, DECT, Hiperlan, ATM

Embedded Systems

Robots
Control systems
Feature extraction and recognition
Sensors/actors
A/D-converters

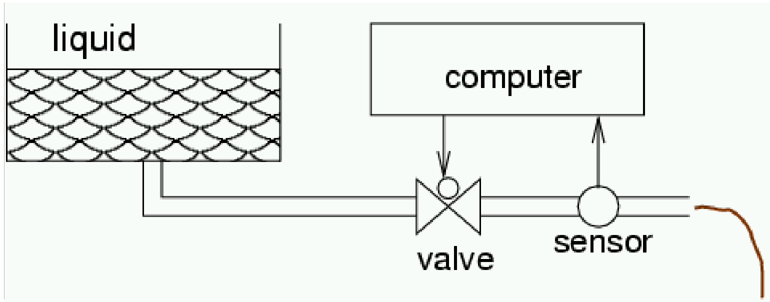
Pervasive/Ubiquitous computing
Distributed systems
Embedded web systems

Application areas (1)

- Automotive electronics
- Avionics
- Trains
- Telecommunication

Application areas (2)

- Industrial automation

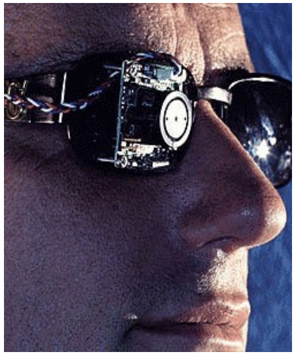


- Smart buildings

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

Application areas (2)

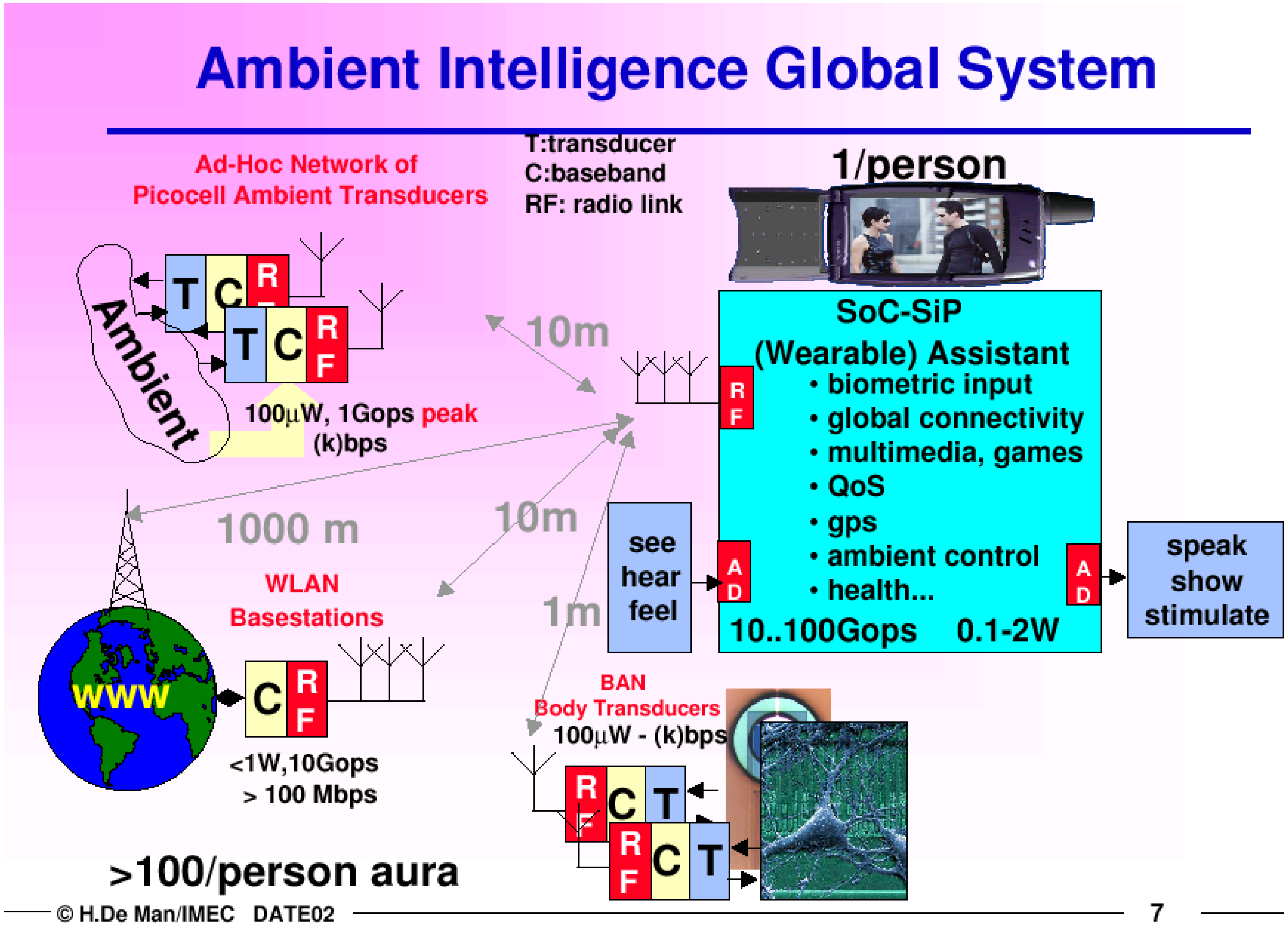
- Medical systems
  For example:
  - Artificial eye: several approaches, e.g.:
    - Camera attached to glasses; computer worn at belt; output directly connected to the brain, “pioneering work by William Dobelle”. Previously at [www.dobelle.com]



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

Application areas (4)

- Consumer electronics



Ambient Intelligence Global System

Ad-Hoc Network of
Picocell Ambient Transducers

T:transducer
C:baseband
RF: radio link

1/person

Ambient

T C RF

T C RF

100µW, 1Gops peak
(k)bps

10m

SoC-SiP
(Wearable) Assistant
- biometric input
- global connectivity
- multimedia, games
- QoS
- gps
- ambient control
- health...

10..100Gops 0.1-2W

RF

AD

AD

see
hear
feel

speak
show
stimulate

1000 m

10m

1m

WLAN
Basestations

WWW

C RF

<1W,10Gops
> 100 Mbps

BAN
Body Transducers
100µW - (k)bps

RF C T

RF C T

>100/person aura

© H.De Man/IMEC DATE02

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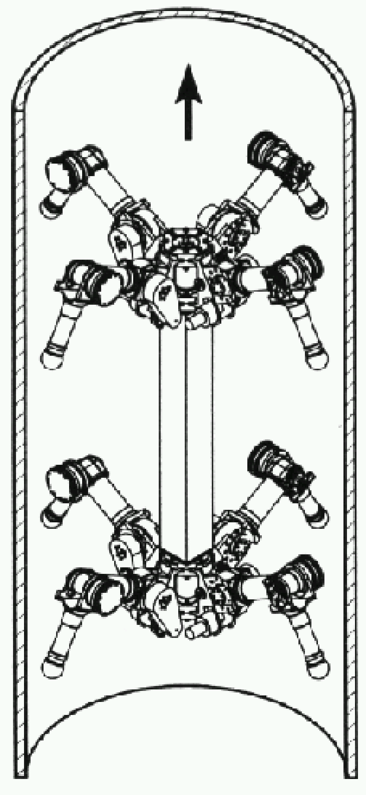
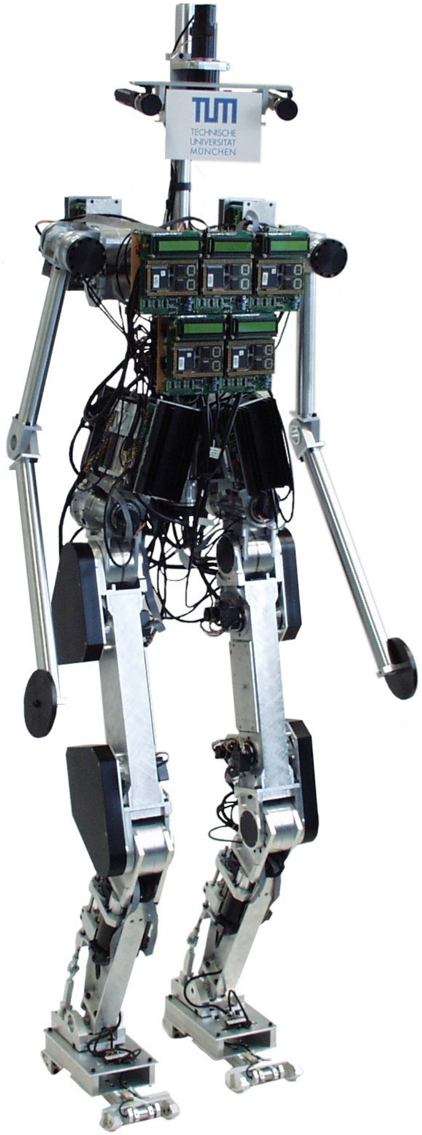
Application areas (5)

- Robotics

"Pipe-climber"



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

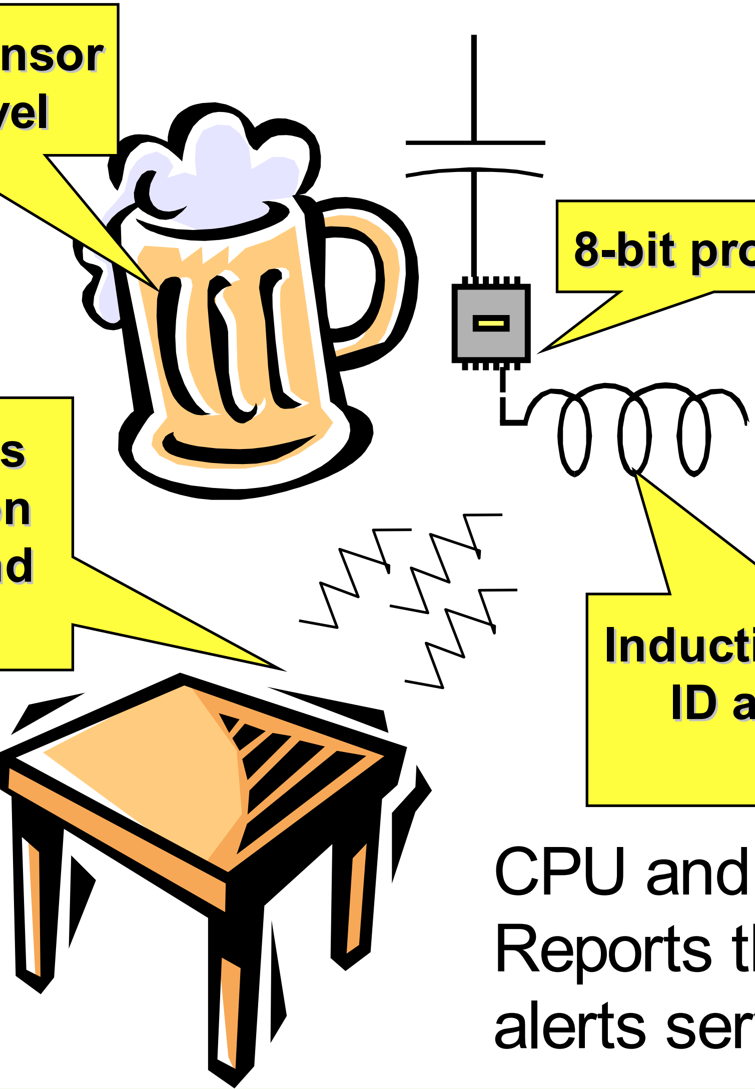


Show movie of 2-legged robot(s)

Examples

Some embedded systems
from “real” life

Smart Beer Glass


Capacitive sensor for fluid level
8-bit processor
Contact less transmission of power and readings
Inductive coil for RF ID activation & power

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

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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”

© Jakob Engblom

Cars

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 processors

- Up to 100
- Networked together

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If you want to play

Lego mindstorms robotics kit

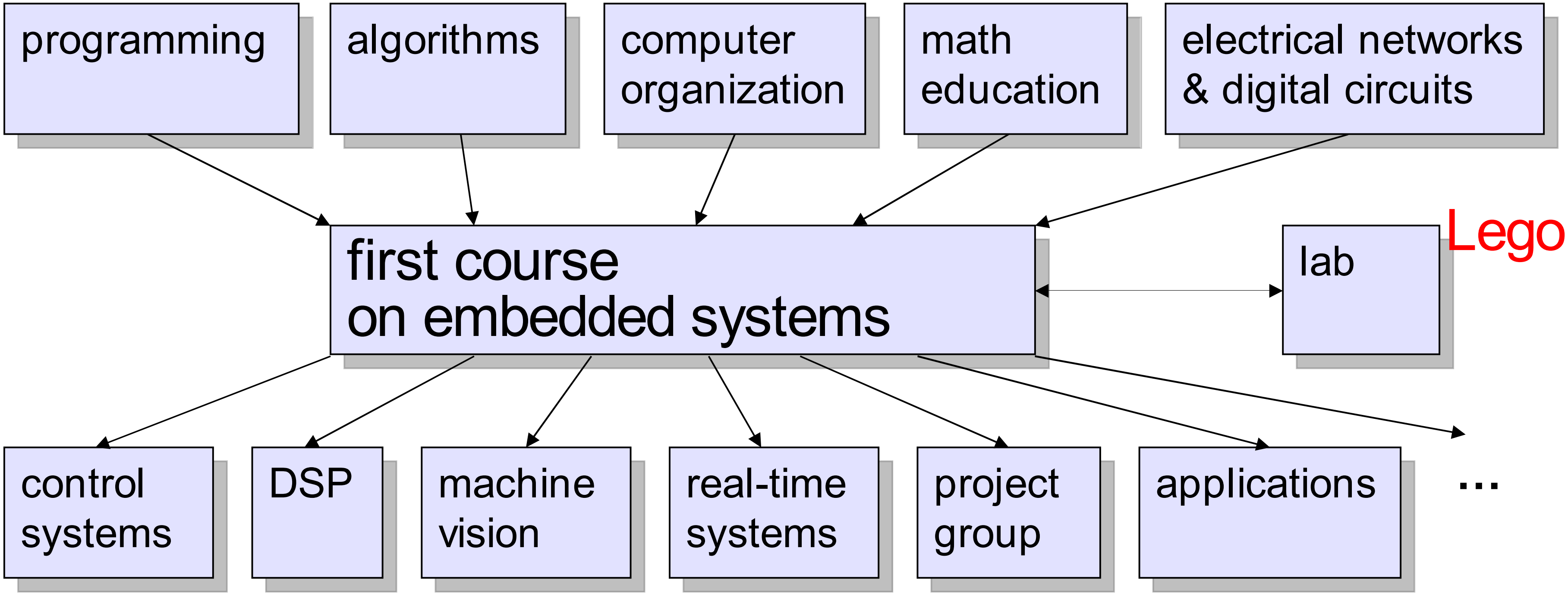
- Standard controller
  - 8-bit processor
  - 64 kB of memory
- Electronics to interface to motors and sensors

Good way to learn embedded systems

Educational concept

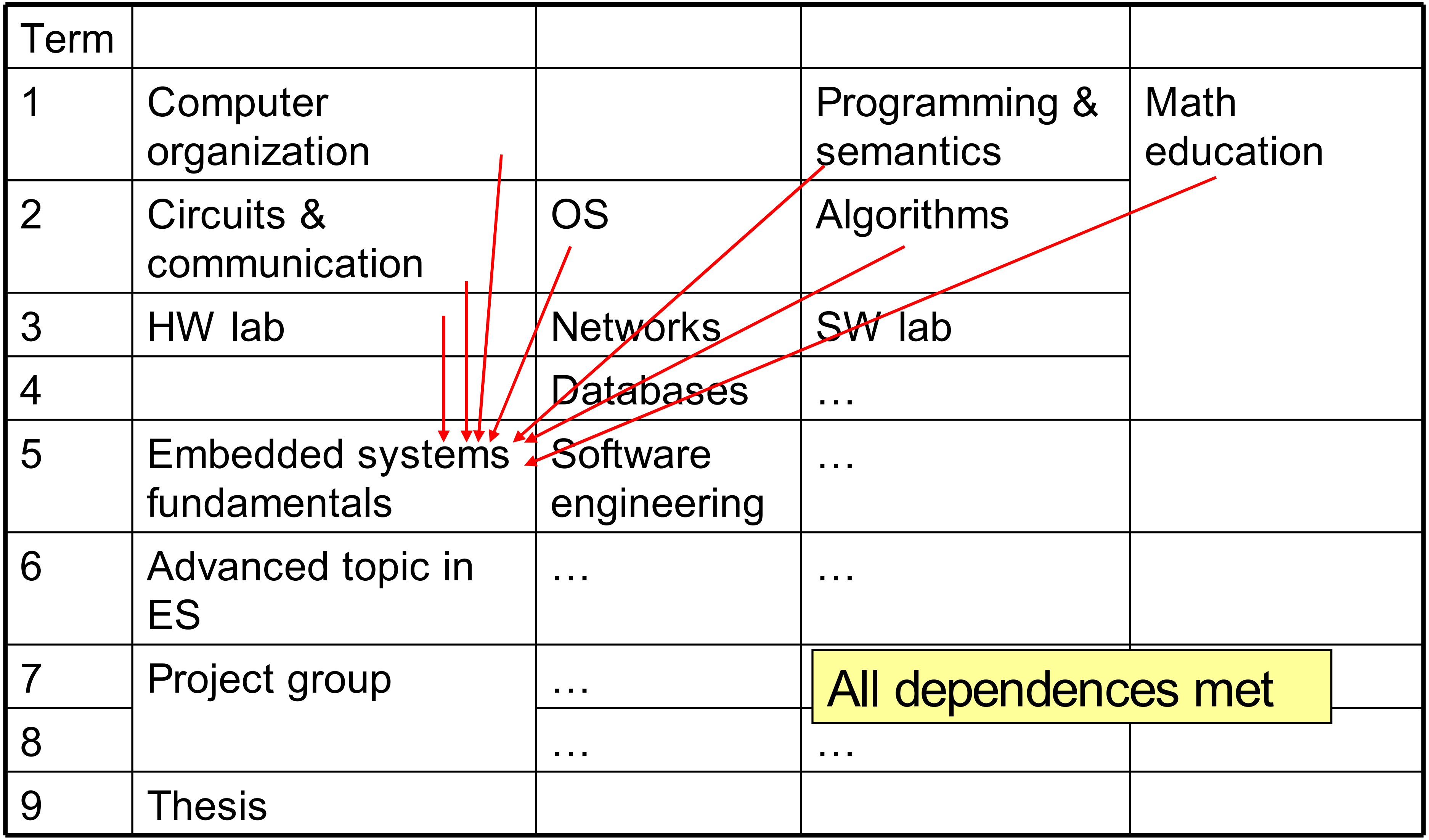
Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

Concept of ES education at Dortmund



- Can typically be taught in 4th or 5th term
- Provides motivation and context of other work in the area
- Mix of students and courses from CS and EE departments

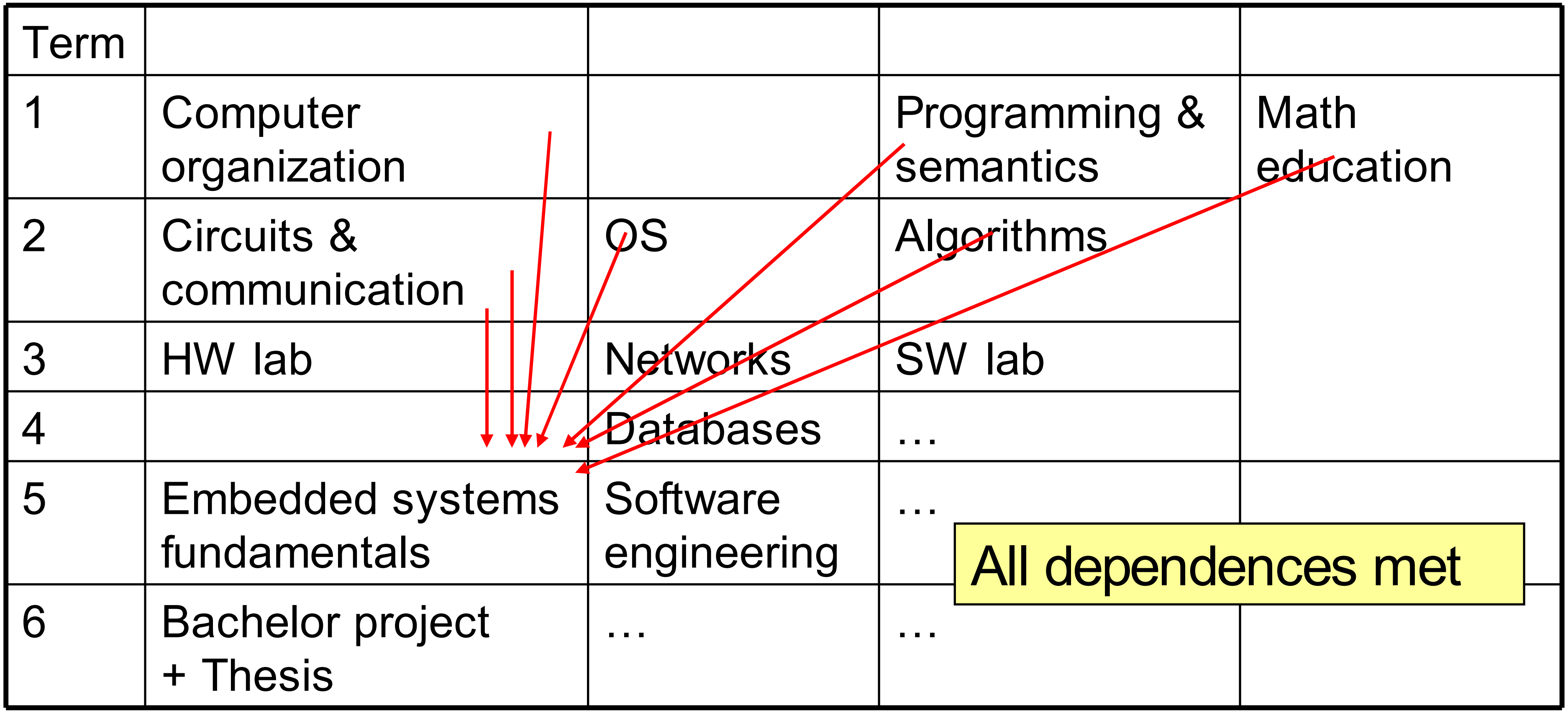
Structure of the CS curriculum at Dortmund
- 4.5 year diploma program -



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

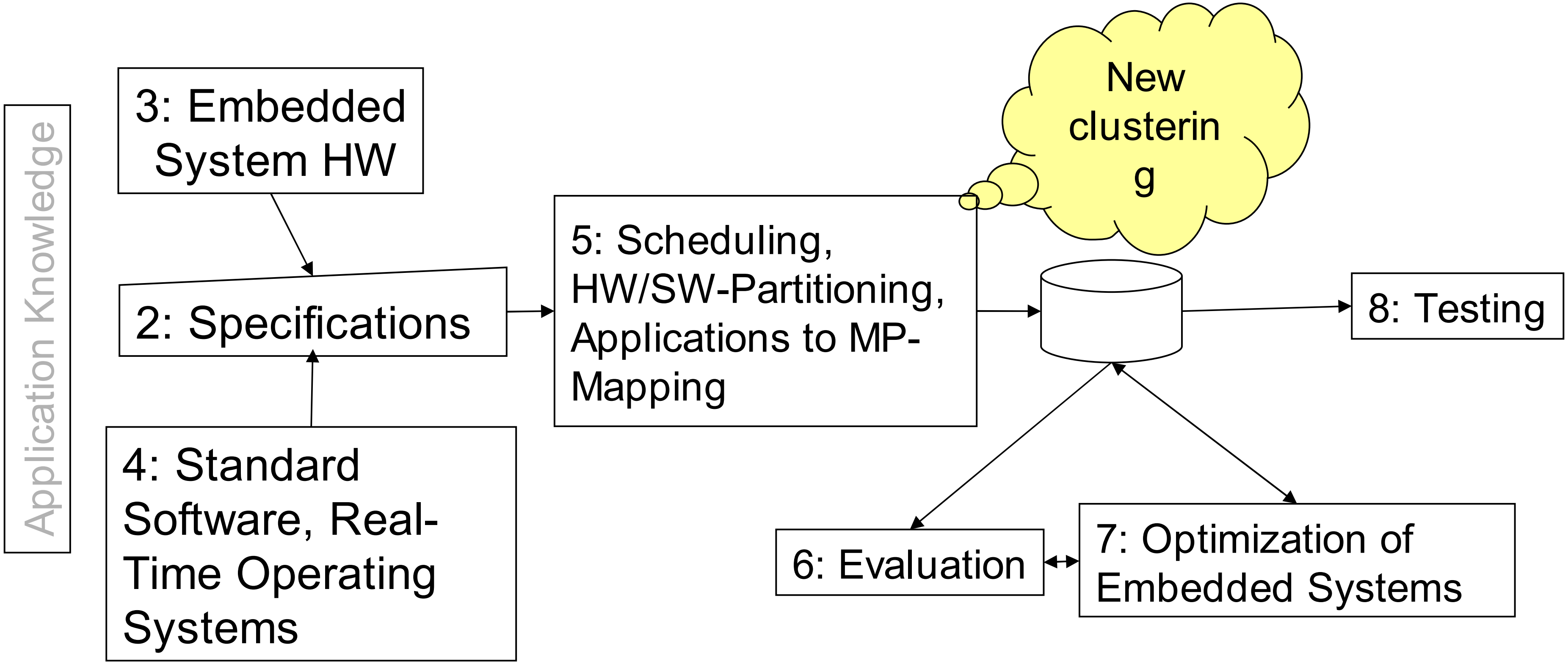
Structure of the CS curriculum at Dortmund
- 3 year bachelor program -



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

Structure of this course


Application Knowledge
3: Embedded System HW
2: Specifications
4: Standard Software, Real-Time Operating Systems
5: Scheduling, HW/SW-Partitioning, Applications to MP-Mapping
New clusterin g
8: Testing
6: Evaluation
7: Optimization of Embedded Systems

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:

- Original hardcover version, Kluwer, 2003, >100 $/€
- Reprint, lighter cover borders
- 2nd edition, soft cover, with corrections, Springer, end of Dec.2005/Jan.2006, 37-39€
- German edition, March 2007, 29 €
- Reprint of the 1st German edition, 2008
- Chinese edition, April 2007, only preface in Chinese, not for sale outside China
- Russian edition (contract)

Slides

- Slides are available at: http://ls12-www.cs.tu-dortmund.de/staff/marwedel/es-book/slides08/index.html
- Master format: Powerpoint;
- Derived format: PDF
-

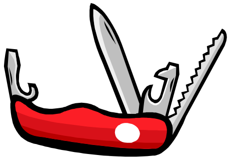
Characteristics

Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

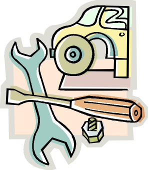
Characteristics of Embedded Systems (1)

- 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.



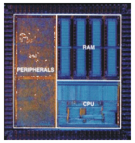
  - **Availability *A*(*t*)**: probability of system working at time *t*
  - **Safety**: no harm to be caused

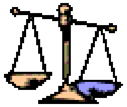
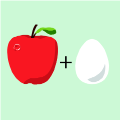
  - **Security**: confidential and authentic communication

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

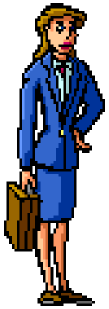
Making the system dependable must not be an after-thought, it must be considered from the very beginning

Characteristics of Embedded Systems (2)

- Must be **efficient**
  - Energy efficient
  - Code-size efficient (especially for systems on a chip) 

  - Run-time efficient
  - Weight efficient 
  - Cost efficient 
- **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)

Characteristics of Embedded Systems (3)

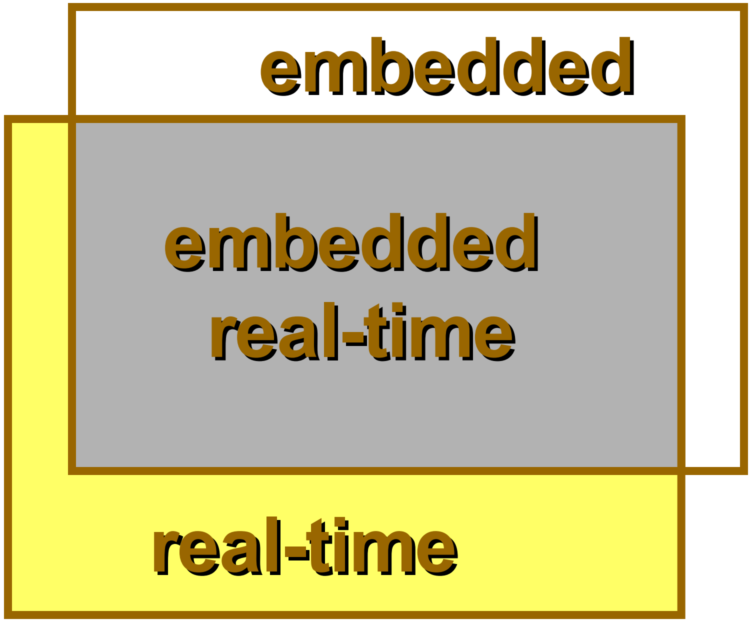


- Many ES must meet **real-time constraints**
  - A real-time system must react to stimuli from the controlled object (or the operator) within the time interval **dictated** by the environment.
  - For real-time systems, right answers arriving too late are wrong.
  - **„A real-time constraint is called 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



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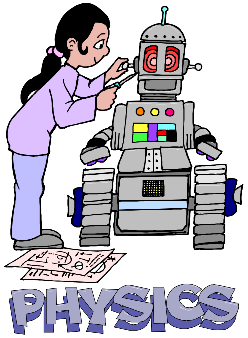
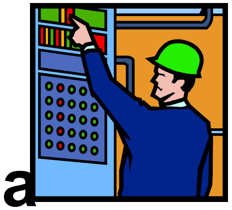
Characteristics of Embedded Systems (4)



- Frequently **connected to physical environment** through sensors and actuators,
- **Hybrid systems** (analog + digital parts).



- 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.

Characteristics of Embedded Systems (5)

- 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.

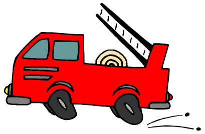
Def.: Information processing systems having most of the above characteristics are called embedded systems.

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

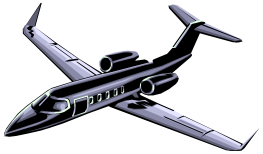
Quite a number of challenges, e.g. dependability

Dependability?

- Non-real time protocols used for real-time applications (e.g. Berlin fire department)



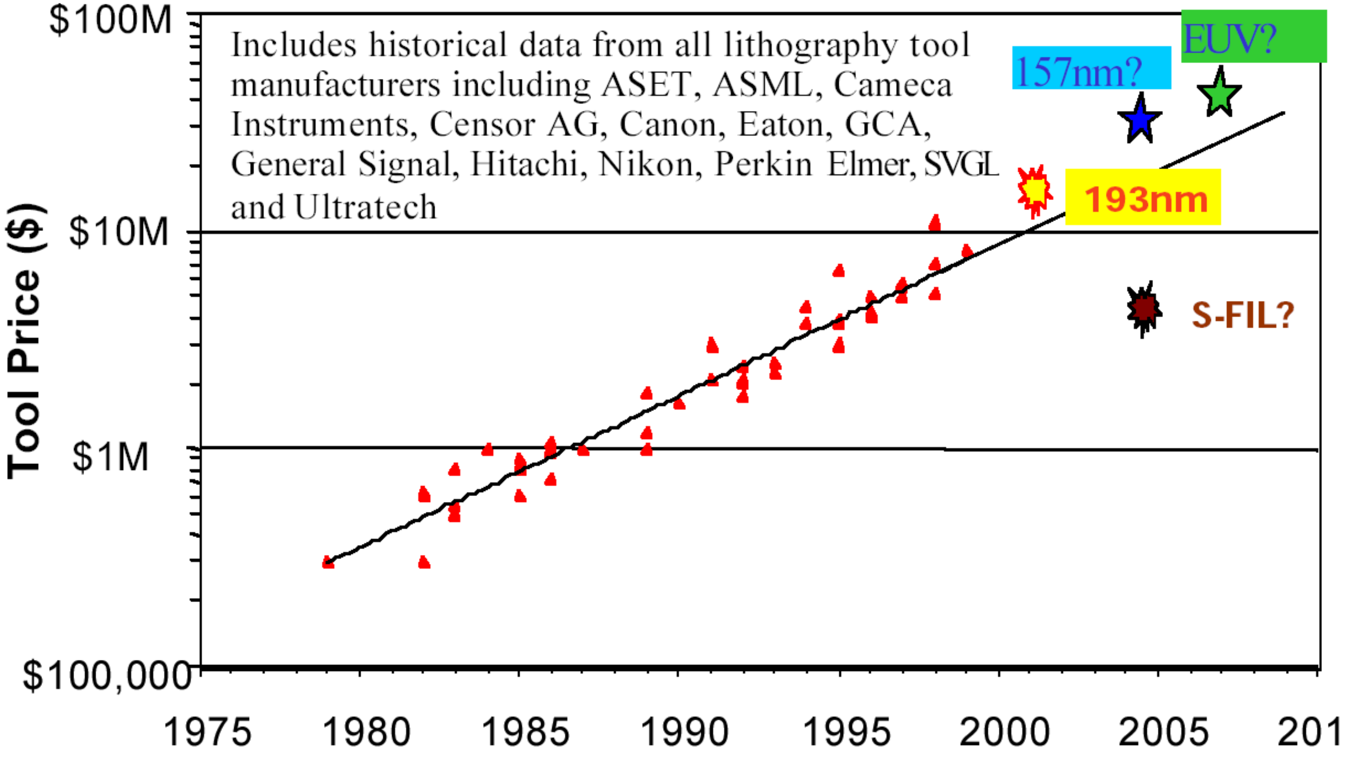
- Over-simplification of models (e.g. aircraft anti-collision system)



- Using unsafe systems for safety-critical missions (e.g. voice control system in Los Angeles; ~ 800 planes without voice connection to tower for > 3 hrs

Challenges for implementation in hardware

- Lack of flexibility (changing standards).
- Mask cost for specialized HW becomes very expensive



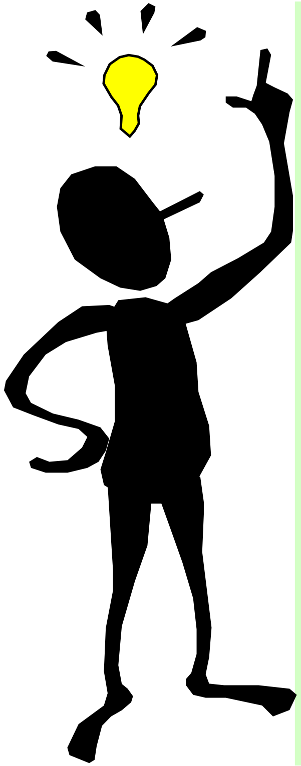
☞Trend towards implementation in Software

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

Importance of Embedded Software and Embedded Processors

"... the New York Times has estimated that the average American comes into contact with about 60 micro-processors every day...." [Camposano, 1996]

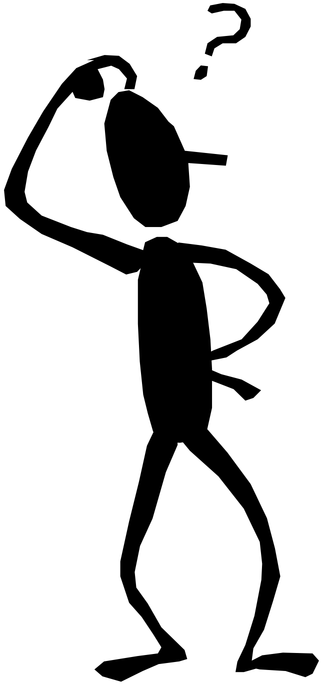
Latest top-level BMWs contain over 100 micro-processors
[Personal communication]



Most of the functionality will be implemented in software

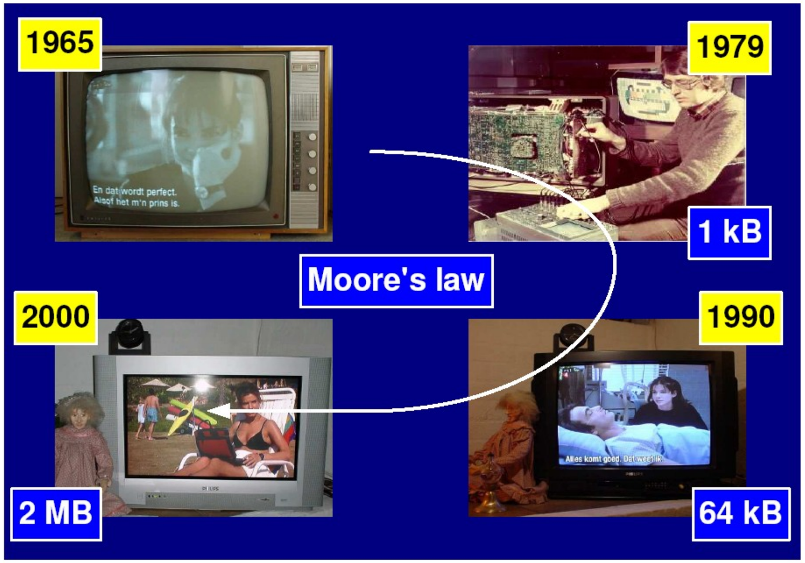
Challenges for implementation in software

If embedded systems will be implemented mostly in software, then why don‘t we just use what software engineers have come up with?

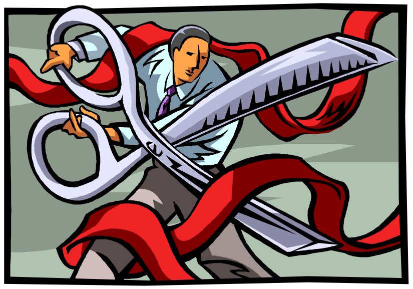


Software complexity is a challenge

- Exponential increase in software complexity
- In some areas code size is doubling every 9 months [ST Microelectronics, Medea Workshop, Fall 2003]
- *... > 70% of the development cost for complex systems such as automotive electronics and communication systems are due to software development*
  [A. Sangiovanni-Vincentelli, 1999]

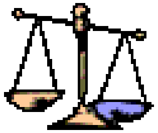


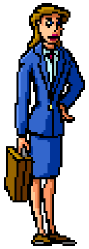
Rob van Ommering, COPA Tutorial, as cited by: Gerrit Müller: Opportunities and challenges in embedded systems, Eindhoven Embedded Systems Institute, 2004



Challenges for Embedded Software

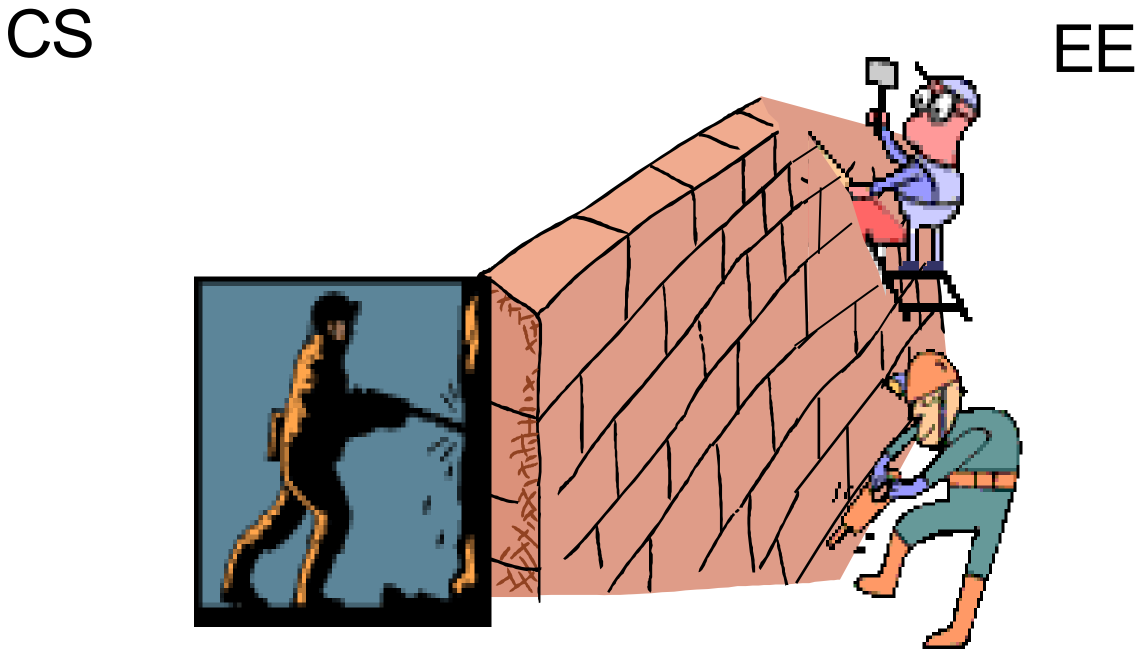
- Dynamic environments
- Capture the required behaviour!
- Validate specifications
- Efficient translation of specifications into implementations!
- How can we check that we meet real-time constraints?
- How do we validate embedded real-time software? (large volumes of data, testing may be safety-critical)





It is not sufficient to consider ES just as a special case of software engineering

EE knowledge must be available, Walls between EE and CS must be torn down



Summary

- Growing importance of embedded systems
- Definition of embedded systems
- Application areas
- Examples
- Curriculum
- Characteristics
  - Reliability
- Challenges in embedded system design