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Embedded System Design:

Embedded Systems Foundations of Cyber-Physical Systems

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2012年 10 月 16 日

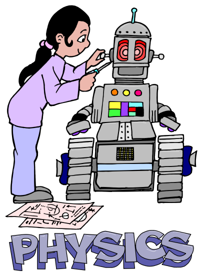
Motivation for course (1)

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 System technologies*
- Communication technologies

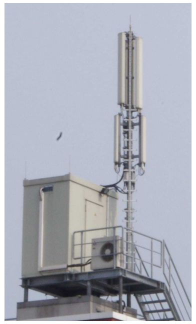


Motivation for Course (2)

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


"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. ...

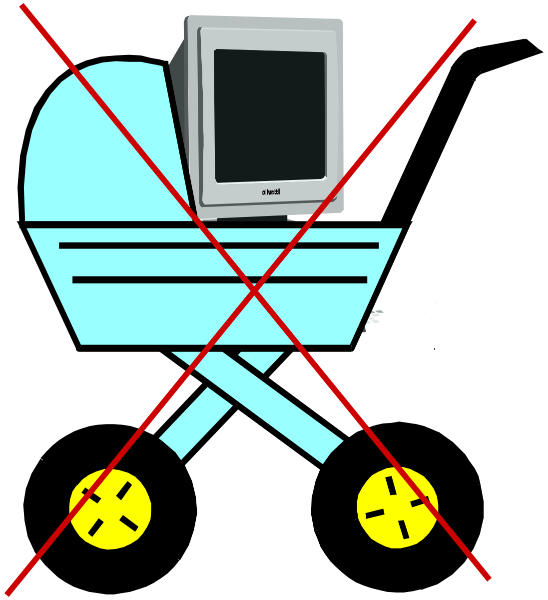


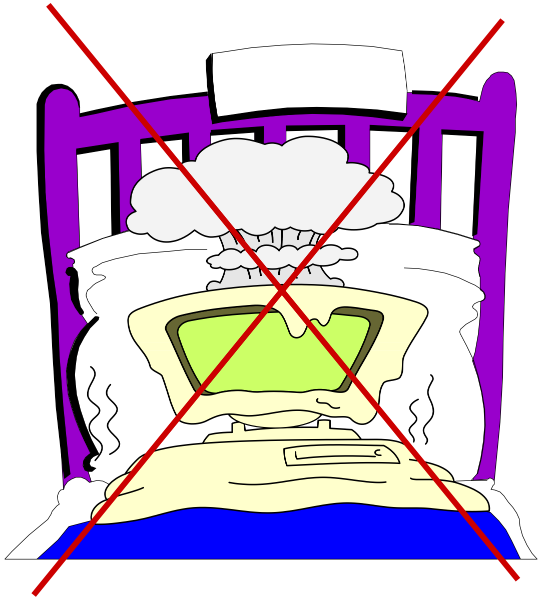

The use … throughout society could well dwarf previous milestones in the information revolution."

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

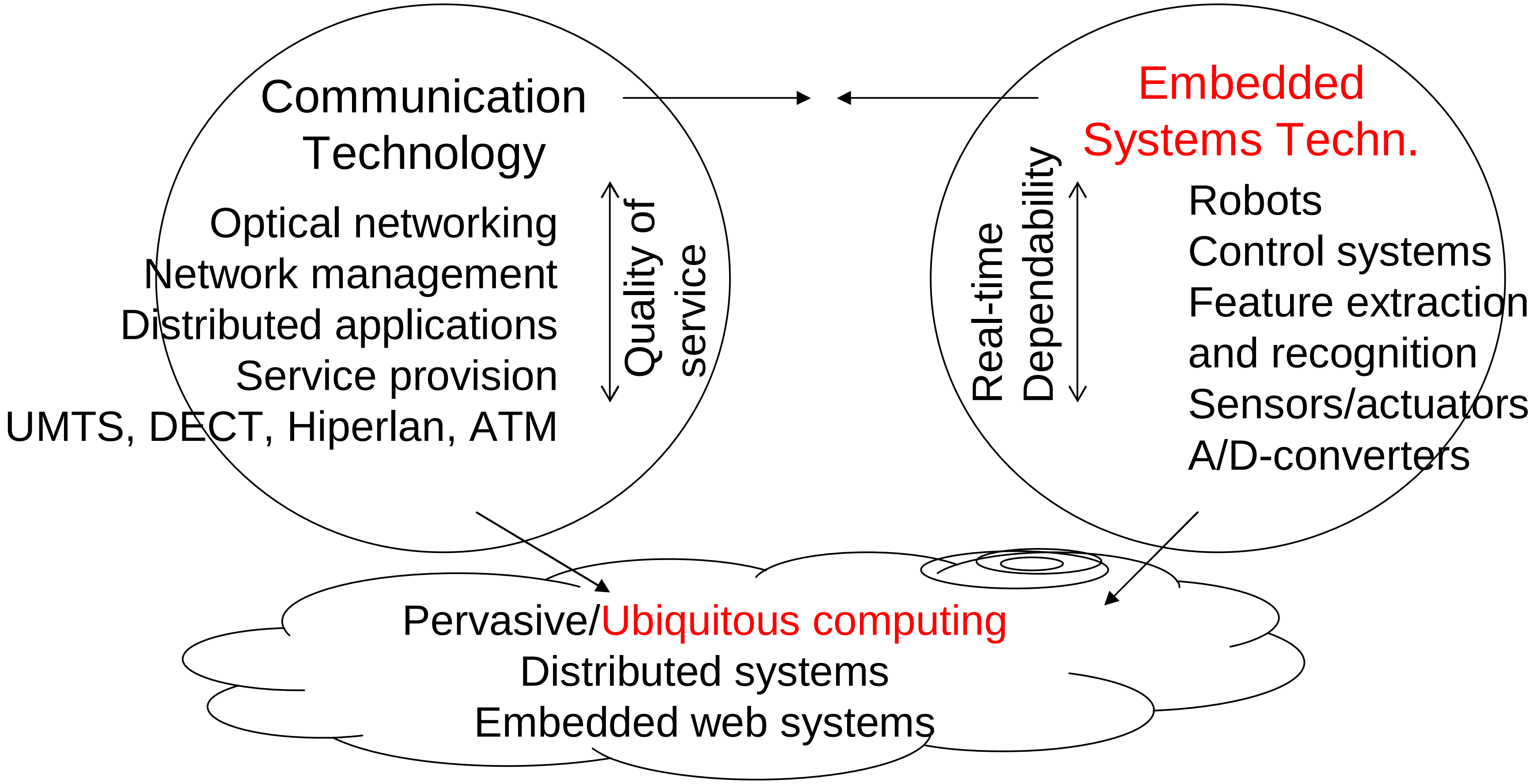
Berkeley: [Edward A. Lee]*:*
Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.

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

Cyber-physical system (CPS) =
Embedded System (ES) + *physical environment*

Extending the motivation: Embedded systems and ubiquitous computing

Ubiquitous computing: Information anytime, any-where. Embedded systems provide fundamental technology.



Growing importance of cyber-physical/ embedded systems

- *49.7% of Americans own smartphones*
  [www.itfacts.biz, March 31, 2012]
- *…, 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]
- Funding in the 7th European Framework
- Creation of the ARTEMIS Joint Undertaking in Europe
- Funding of CPS research in the US
- Joint education effort of Taiwanese Universities
- ….

Growing importance of cyber-physical & 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]
- Foundation for the "post PC era"
- CPS & ES hardly discussed in other courses
- CPS & ES important for TU Dortmund
- CPS & ES important for many industries
- Scope: sets context for specialized courses

Importance of education

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Application areas and examples

Application area Automotive electronics: clearly cyber-physical

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
- Multiple networked processors

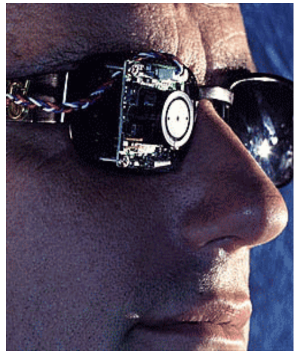
Application area avionics: also cyber-physical

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

Dependability is of outmost importance.

Medical systems: cyber-physical

- 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]

Forestry machines: cyber-physical

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"

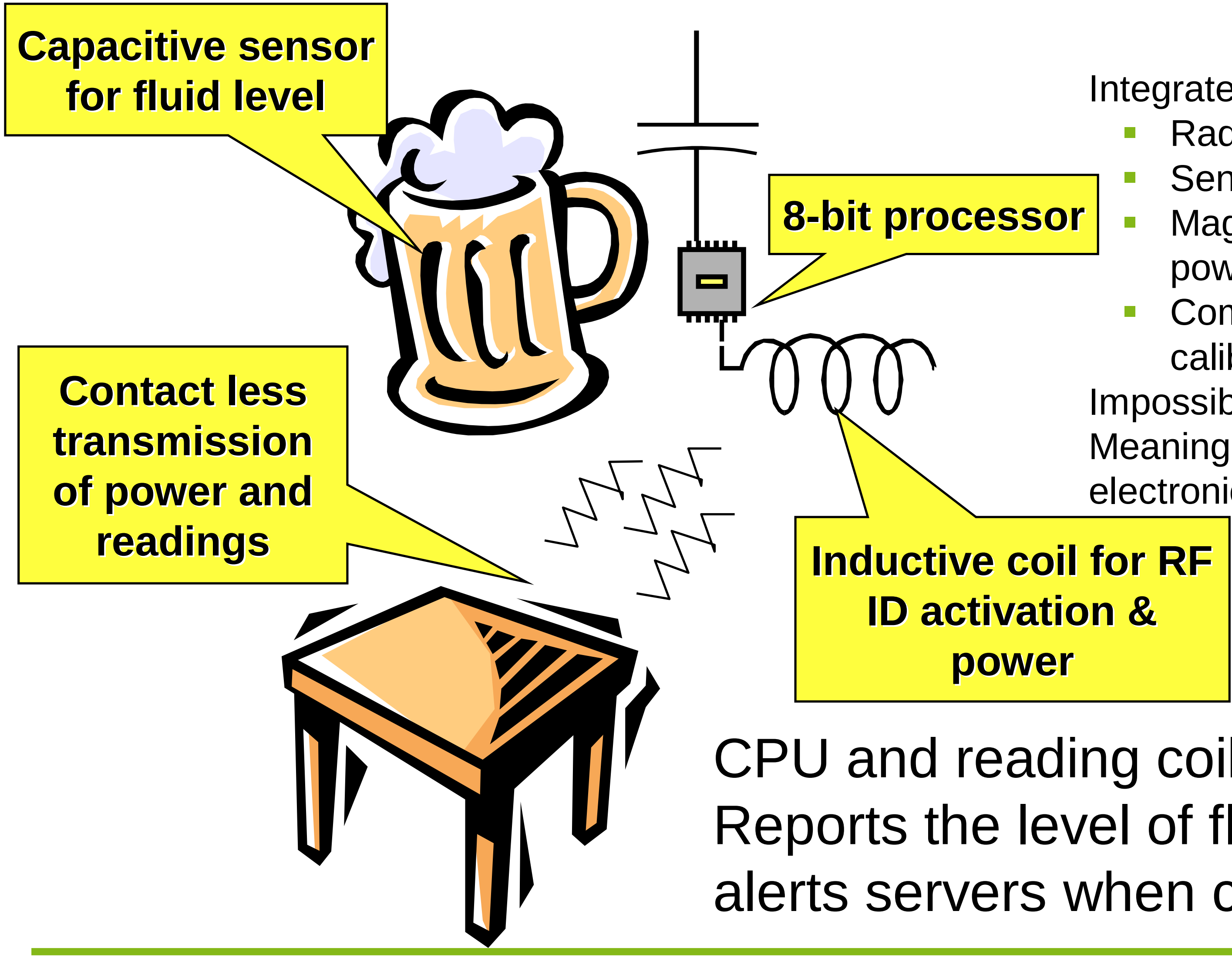
Logistics

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

Smart Beer Glass



Integrates several technologies:

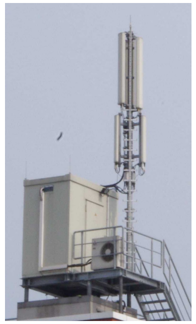
- Radio transmissions
- Sensor technology
- Magnetic inductance for power
- Computer used for calibration

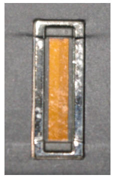
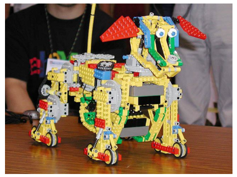
Impossible without the computer
Meaningless without the electronics

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

More application areas

- Railways
- Telecommunication
- Consumer electronics
- Robotics
- Public safety
- Smart homes
- Military systems

Mostly cyber-physical

Educational concept

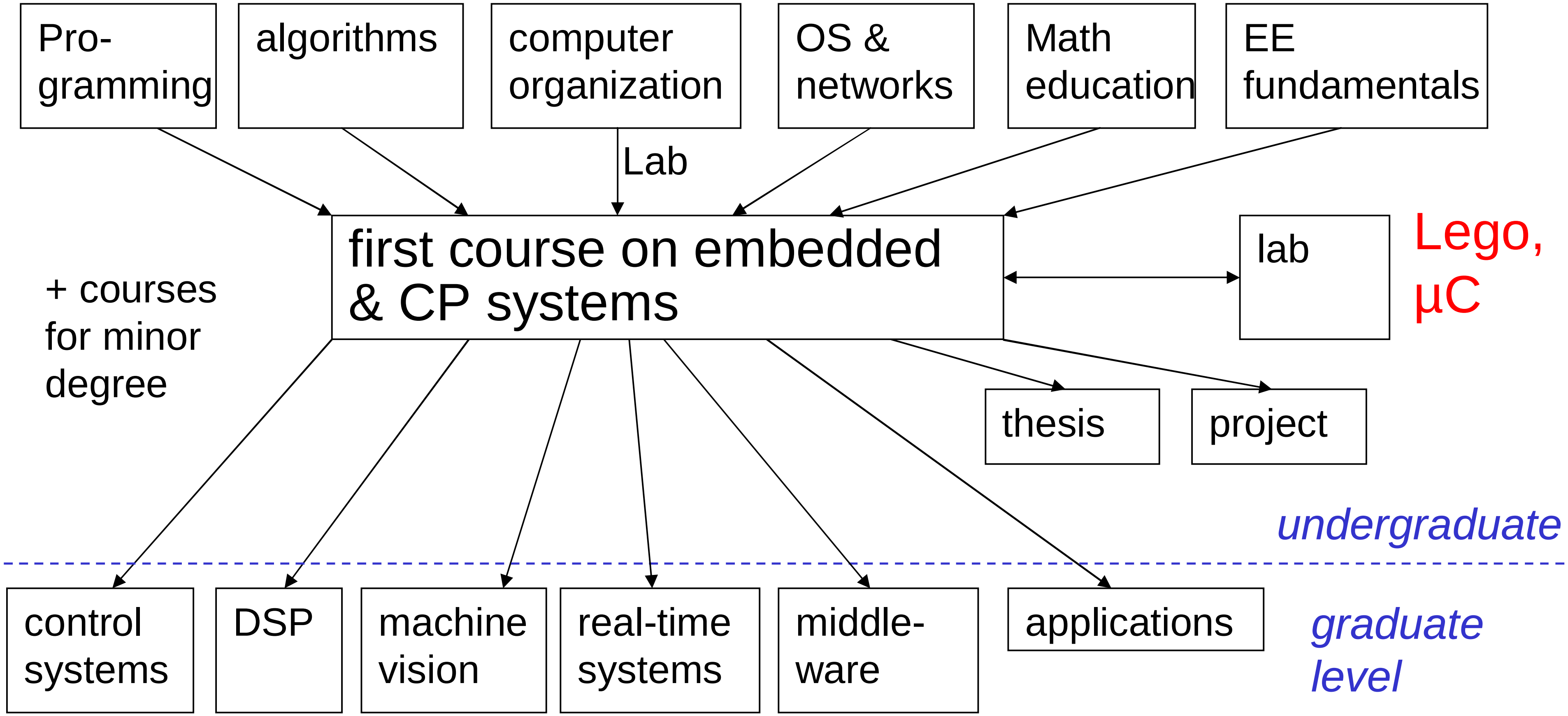
Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

Broad set of topics

1. Introduction
2. Specification and modeling
3. CPS/ES hardware
4. CPS/ES system software
5. Evaluation
6. Mapping of applications to execution platforms
7. Optimizations
8. Test

Concept of CPS & 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

Scope avoids problems with narrow perspectives reported by ARTIST

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

"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."

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."

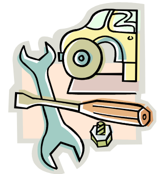
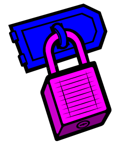
$$\int P\, dt$$

"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."

Common characteristics

Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

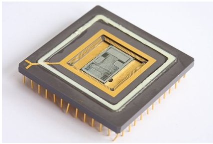
Dependability

- CPS/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

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



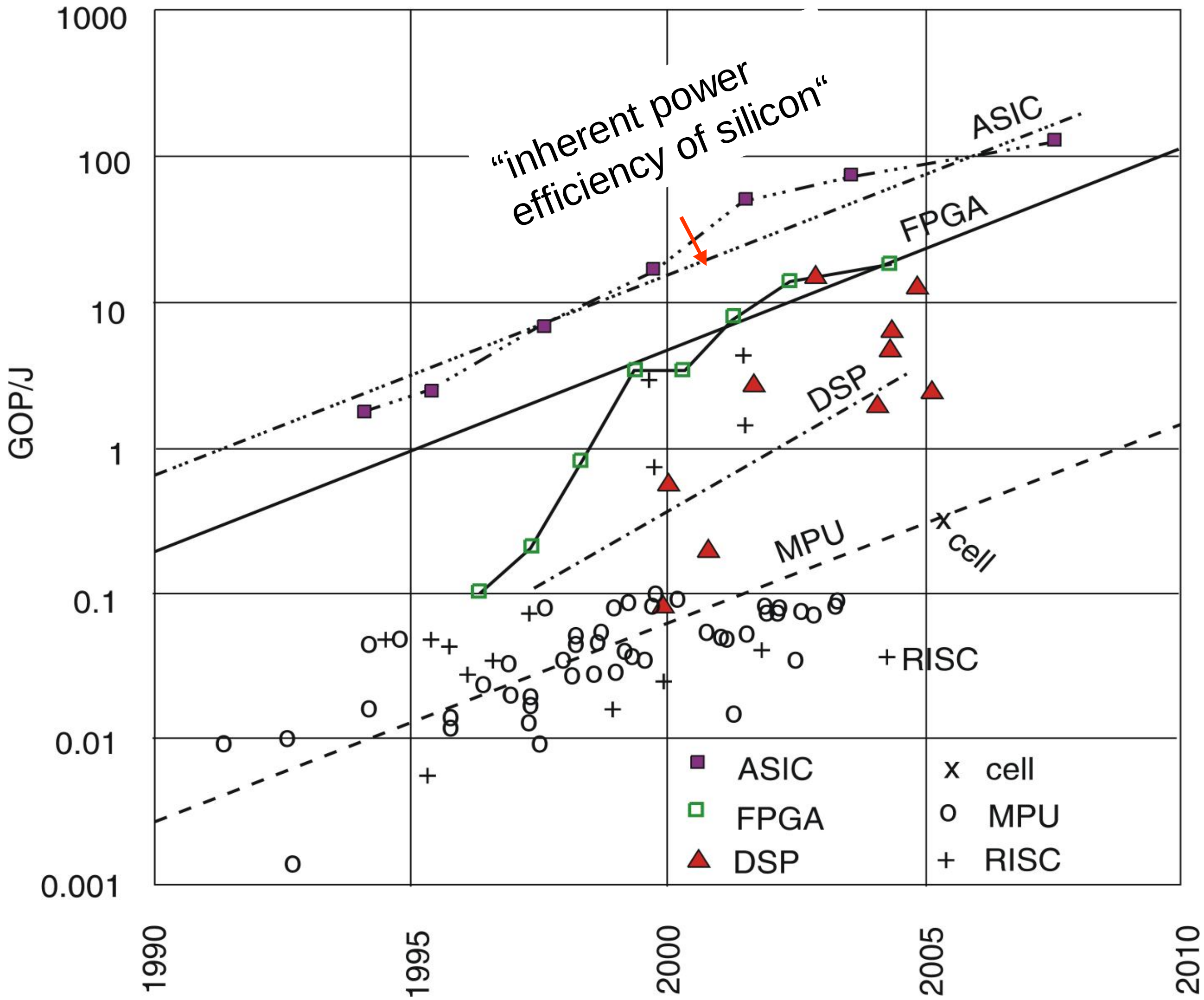
  - Run-time efficient

  - Weight efficient

  - Cost efficient

  - Energy efficient

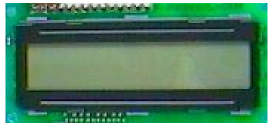
Importance of Energy Efficiency

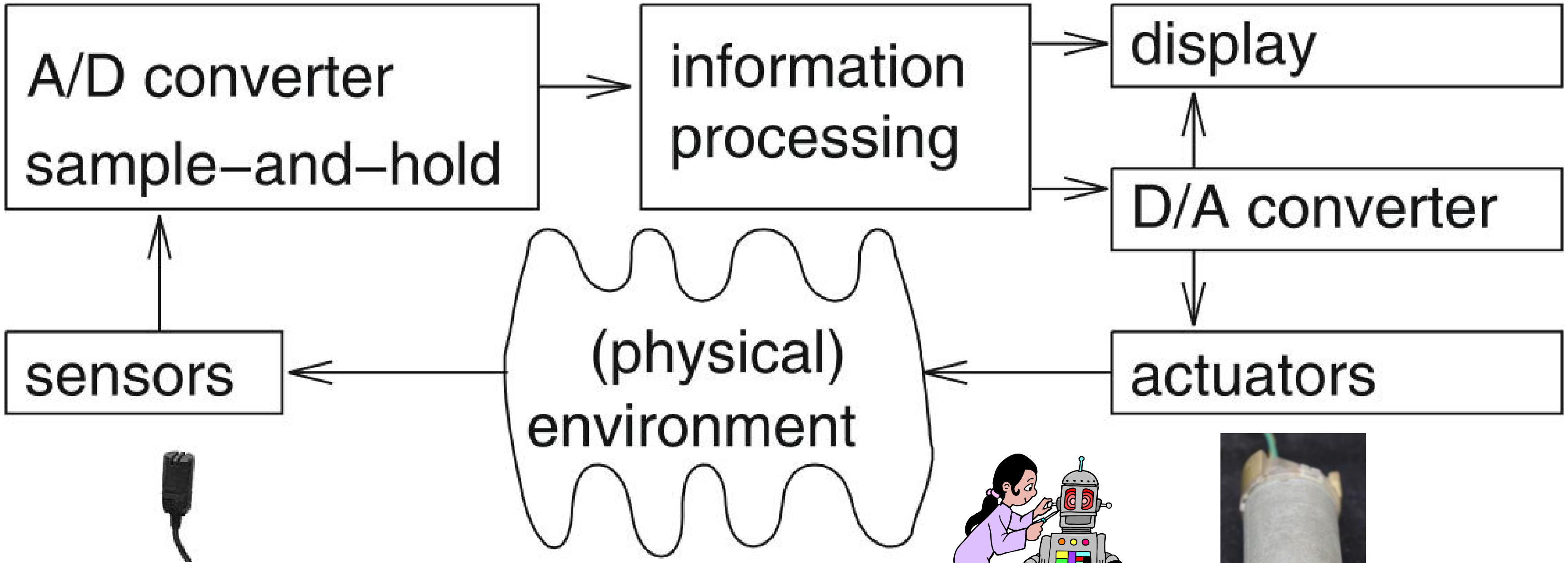


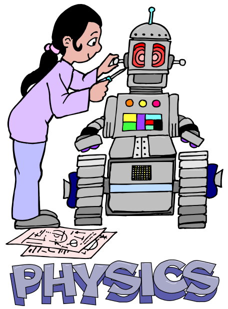
Efficient software design needed, otherwise, the price for software flexibility cannot be paid.

CPS & ES Hardware

CPS & ES hardware is frequently used in a loop ("***hardware in a loop***"):



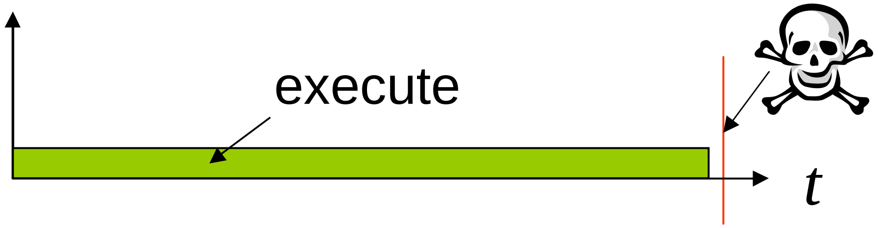


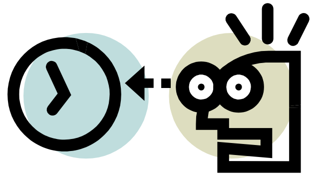


Cyber-physical systems (!)

Real-time constraints

- CPS 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.





- **"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 [Kopetz, 1997].

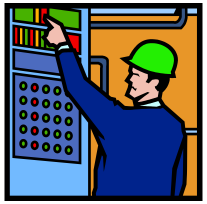
Real-Time Systems & CPS

CPS, ES and Real-Time Systems synonymous?

- For some embedded systems, real-time behavior is less important (smart phones)
- For CPS, real-time behavior is essential, hence RTS $\cong$ CPS
- CPS models also include a model of the physical system

Reactive & hybrid systems

- Typically, CPS 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)
- Situation is slowly changing here: systems become less dedicated

Underrepresented in teaching

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

Not every CPS & 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 foundations of CPS makes sense because of the number of common characteristics.

Textbook(s)

Several editions/translations:

- 1st edition
  - English
    - Original hardcover version
    - Reprint, soft cover, 2006
  - German, 2007
  - Chinese, 2006
  - Macedonian, 2010
- 2nd edition, with CPS
  - English, Dec. 2010/Jan. 2011
  - Contracts for German and (translated) Chinese edition

Slides

- Slides are available at:
  - http://ls12-www.cs.tu-dortmund.de/~marwedel/es-book
    Click in Embedded Systems text book
- Master format: Powerpoint (XP);
- Derived format: PDF

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
- Common characteristics