technische universität
dortmund

fakultät für informatik
informatik 12

Embedded System Design:
Embedded Systems Foundations of Cyber-Physical Systems

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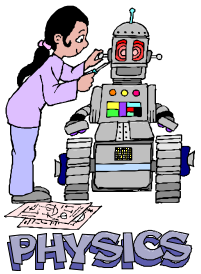
Motivation for course (1)

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. …..

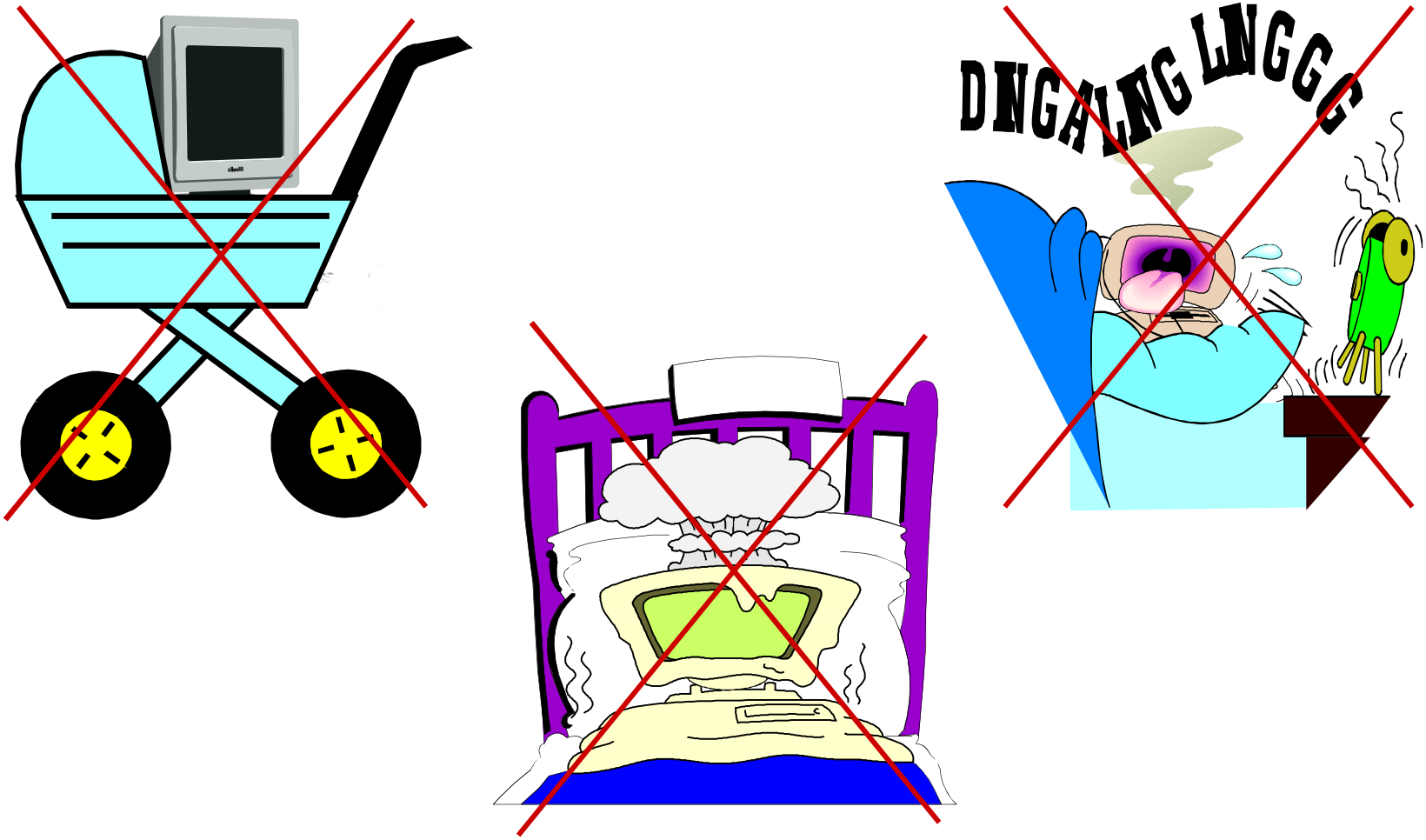
networked systems of embedded computers ... have the potential to change radically the way people interact with their environment by linking together a range of devices and sensors that will allow information to be collected, shared, and processed in unprecedented ways. ...

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

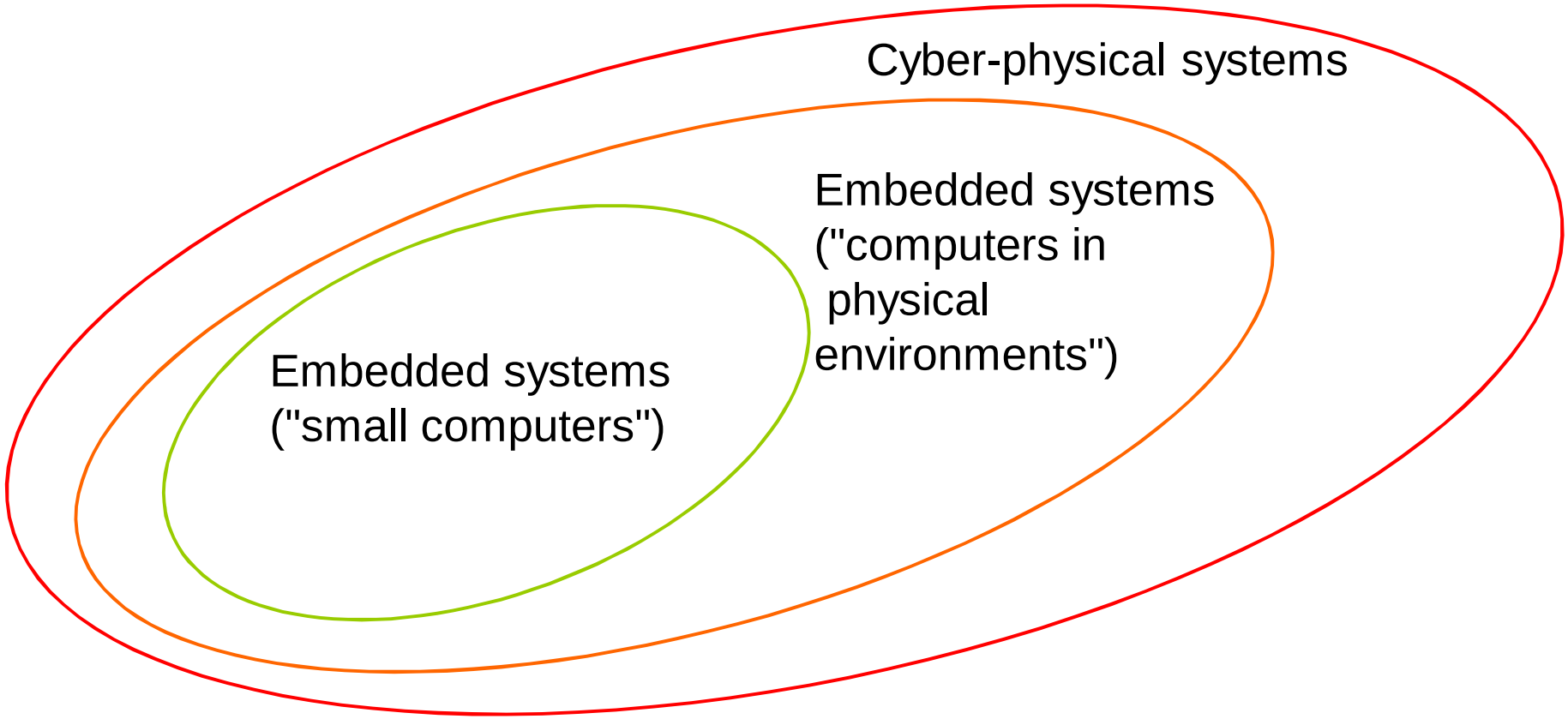
Berkeley: [Edward A. Lee]*:*
Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.

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*

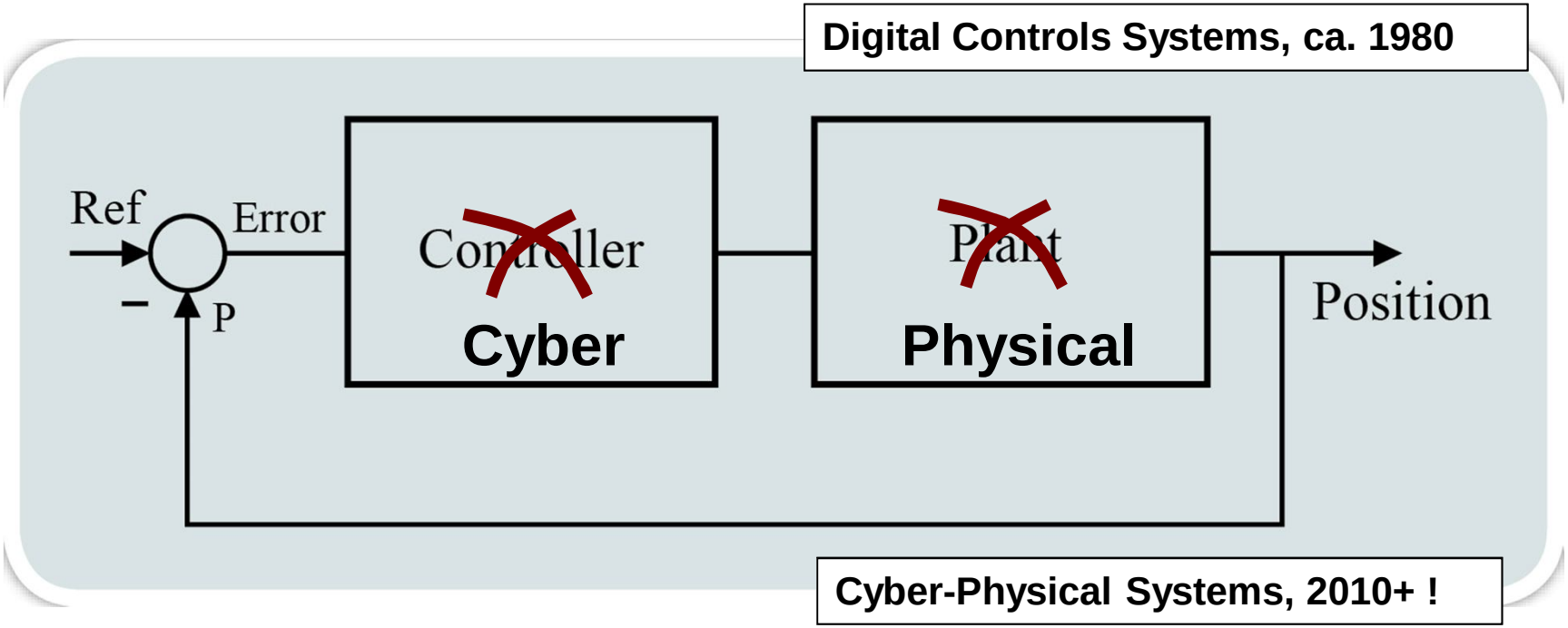
Cyber-physical systems and embedded systems

CPS = ES + physical environment



What is a *Cyber-Physical System*?

Extreme view:



Definition according to National Science Foundation (US)

Cyber-physical systems (CPS) are engineered systems that are built from and depend upon the ***synergy of computational and physical components.***

Emerging CPS will be ***coordinated, distributed****, and* ***connected****, and must be* ***robust*** *and* ***responsive****.*

The CPS of tomorrow will need to far exceed the systems of today in capability, adaptability, resiliency, safety, security, and usability.

Examples of the many CPS application areas include the ***smart electric grid, smart transportation, smart buildings, smart medical technologies, next-generation air traffic management, and advanced manufacturing****.*

CPS: Integration of Cyber and Physics

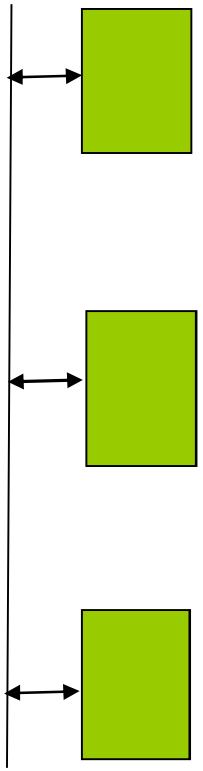
Cyber

Physics

CPS

Definition according to akatech

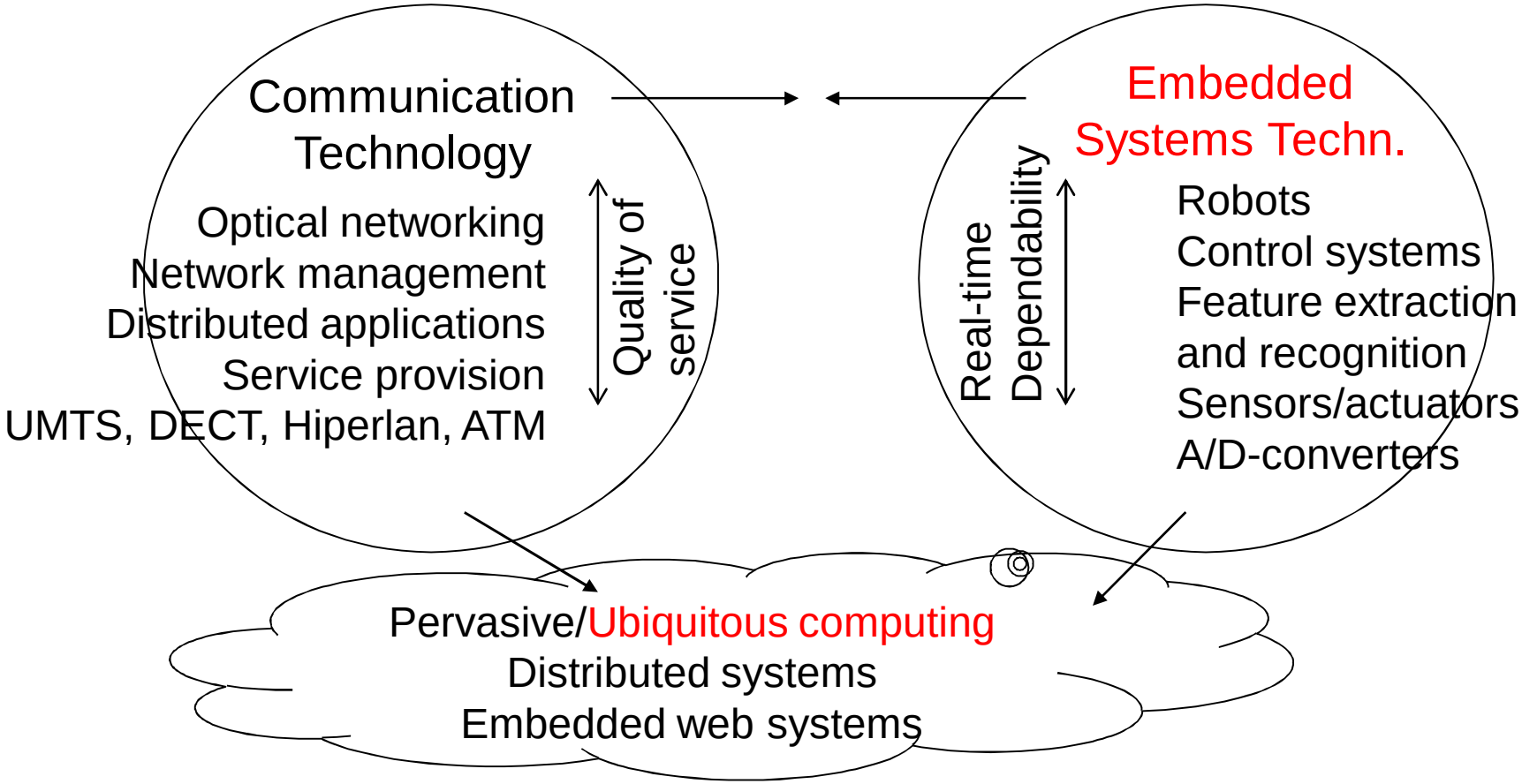
The physical world and the virtual world – or cyber-space – are merging; cyber-physical systems are developing. Future cyber-physical systems will contribute to security, efficiency, comfort and health systems as never before, and as a result, they will contribute to solving key challenges of our society, such as the aging population, limited resources, mobility, or energy transition.



[Akatech: Cyber-Physical Systems. Driving force for innovation in mobility, health, energy and production, http://www.acatech.de/de/publikationen/stellungnahmen/kooperationen/detail/artikel/cyber-physical-systems-innovationsmotor-fuer-mobilitaet-gesundheit-energie-und-produktion.html]

Extending the motivation: Embedded systems and ubiquitous computing

Ubiquitous computing: Information anytime, anywhere. 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

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,
- …

© P. Marwedel, 2011

Dependability is of outmost importance.

More application areas:

- railroad

- water ways

Dependability is of outmost importance.

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

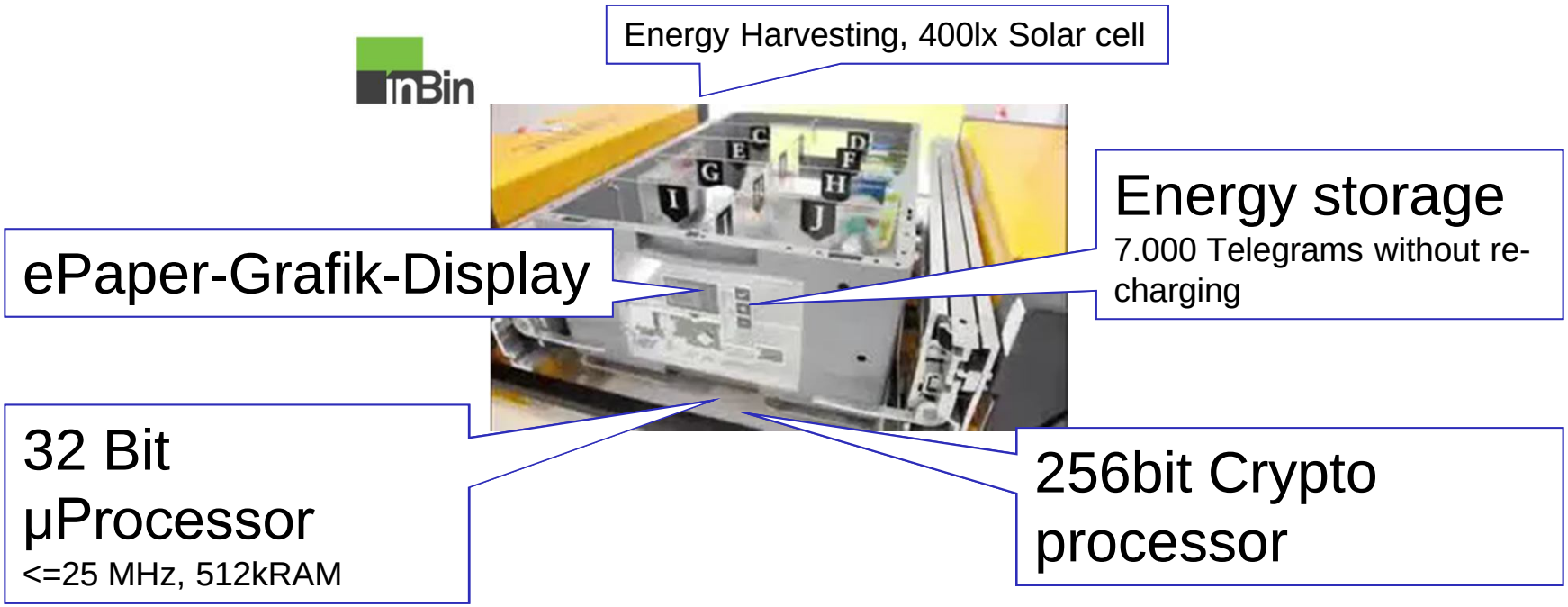
Applications of embedded/cyber-physical system

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

Internet of Things

Internet of things and services



Innovationspartner:
Würth Industrie Services GmbH
Debrunner Koenig Management AG

Fabrication

Production resources are self-configuring and distributed *social machines*

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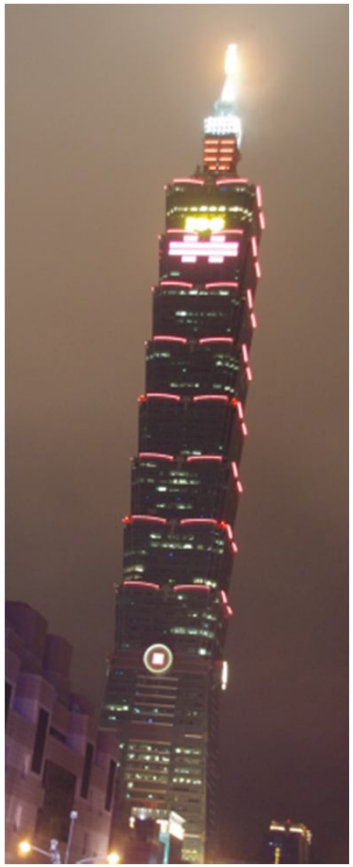
Structural safety

Sensors + data analysis

Möhne lake dam

Kilauea, Hawaii

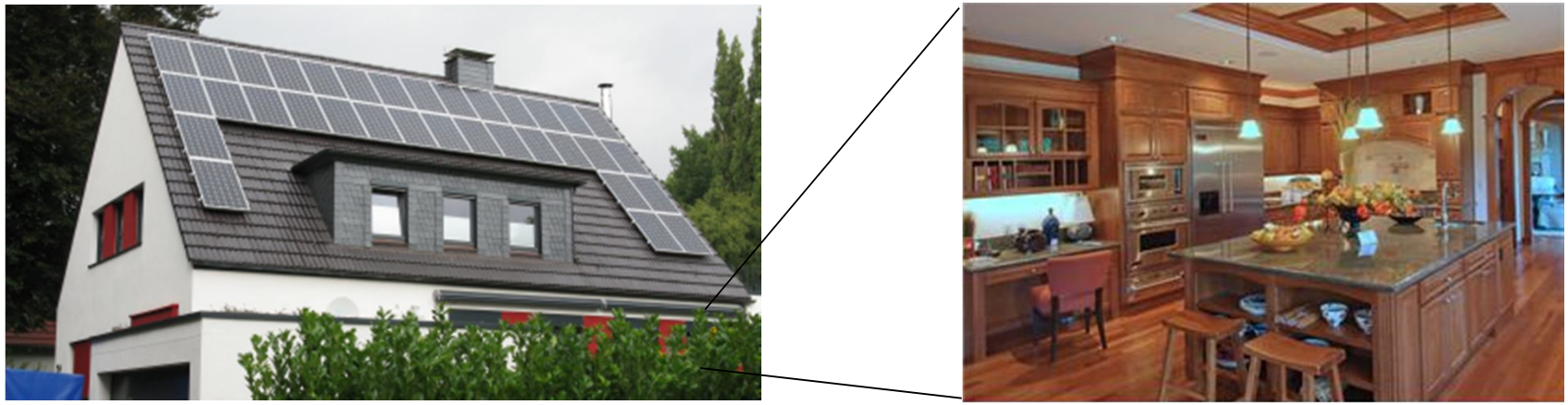
Bridge at Vancouver



Taipeh 101

Smart Home

- Zero energy building, generates as much energy as it consumes
- Provides safety and security
- Supports owners
- Provides maximum comfort
- ambient assisted living



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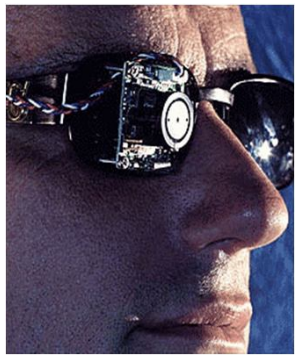
Medical systems: cyber-physical

- 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]

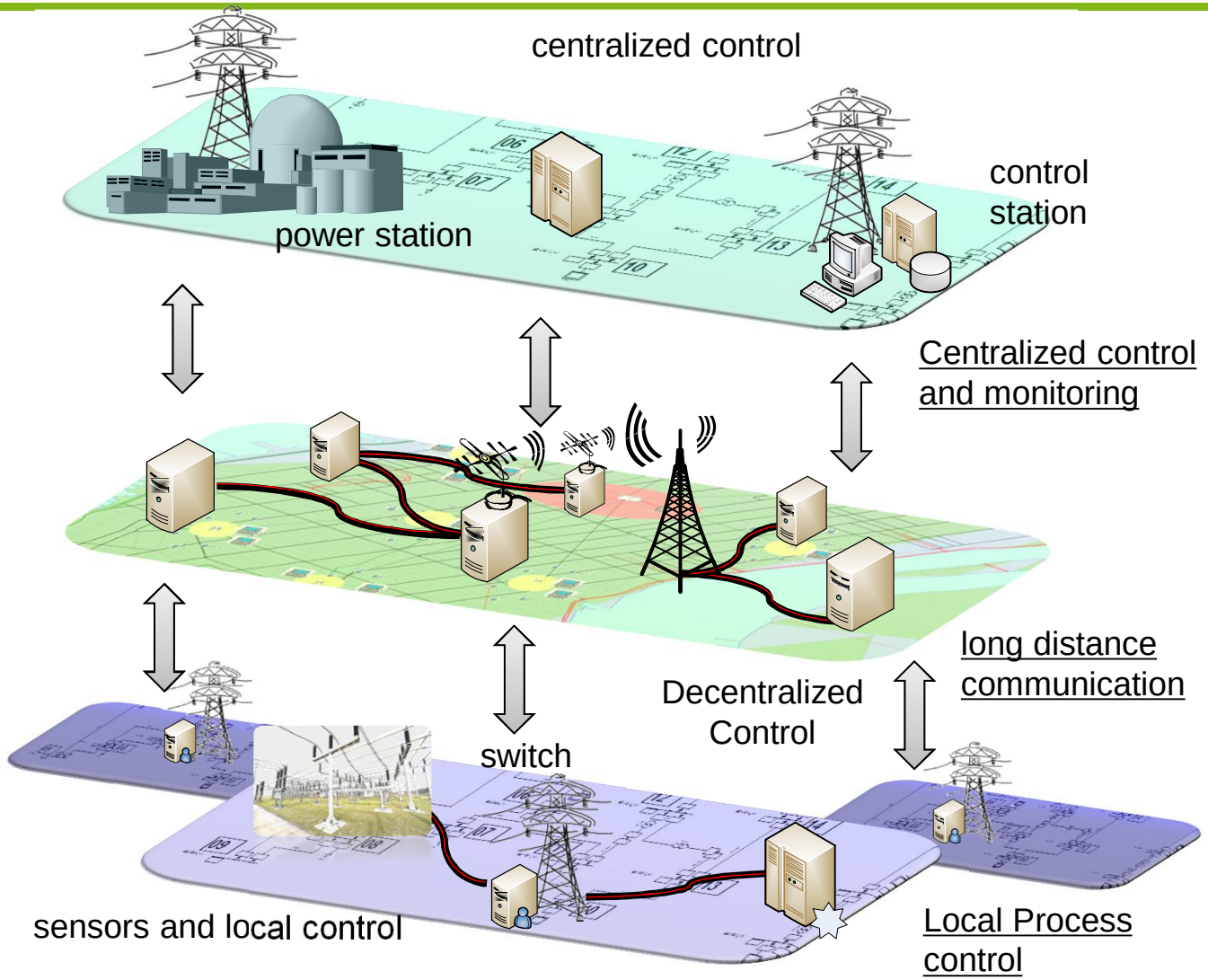


- Translation into sound; claiming much better resolution. [http://www.seeingwithsound.com/etumble.htm]

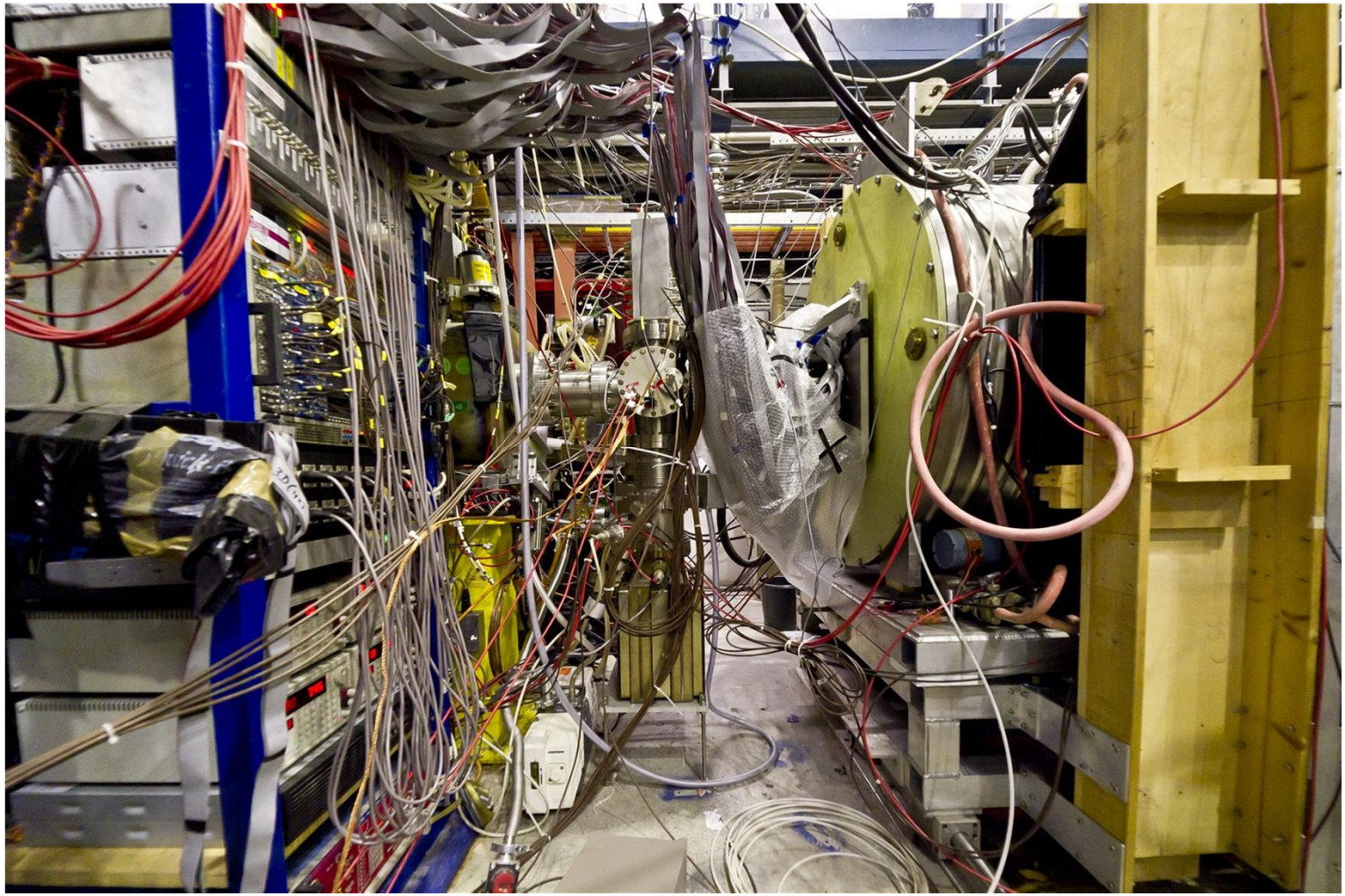
Smart Medicine

- Diagnosis
- Support of therapy
- evaluation
- risk analysis
- Information about patients

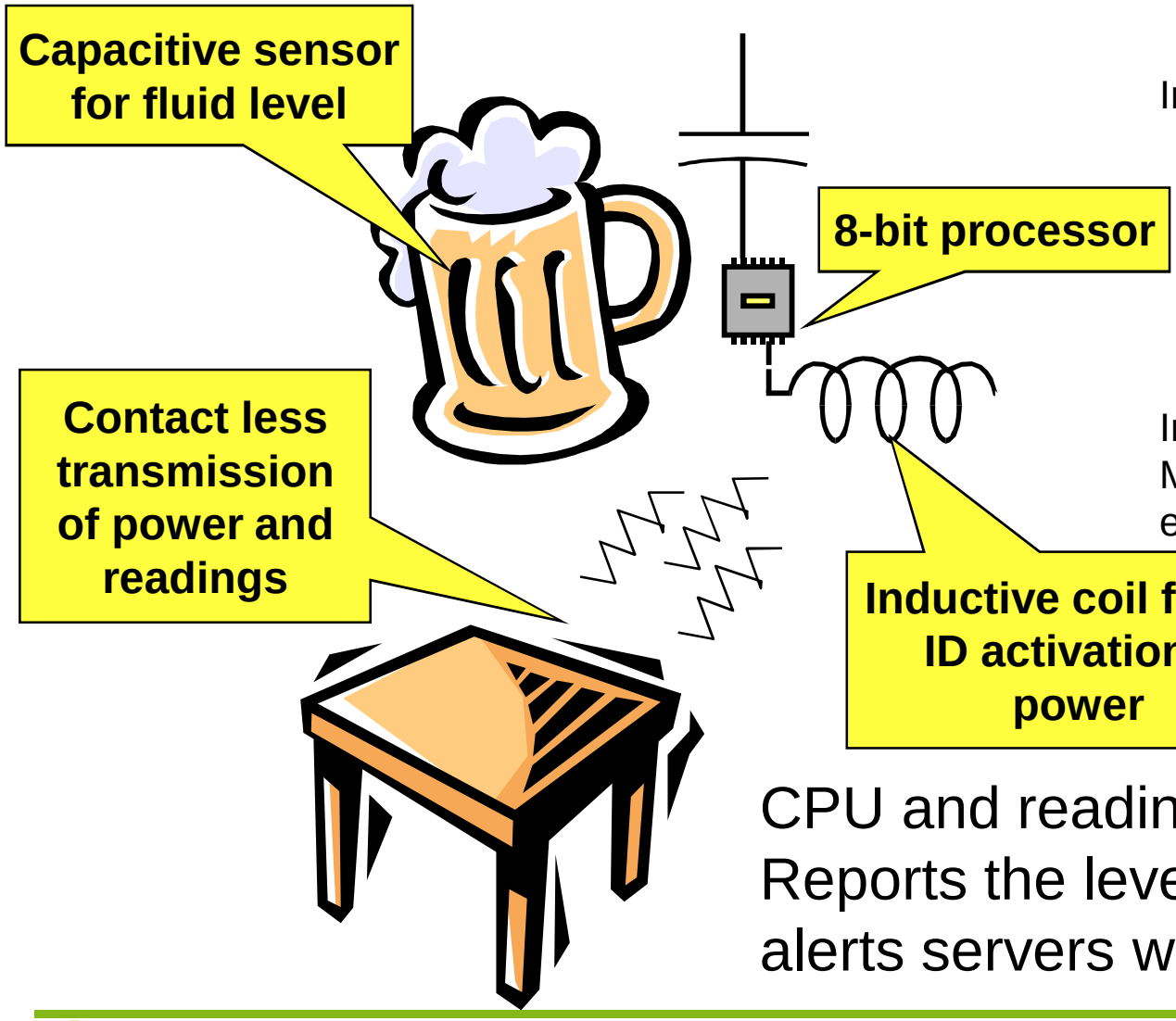
Smart Grid


centralized control
power station
control station
Centralized control and monitoring
Decentralized Control
long distance communication
switch
sensors and local control
Local Process control

Integration of Physics and Cyber in Physical Experiments



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

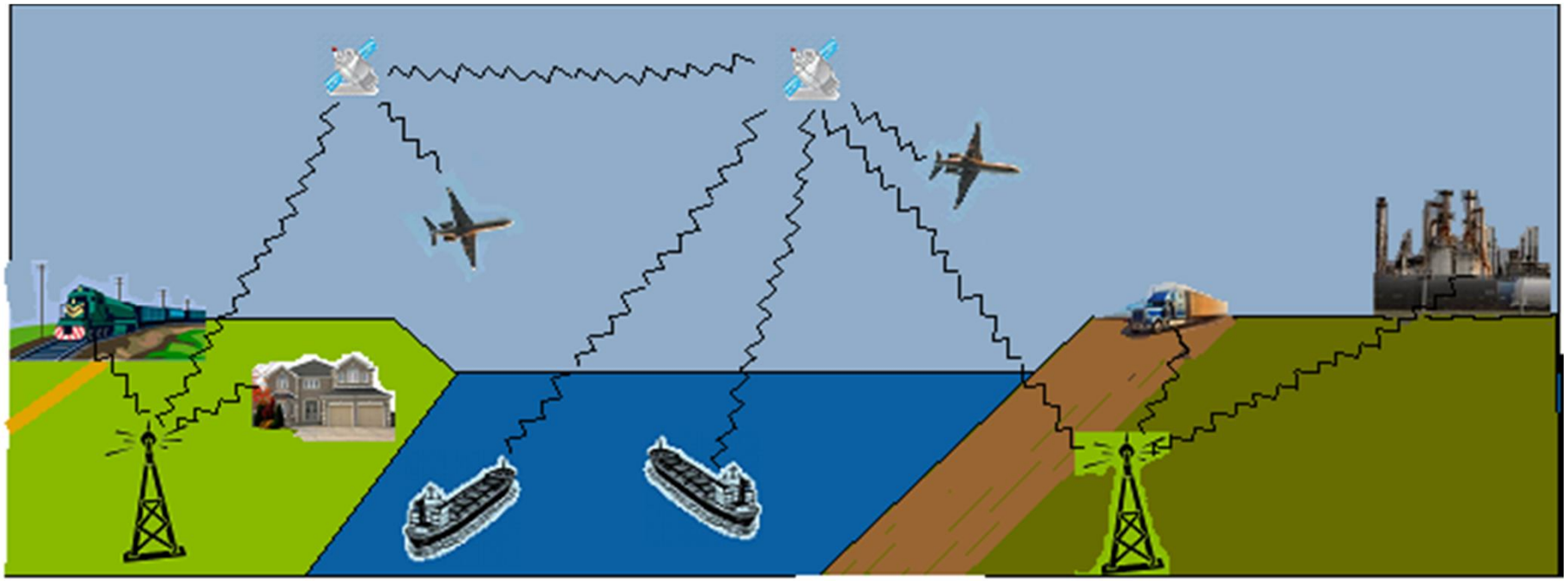
- Telecommunication
- Consumer electronics
- Robotics
- Public safety
- Military systems






Mostly cyber-physical

Connecting previously isolated systems



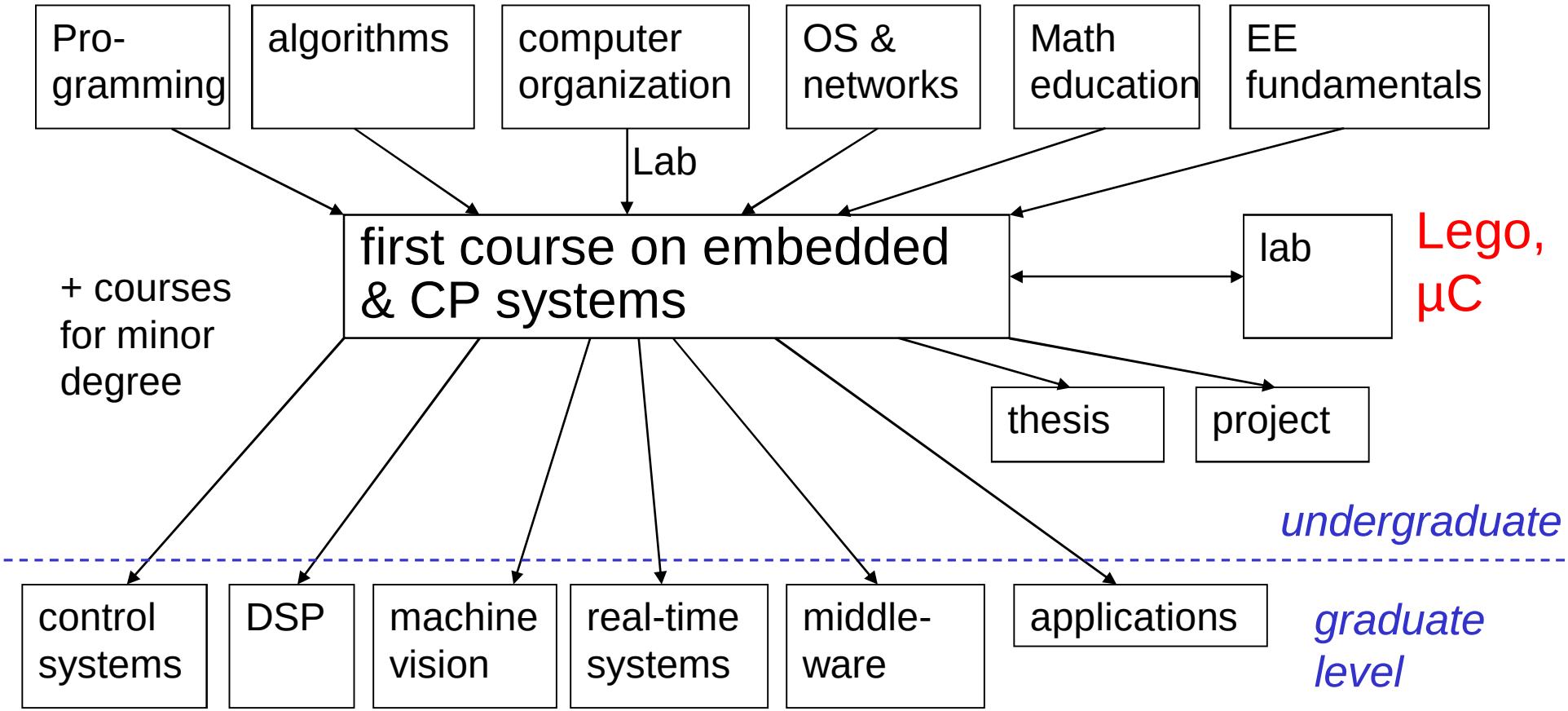
Educational concept

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
- 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 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	…	All dependences met	
8		…	…	
9	Thesis			

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."

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
- Master format: Powerpoint (2010 –new-);
- 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