# Embedded Systems

# 1. Introduction

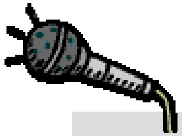
Lothar Thiele

# Organization

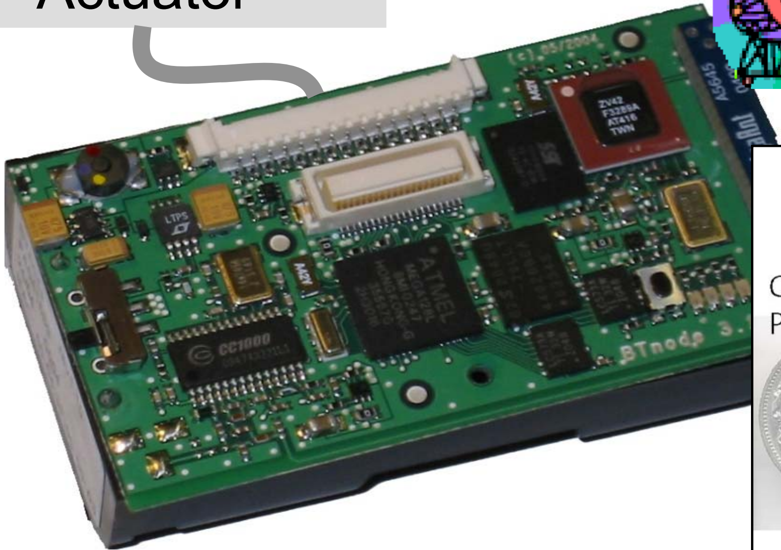
- WWW: http://www.tik.ee.ethz.ch/tik/education/lectures/ES/
- Lecture: Lothar Thiele, thiele@ethz.ch
- Coordination: Olga Saukh, olga.saukh@tik.ee.ethz.ch
- References:
  - ***P. Marwedel: Embedded System Design (paperback), Springer Verlag, December 2011, ISBN: 978-94-007-0256-1.***
  - *G.C. Buttazzo: Hard Real-Time Computing Systems. Springer Verlag, 2011.*
  - W. Wolf: Computers as Components – Principles of Embedded System Design. Morgan Kaufman Publishers, 2012.
  - J. Teich: Digitale Hardware/Software Systeme, Springer Verlag, 2007.
- The slides contain material of J. Rabaey, K. Keuzer, Wayne Wolf, Peter Marwedel, Philip Koopman and from the above books of J. Teich, G.C. Buttazzo, W. Wolf and P. Marwedel.

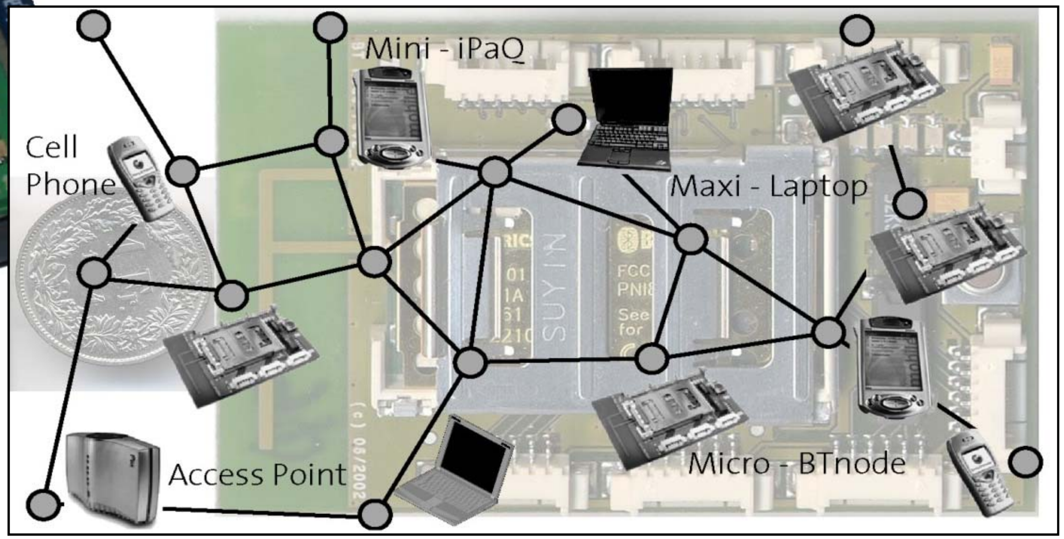
# Communicating Embedded Systems

- Example: BTnodes
  - complete platform including OS
  - especially suited for pervasive computing applications

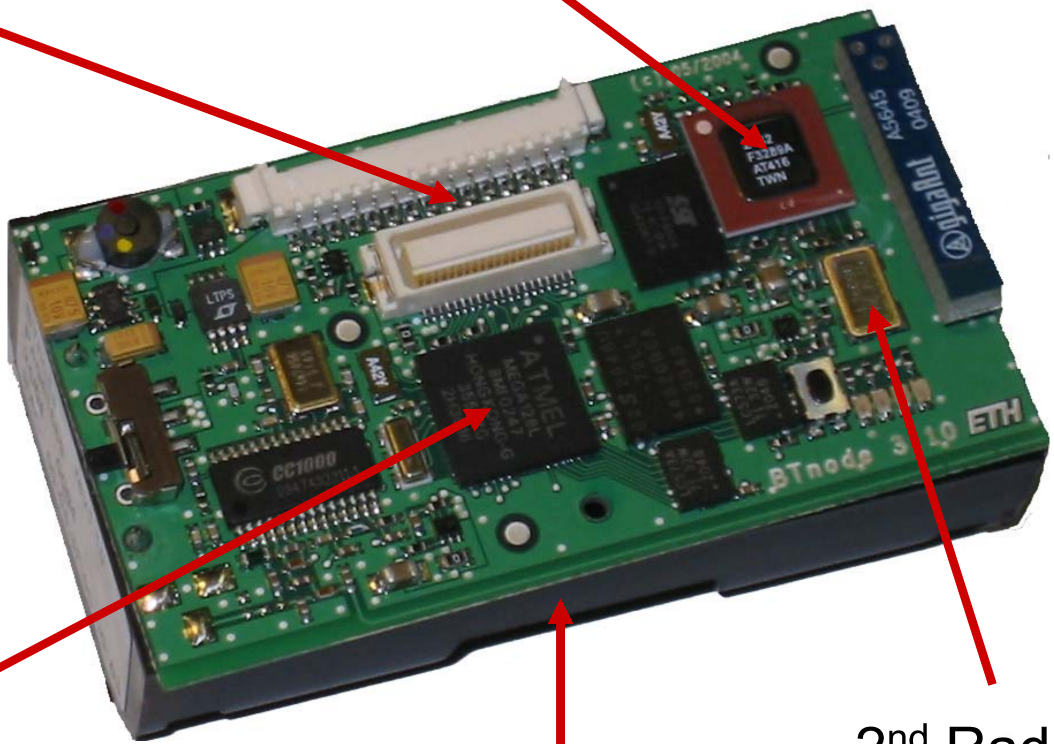


Sensor
Actuator





# BTnode Platform

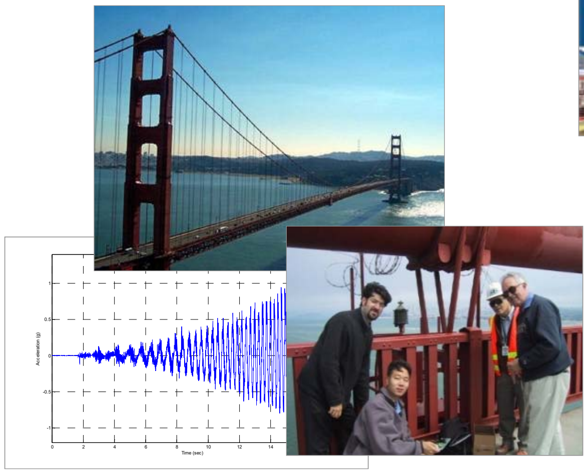



- generic platform for wireless distributed embedded computing
- complete platform including OS
- especially suited for pervasive computing applications (IoT)

# Where are sensor nodes used?

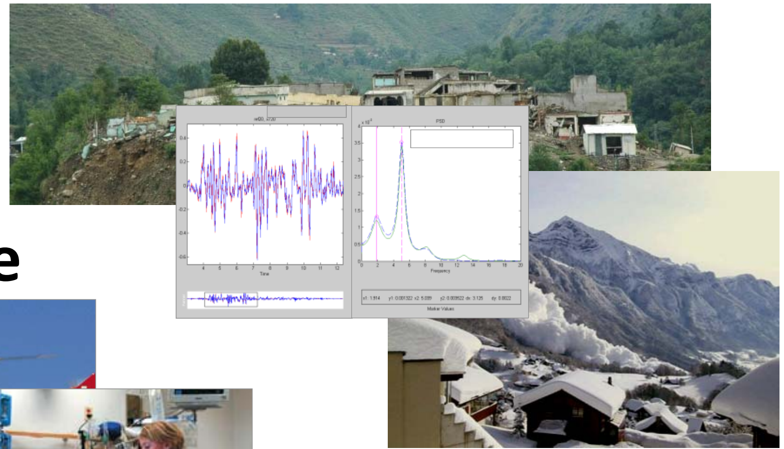
## Logistics

## Maintenance



## Factory Automation

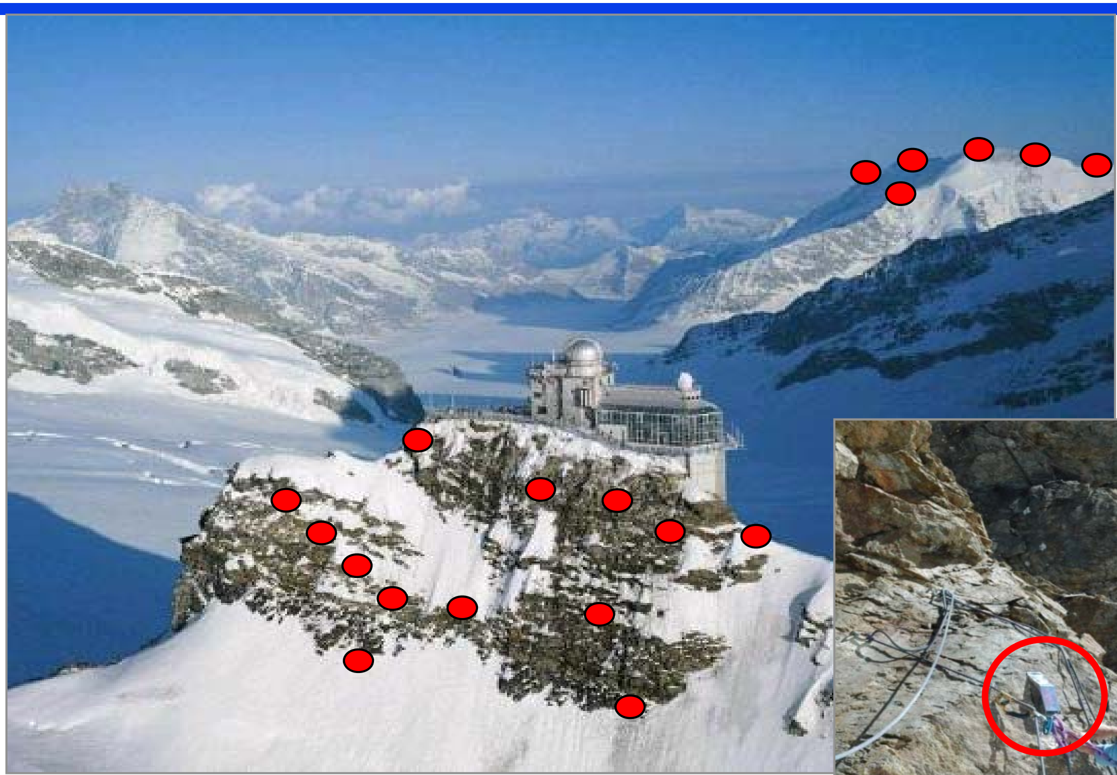
## Natural Hazards



## Building Automation

## Health Care

# PermaSense Project

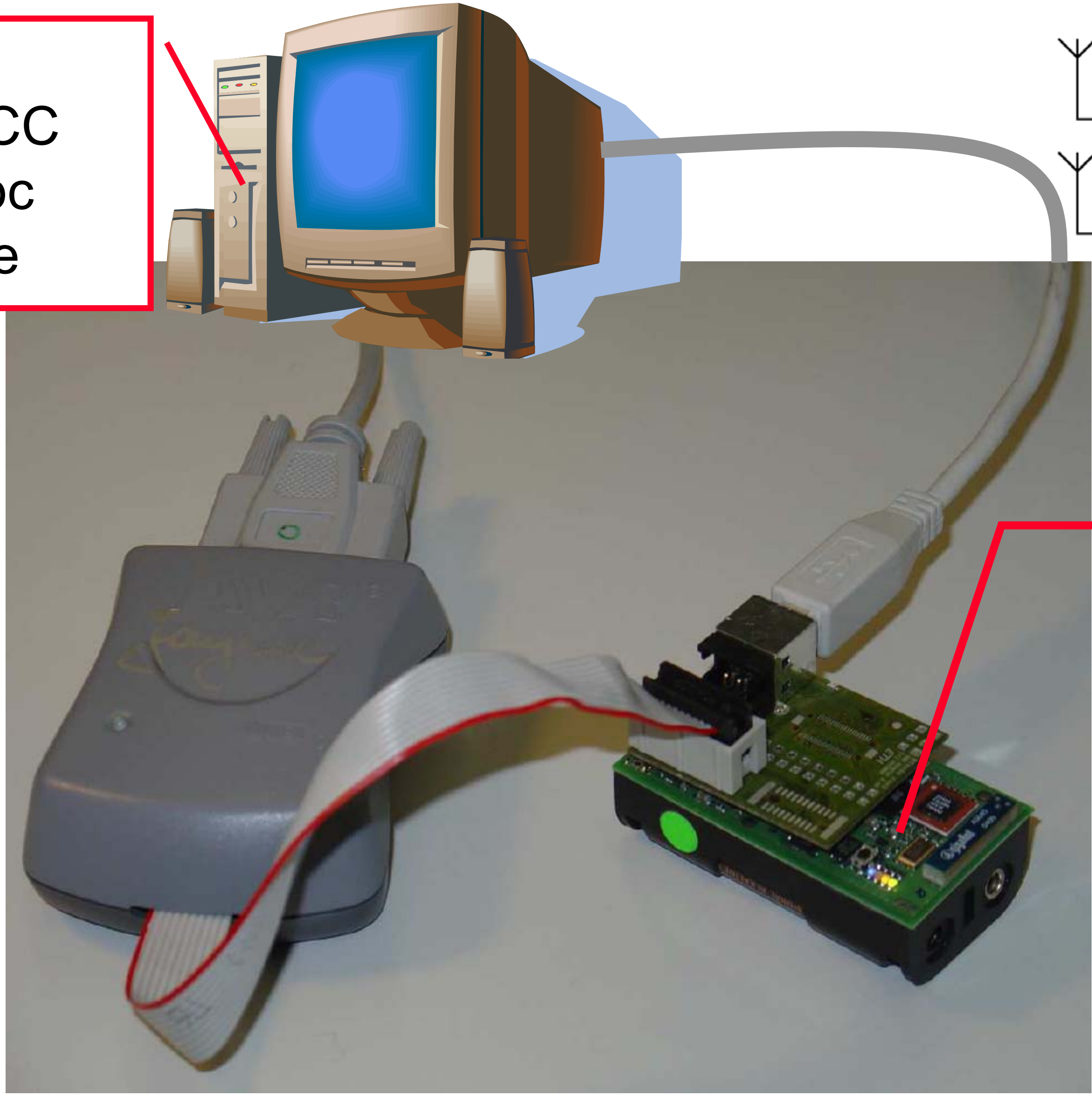


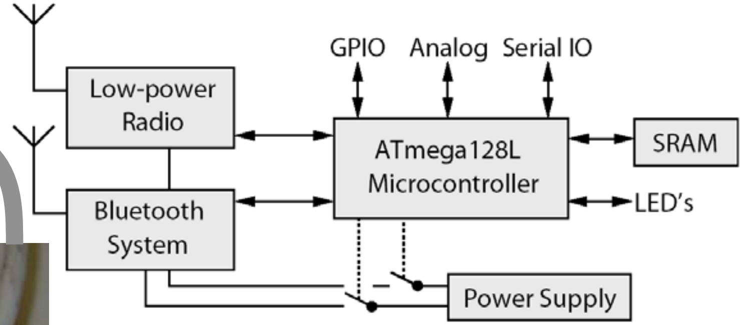
- Jan Beutel – ETH Zurich


PERMASENSE
WIRELESS SENSOR NODE
FOR HIGH-MOUNTAIN
RESEARCH
INFO: +41 44 635 51 21

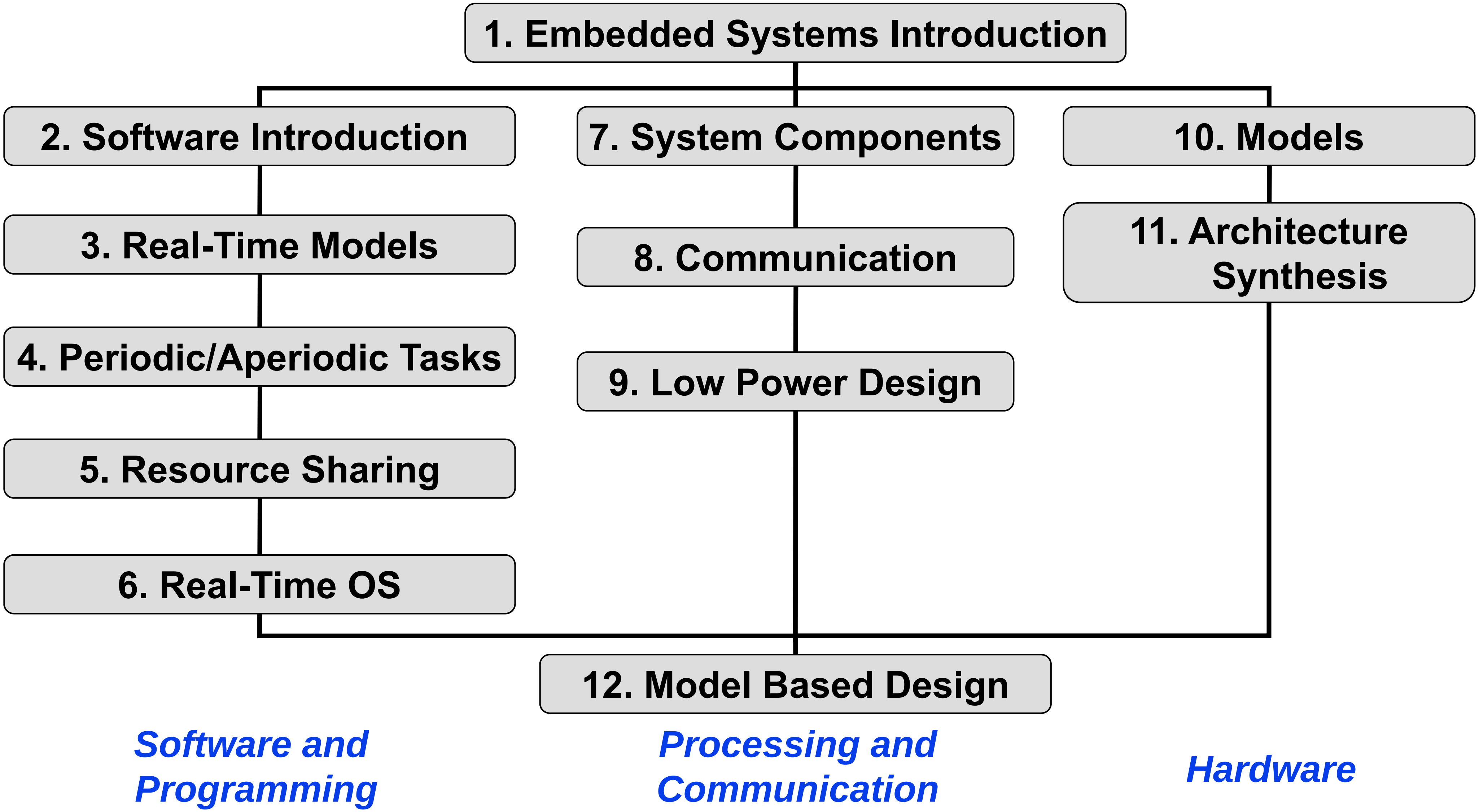
# Development in ES Exercise

Linux
GNU GCC
AVR libc
Eclipse

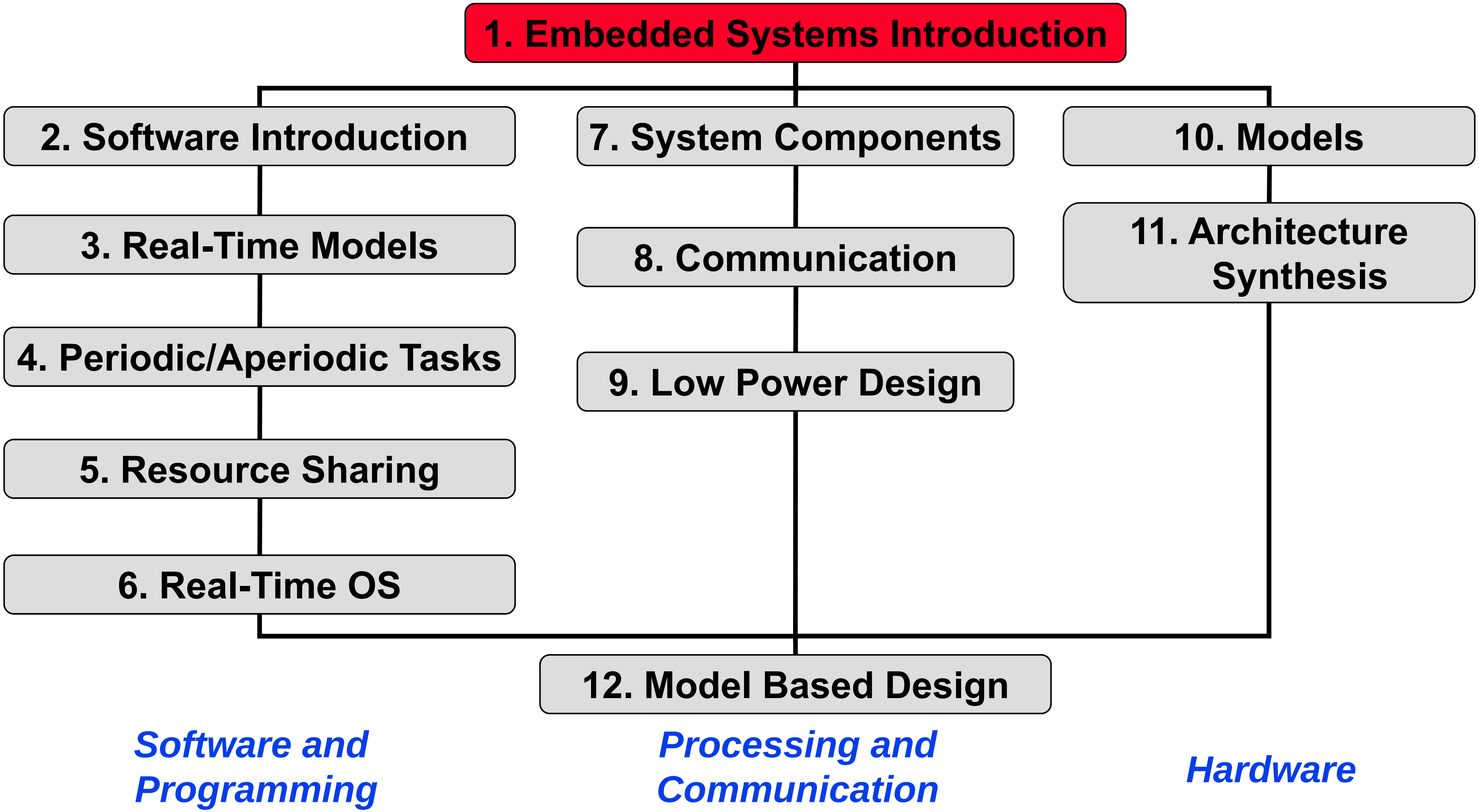





# Contents of Course



# Contents of Course

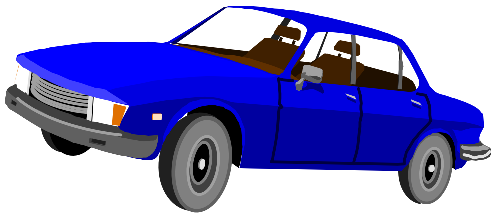


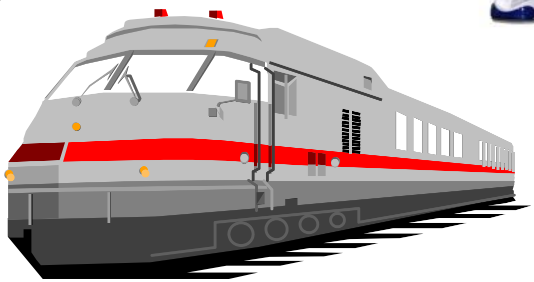
# Embedded Systems

1

Embedded systems (ES) = **information processing systems embedded into a larger product**

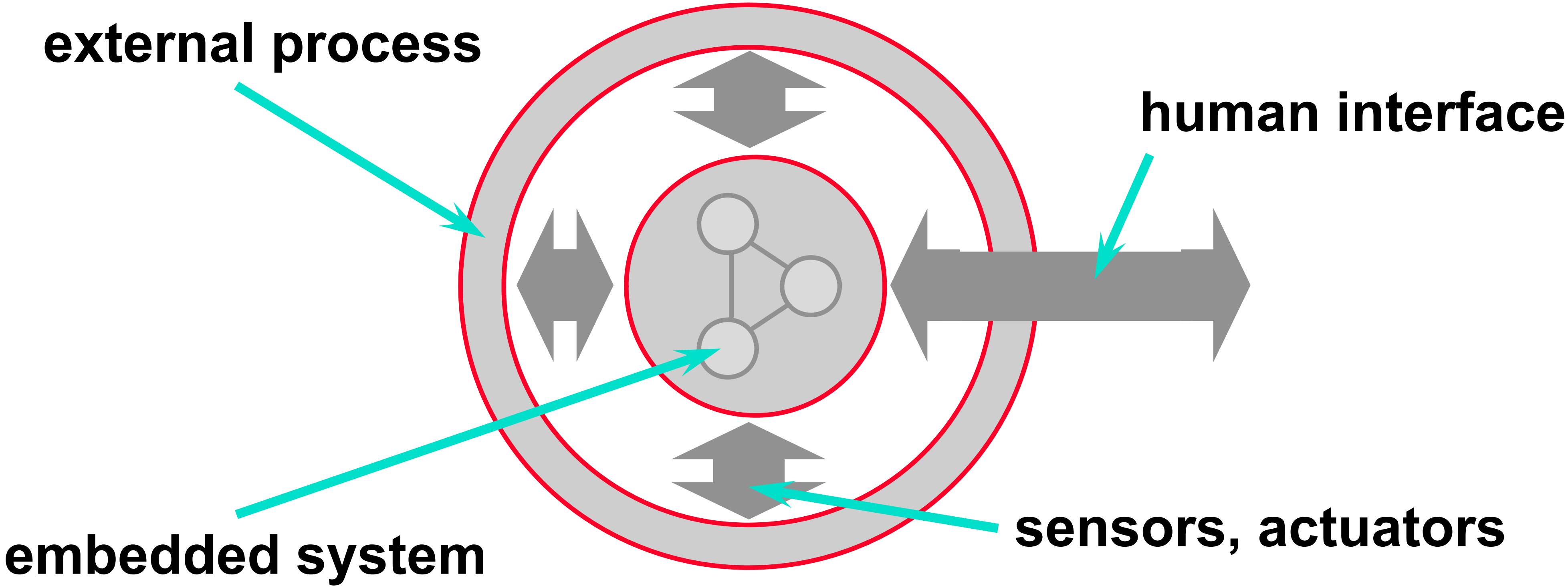
Examples:





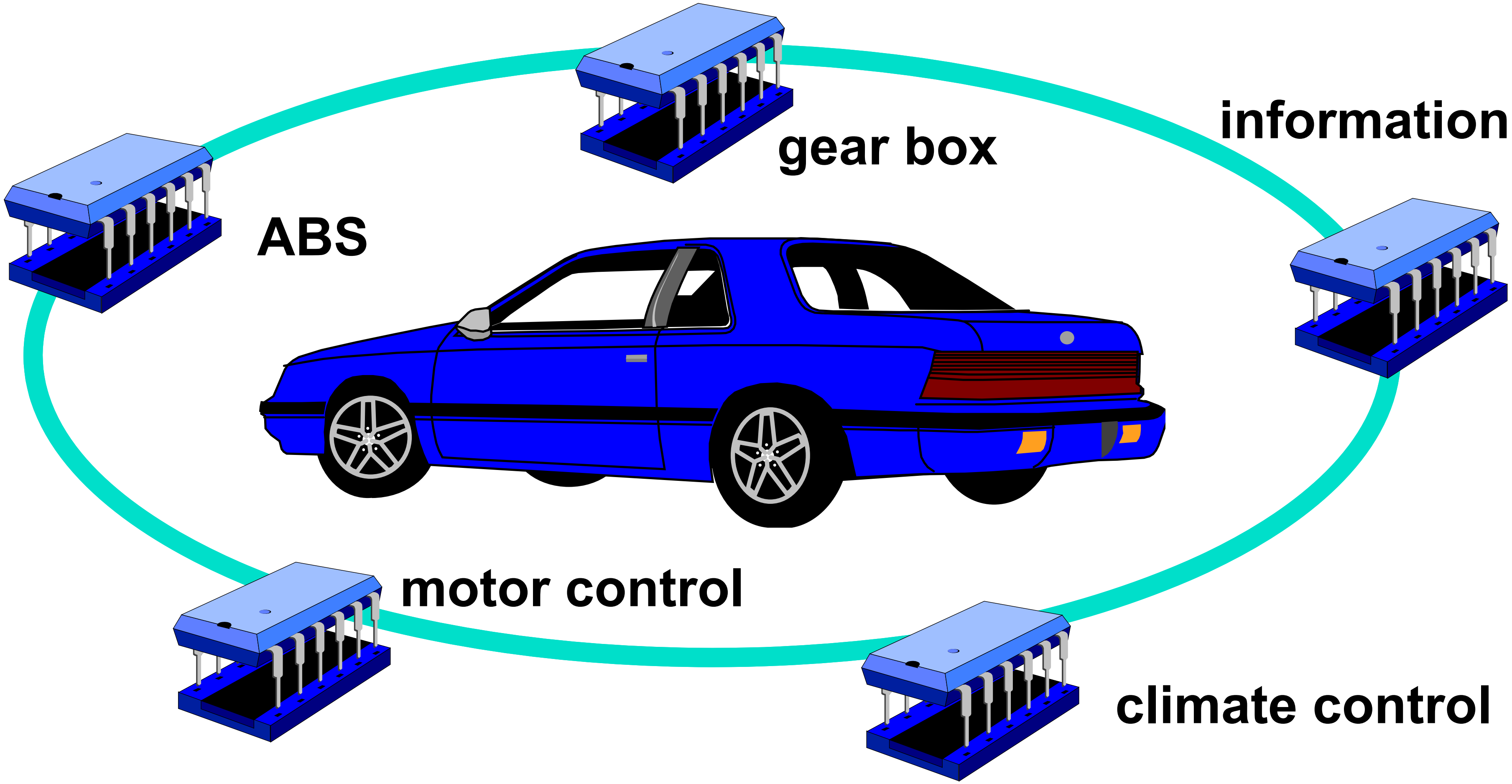
Main reason for buying often is **not** information processing

# Embedded Systems



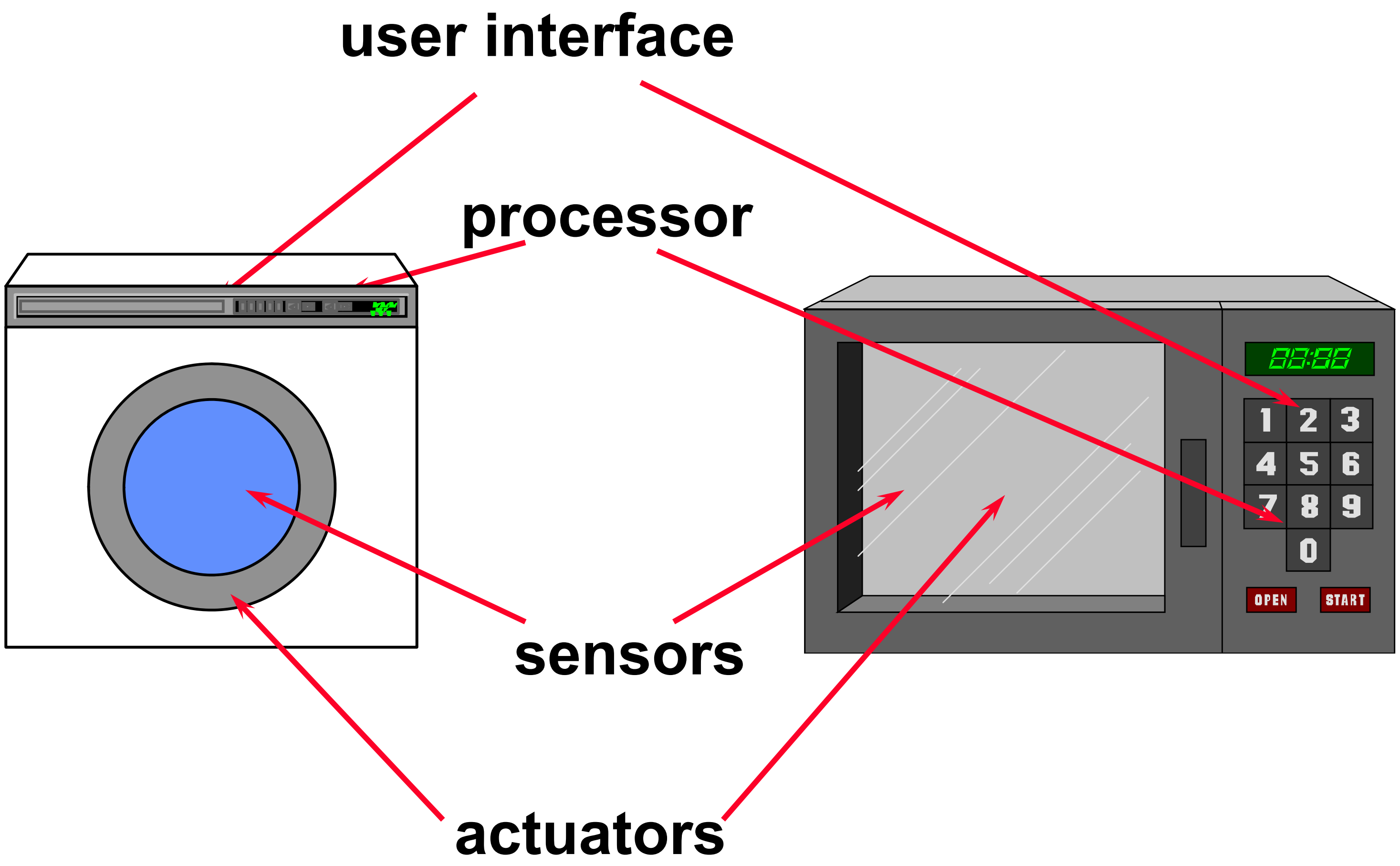
# Examples of Embedded Systems

Car as an integrated control-, communication and information system.



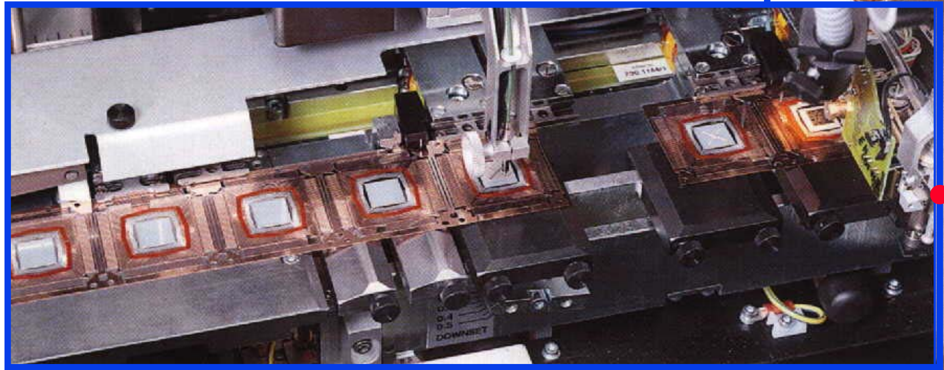
# Examples of Embedded Systems

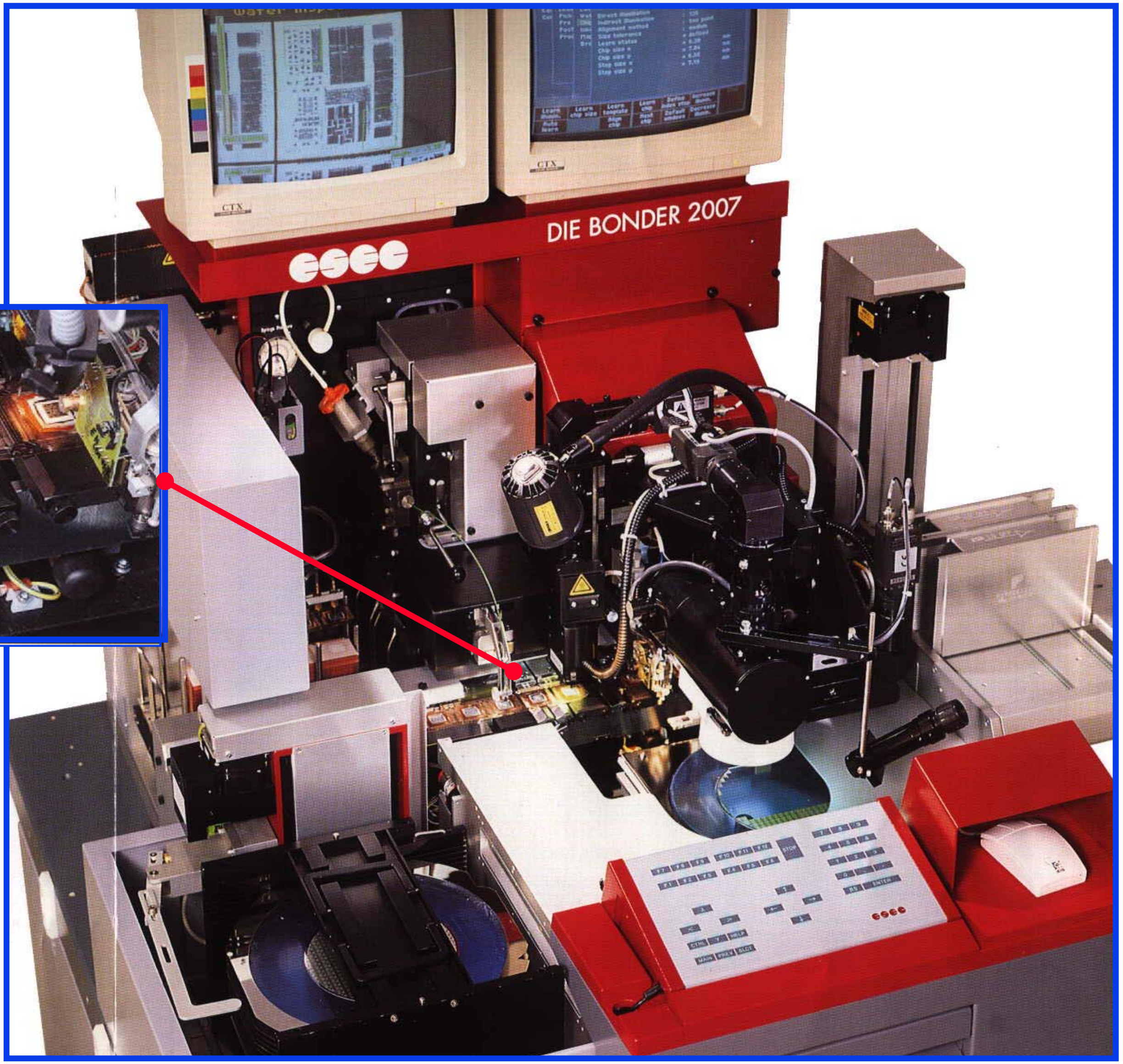
Consumer electronics, for example MP3 Audio, digital camera, home electronics, … .



# Examples of Embedded Systems

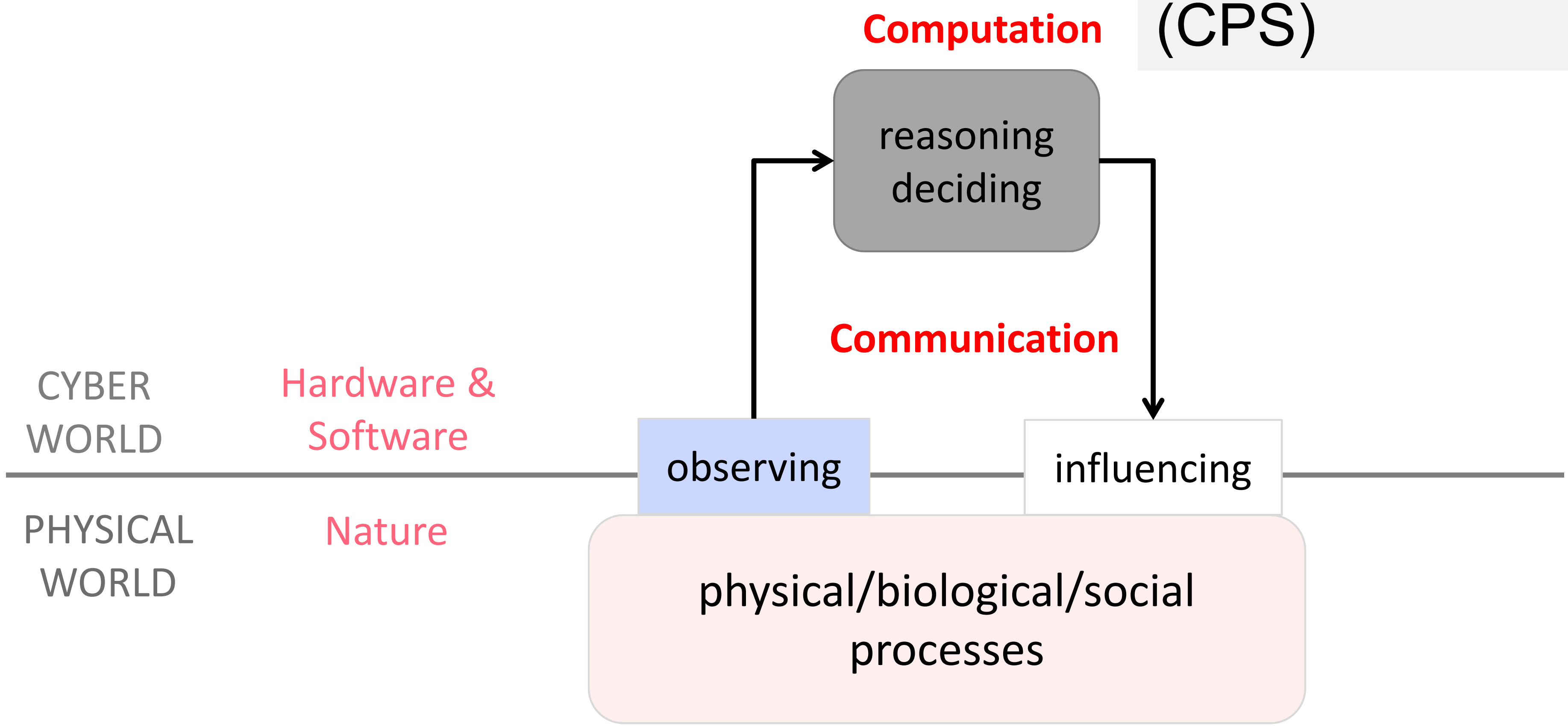
Production systems



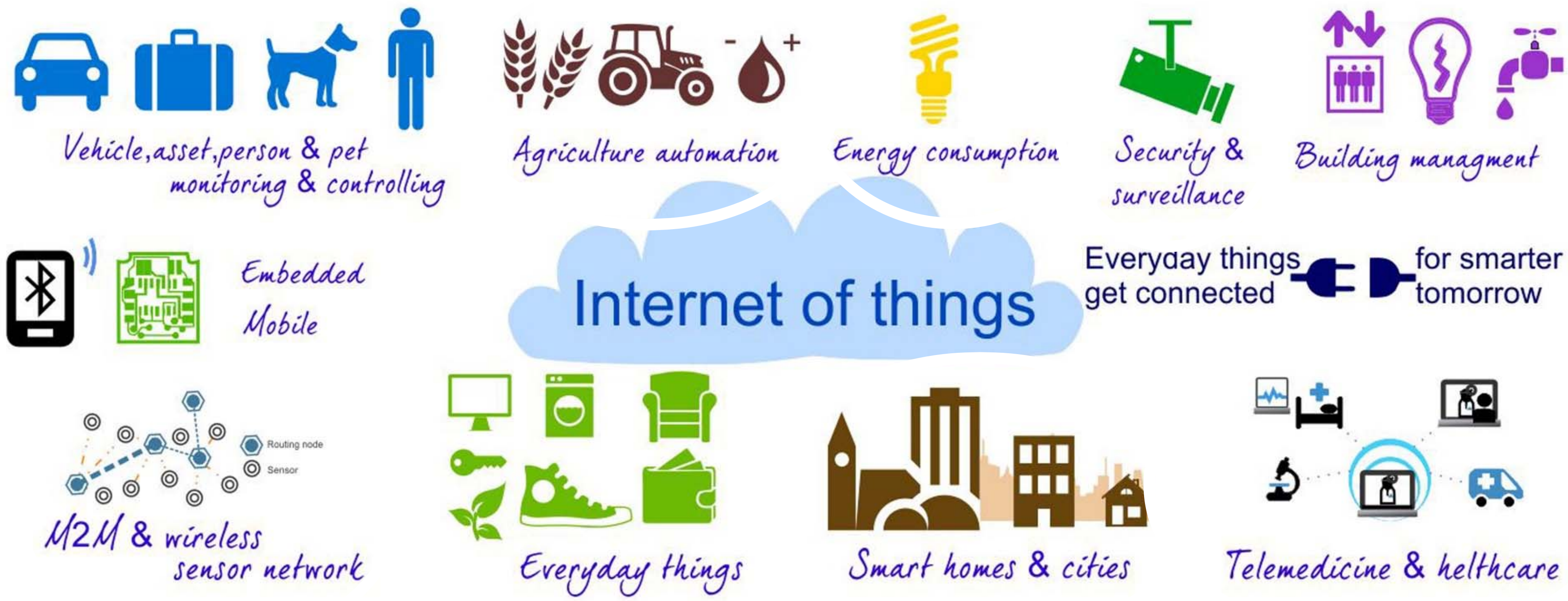


# Smart World

Sometimes denoted as: cyber-physical system (CPS)




Use feedback to influence the dynamics of the physical world by taking smart decisions in the cyber world




Internet of Things (I0T) infrastructure will be omnipresent.

# Predictability & Dependability

CPS = cyber-physical system

"It is essential to **predict** how a CPS is going to behave under any circumstances […] **before** it is deployed."[Maj14]

"CPS must **operate dependably**, safely, securely, efficiently and in real-time."[Raj10]

[Maj14] R. Majumdar & B. Brandenburg (2014). Foundations of Cyber-Physical Systems.
[Raj10] R. Rajkumar et al. (2010). Cyber-Physical Systems: The Next Computing Revolution.

# Characteristics of Embedded Systems (1)

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

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*** and ***data memory*** efficient
  - ***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.

# 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.

# Characteristics of Embedded Systems (4)

- 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]***

- Frequently ***connected to physical environment*** through sensors and actuators (CPS).
- In these cases, the analog and digital system aspects need to be considered: ***hybrid systems***.

# Comparison

- Embedded Systems
  - Few applications that are known at design-time.
  - Not programmable by end user.
  - Fixed run-time requirements (additional computing power not useful).
  - Criteria:
    - cost
    - power consumption
    - predictability
    - …
- General Purpose Computing
  - Broad class of applications.
  - Programmable by end user.
  - Faster is better.
  - Criteria:
    - cost
    - power consumption
    - average speed

# Trends …

- Since long time, embedded systems overtook the market of PCs and Laptops.
- Ubiquitous and pervasive computing, Internet of Things:
  - Information anytime, anywhere; building ambient intelligence into our environment; internet of things:
    - Wearable computers
    - “Smart Labels” on consumer products
    - Intelligent buildings
    - Environmental Monitoring
    - Traffic control and communicating automobiles
  - Embedded systems provide the basic technology.

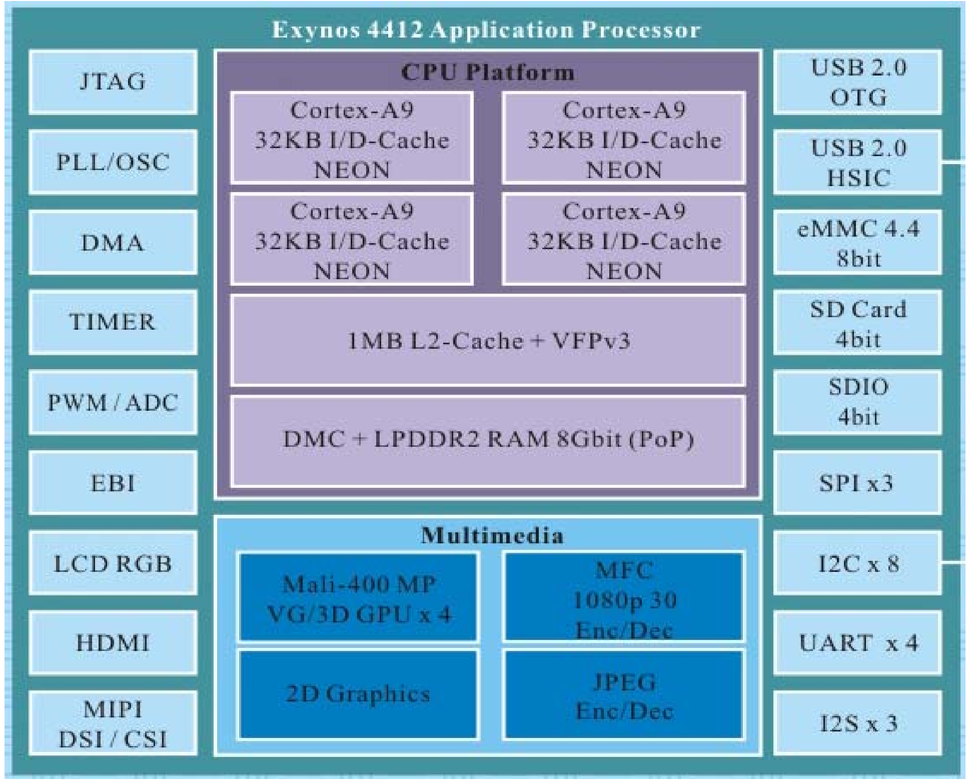
# Trends …

- Embedded systems are communicating, very often wireless.

- Higher degree of integration on a single chip:
  - Memory + processor + I/O-units + (wireless) communication.
  - Network on chip for communication between units.
  - Multiprocessor Systems on a Chip (MPSoC).
  - Microsystems that contain energy harvesting, energy storage, sensing, processing and communication (“zero power systems”).
  - Software increasing (amount and complexity).

- Low  power and energy constraints (portable or unattended devices) are increasingly important, as well as temperature constraints (overheating). Increased interest in energy harvesting to achieve long term autonomous operation.

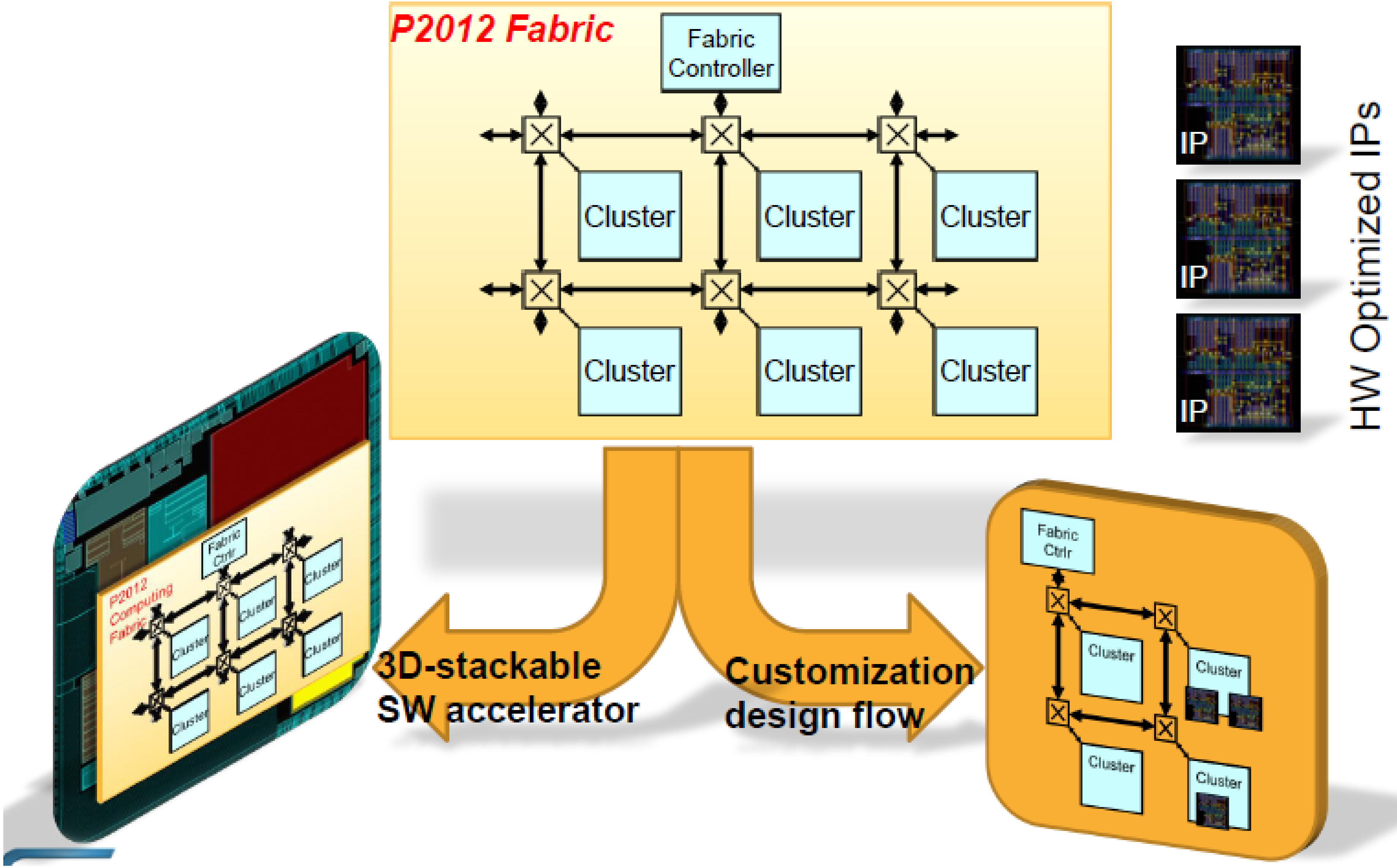
# Multiprocessor systems-on-a-chip (MPSoCs)



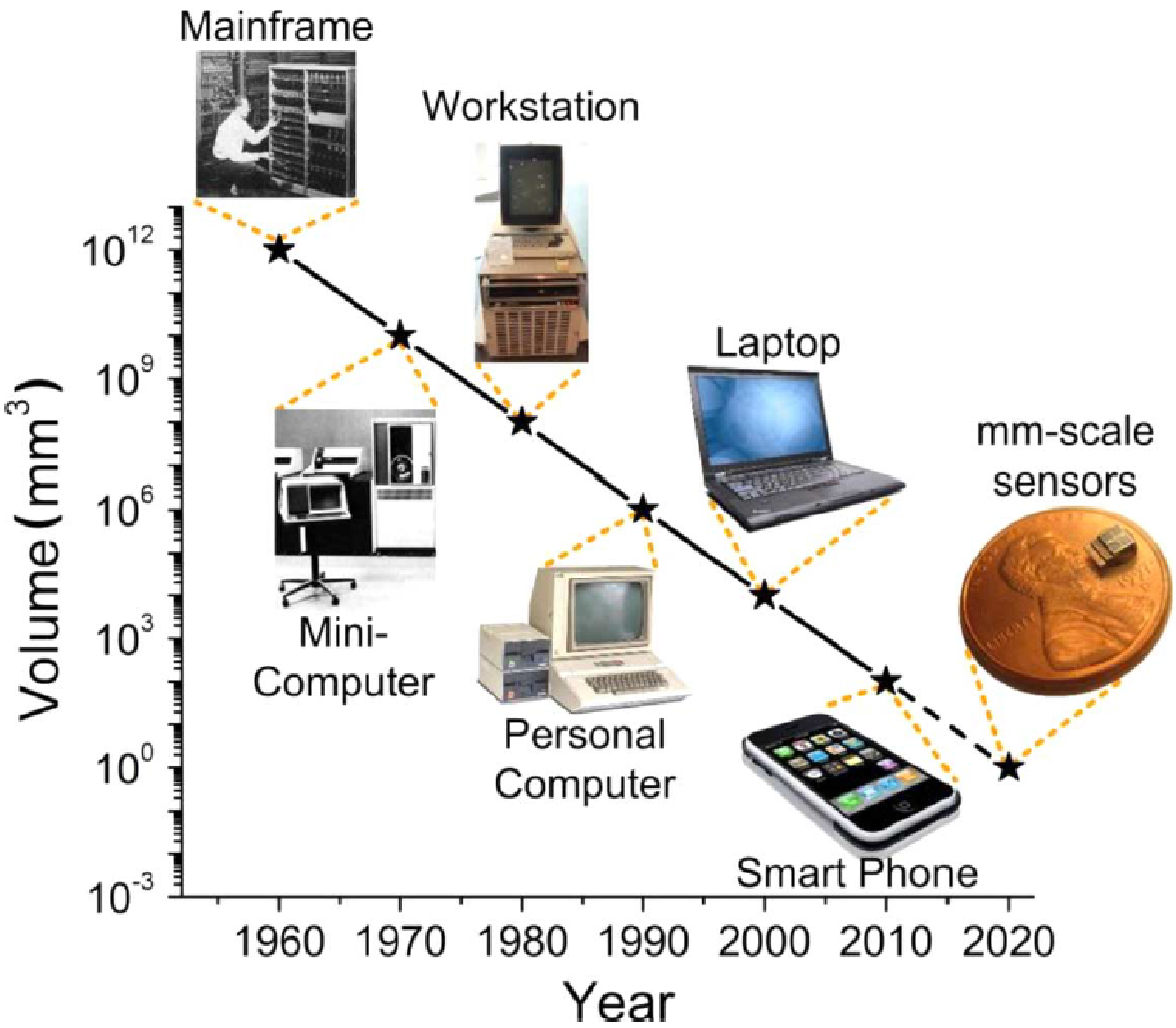

Samsung Galaxy Note II

- Eynos 4412 System on a Chip (SoC)
- ARM Cortex-A9 processing core
- 32 nanometer: transistor gate width
- Four processing cores

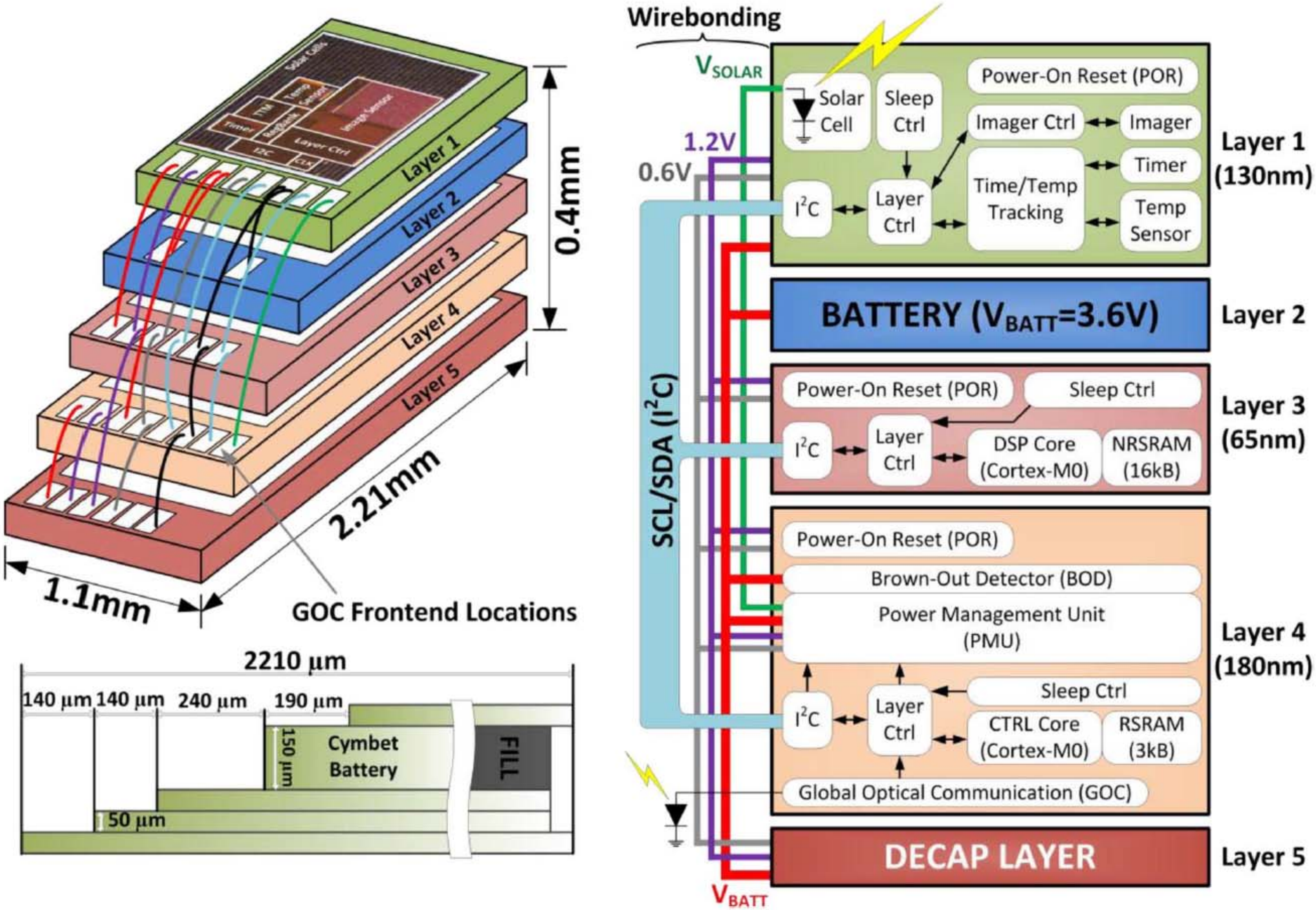
# Example ST2012/STHORM



# Zero Power Systems and Sensors

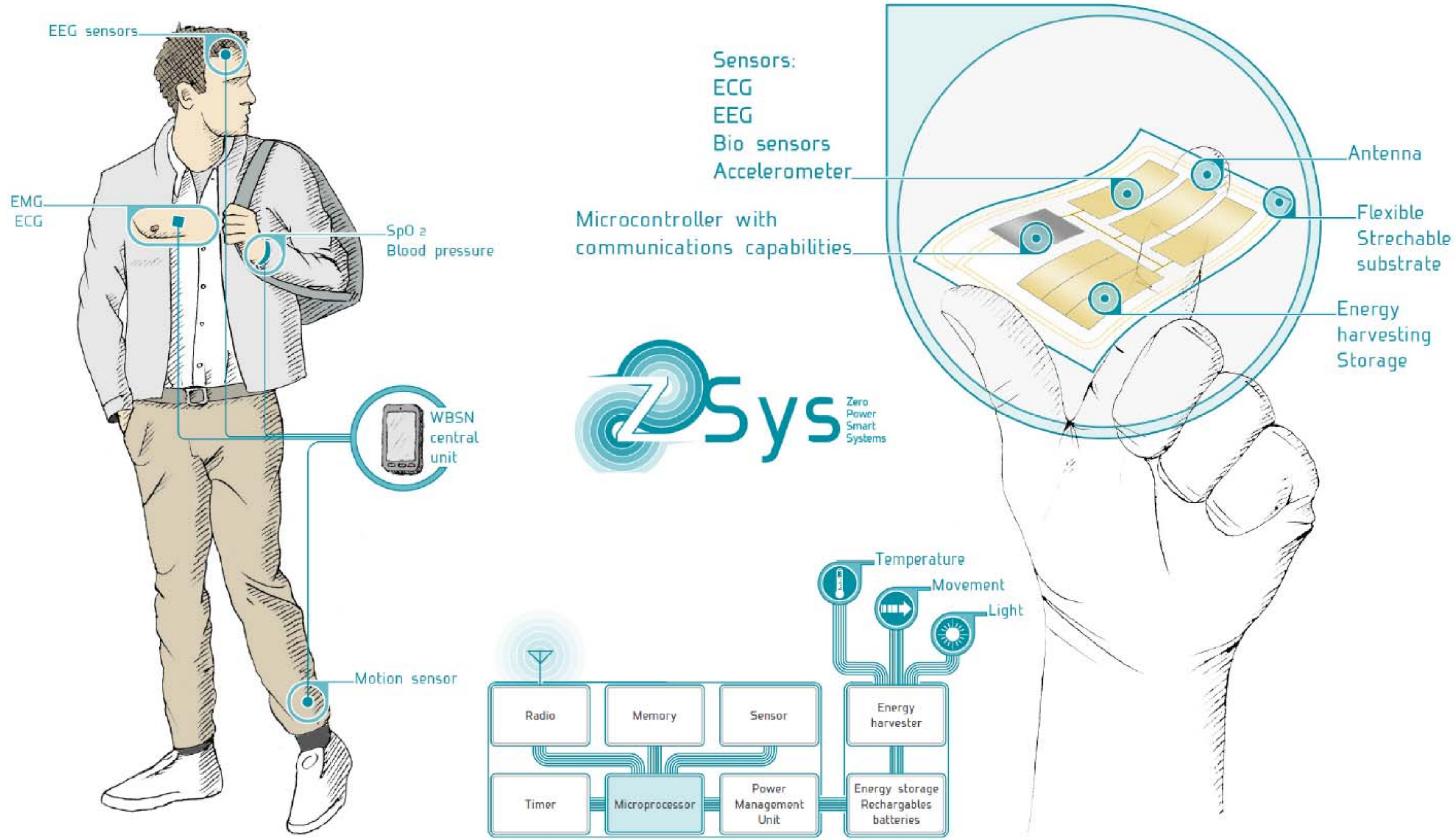


# Zero Power Systems and Sensors




IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 48, NO. 1, JANUARY 2013

# Zero Power Systems and Sensors




Z-Sys and Guardian Angel Research Proposals 2013