technische universität
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informatik 12

Embedded System Design:

Embedded Systems Foundations of Cyber-Physical Systems

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(slides are based on
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2019年 10 月 09 日

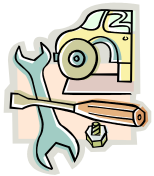
Common characteristics

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

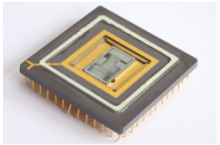
  - **Security**: confidential and authentic communication

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)

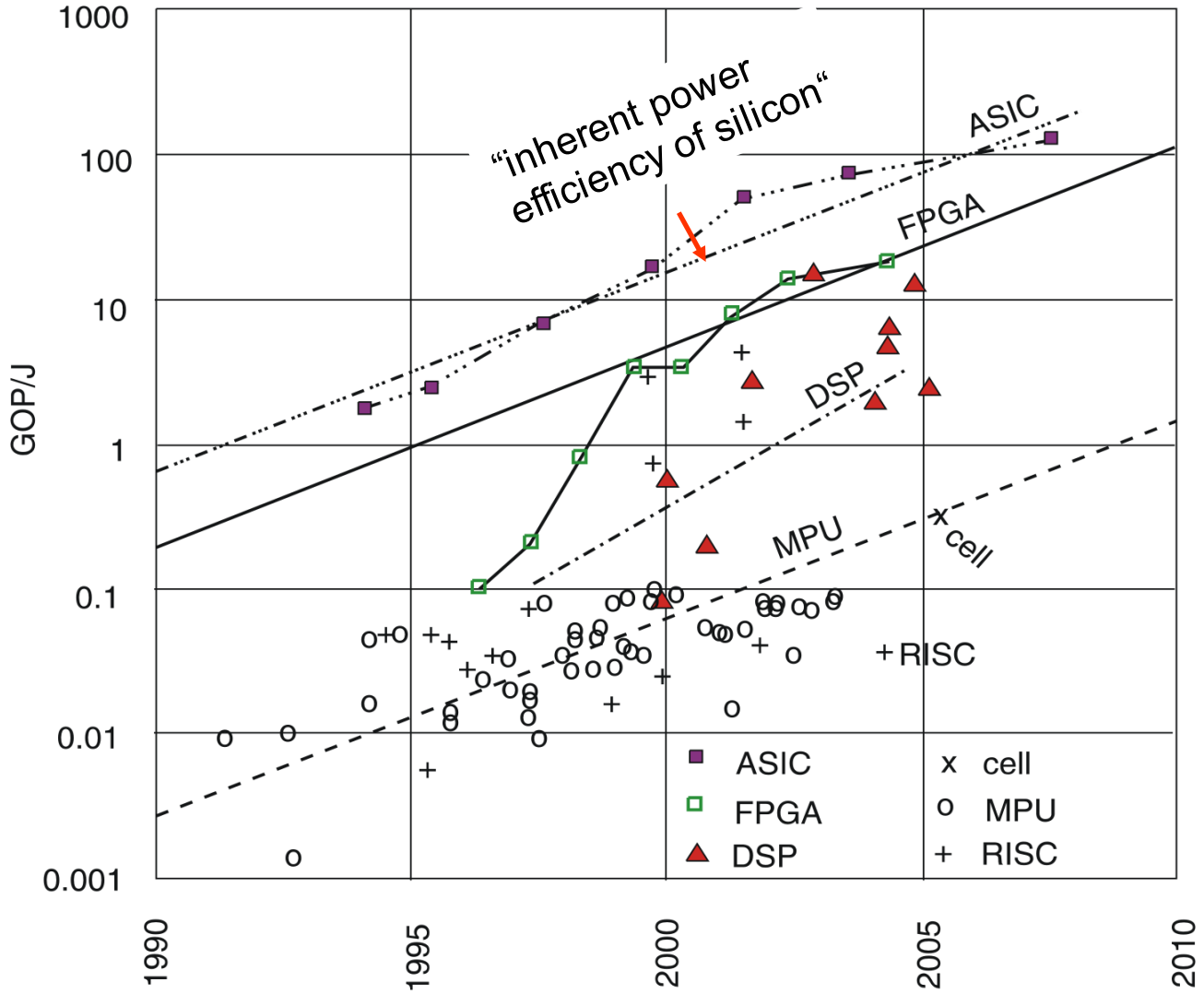


  - Run-time efficient

  - Weight efficient

  - Cost efficient
  - Energy efficient

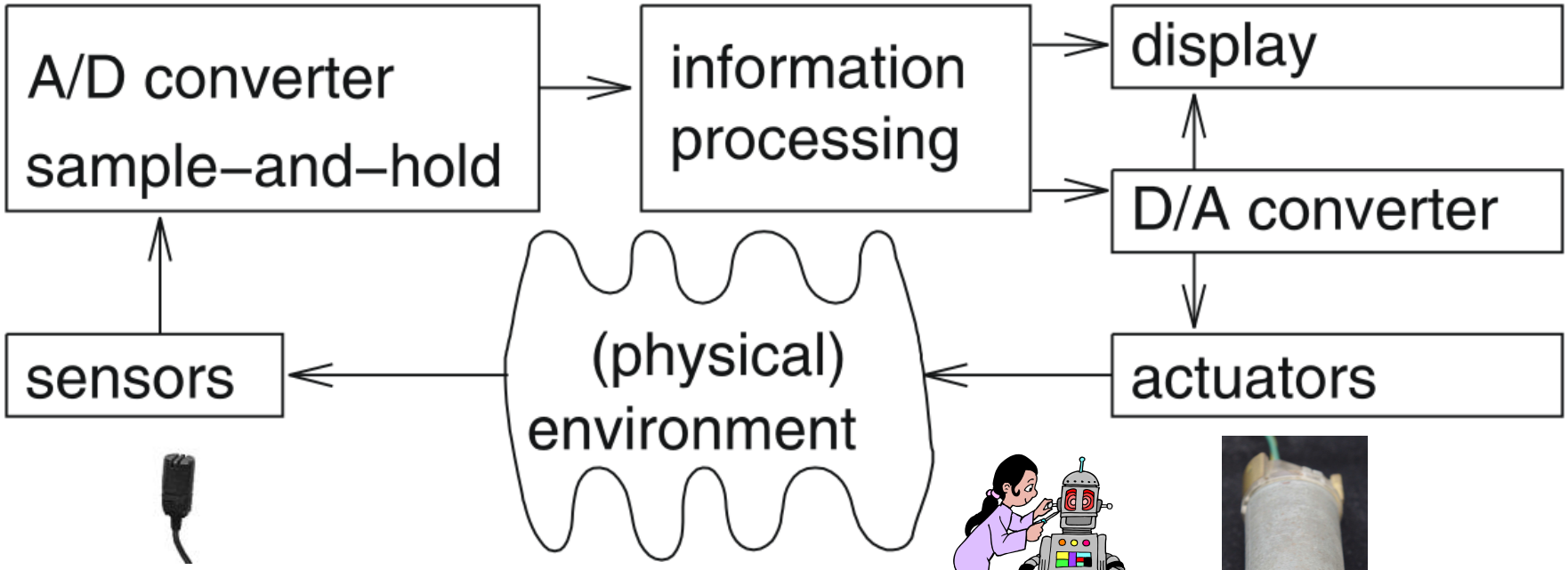
Importance of Energy Efficiency



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

CPS & ES Hardware

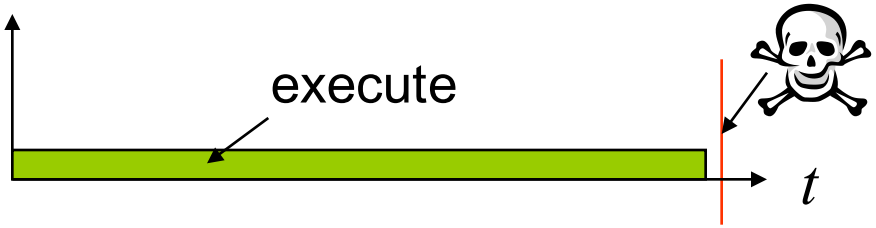
CPS & ES hardware is frequently used in a loop (***"hardware in a loop"***):

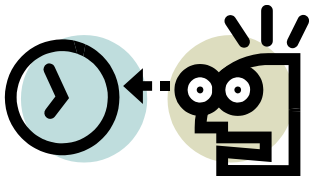


Cyber-physical systems (!)

Real-time constraints

- Embedded systems must meet **real-time constraints**
  - *A guaranteed system response has to be explained without statistical arguments* [Kopetz, 1997].
  - 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 can be roughly called **soft**.

Typical Misconeptions

"Real time" is performance engineering/tuning.

- Timeliness is more important in real-time systems.

Real-time computing is equivalent to fast computing.

- Real-time computing means predictable and reliable computing.

Advances in supercomputing hardware will take care of real-time requirements.

- Buying a "faster" processor may result in timeliness violation.

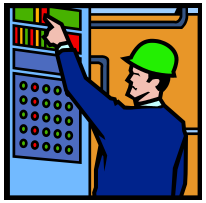
Real-Time Systems & ES &CPS

CPS, ES and Real-Time Systems synonymous?

- For some embedded systems, real-time behavior is less important (Telecommunication)
- For CPS, real-time behavior is essential, hence RTS ≅ CPS
- CPS models also include a model of the physical system

Reactive & hybrid systems

- Typically, ES/CPS are **reactive systems**:
  "**A reactive system is (one which is) in continual interaction with its 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).

Dynamics

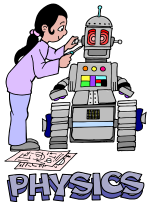
Frequent change of environment

Characteristics lead to corresponding challenges

- Dependability

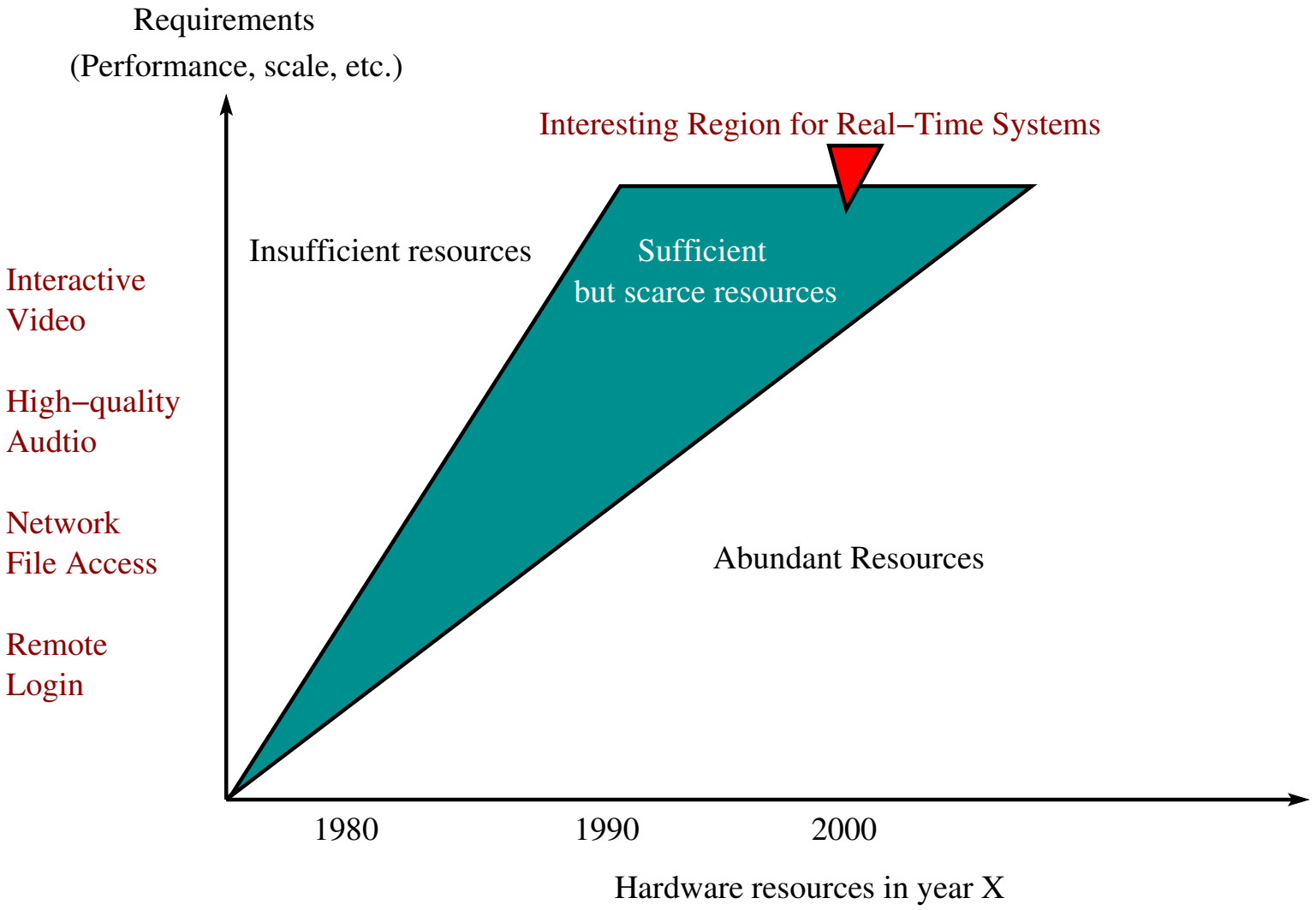
- Efficiency
  - In particular: Energy efficiency

- Hardware properties, physical environment



- Meeting real time requirements
- ….

Space of Design

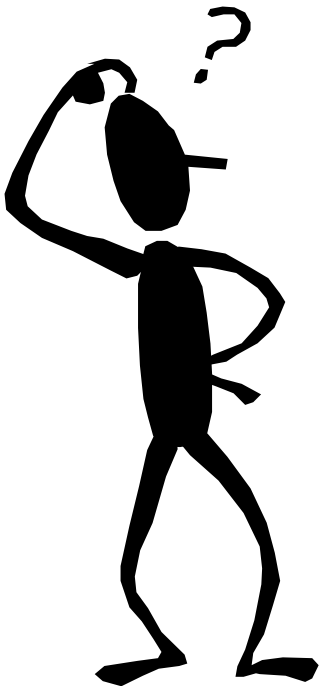


Challenges for implementation in hardware

- Early embedded systems frequently implemented in hardware (boards)
- Mask cost for specialized application specific integrated circuits (ASICs) becomes very expensive (M$ range, technology-dependent)
- Lack of flexibility (changing standards).
- ☞Trend towards implementation in software (or possibly FPGAs, see chapter 3)

Challenges for implementation in software

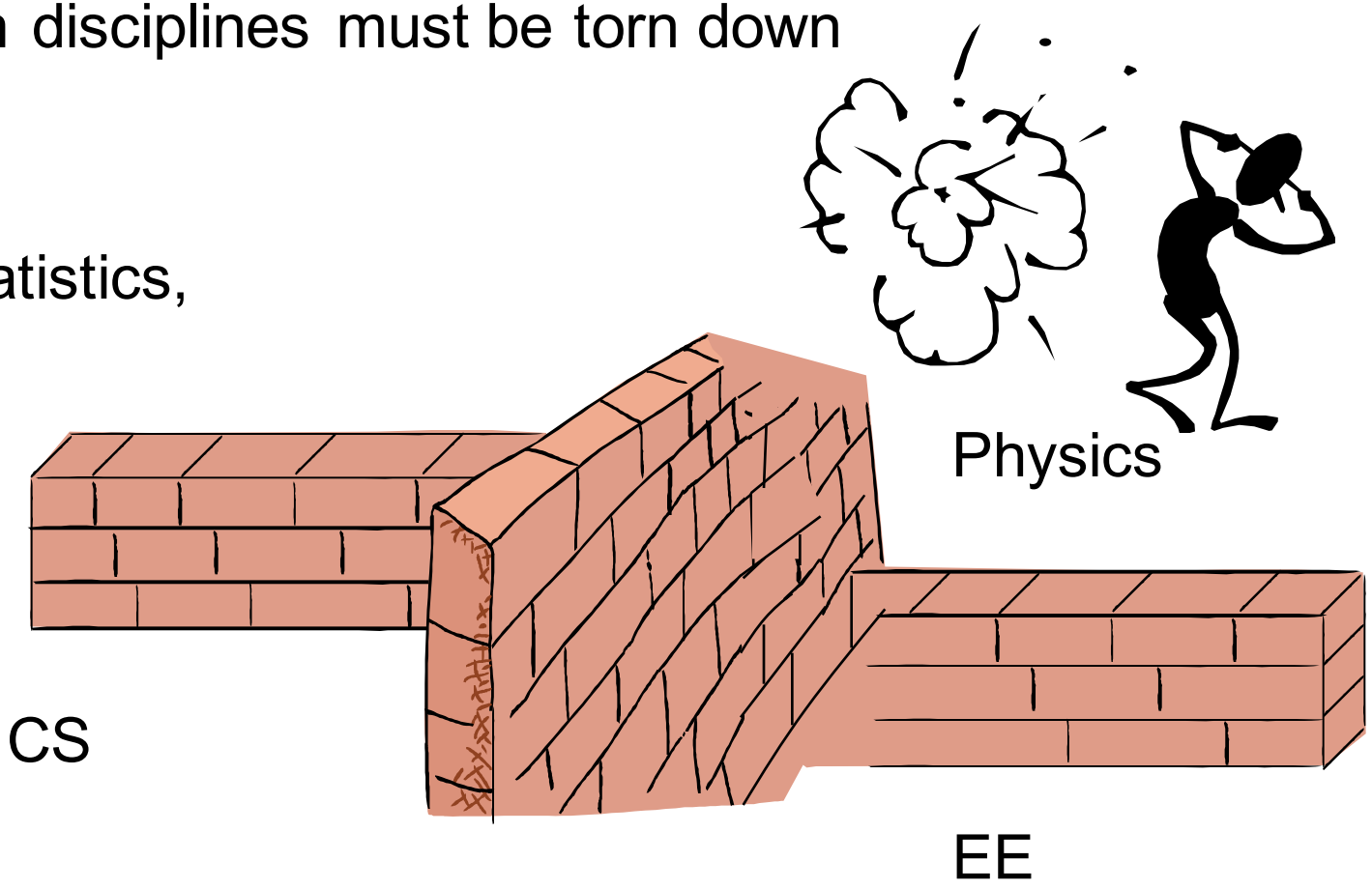
If CPS/ES will be implemented mostly in software, then why don‘t we just use what software engineers have come up with?



It is not sufficient to consider CPS/ES as a special case of SW engineering

Knowledge from many areas must be available,
Walls between disciplines must be torn down

medicine, statistics,
ME, biology



Challenges for CPS/ES 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)

Software complexity is a challenge

Software in a TV set

- Source 1*:

Year	Size
1965	0
1979	1 kB
1990	64 kB
2000	2 MB

- Source 2°: 10x per 6-7 years

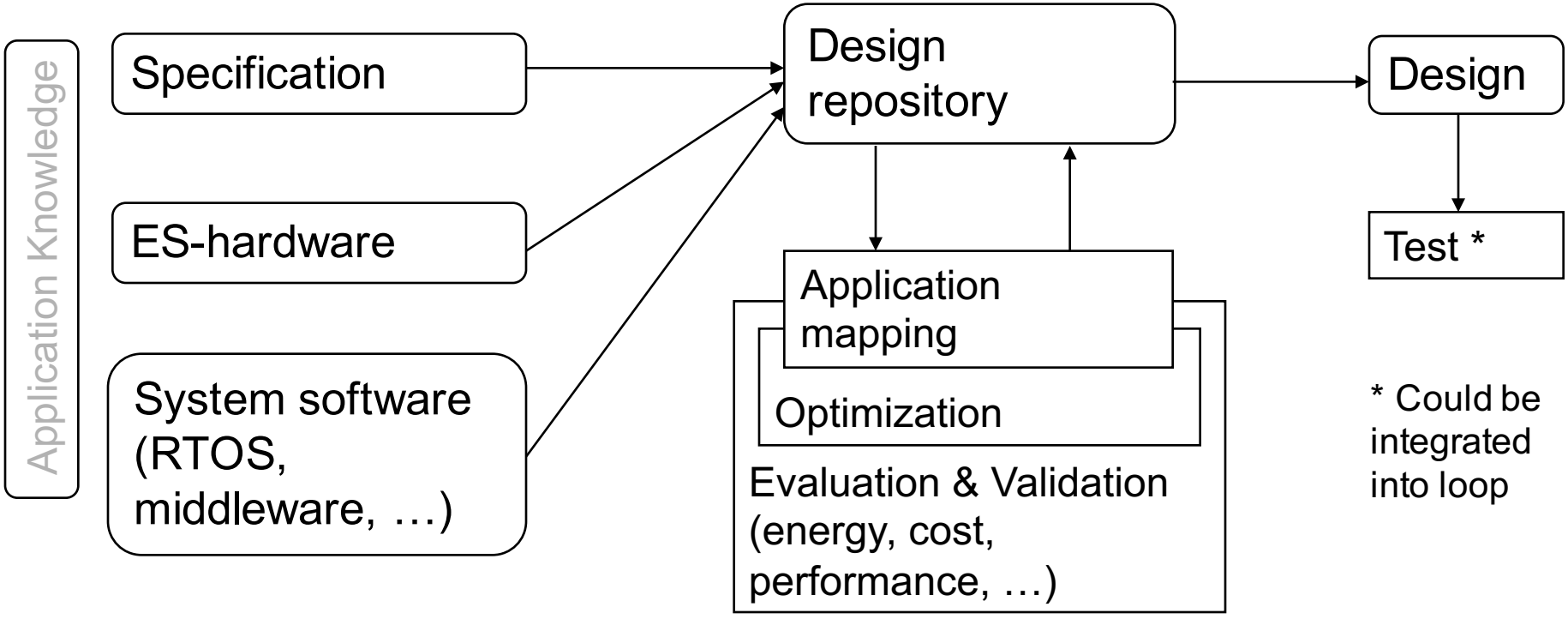
Year	Size
1986	10 KB
1992	100 kB
1998	1 MB
2008	15 MB

- ☞ Exponential increase in software complexity
- *… > 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

° R. Kommeren, P. Parviainen: Philips experiences in global distributed software development, *Empir Software Eng*. (2007) 12:647-660

Hypothetical design flow



Generic loop: tool chains differ in the number and type of iterations

Summary

- Common characteristics
- Challenges (resulting from common characteristics)
- Design Flows