Embedded Systems (ES)

1. Introduction

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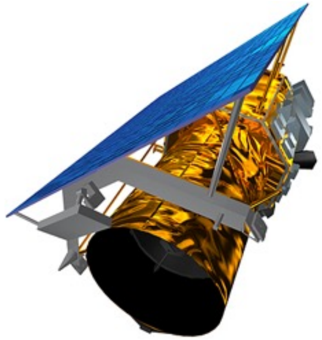
Embedded Systems

- Embedded system = information processing system embedded into a larger product

automotive functions



satellite

hearing aid

industrial control

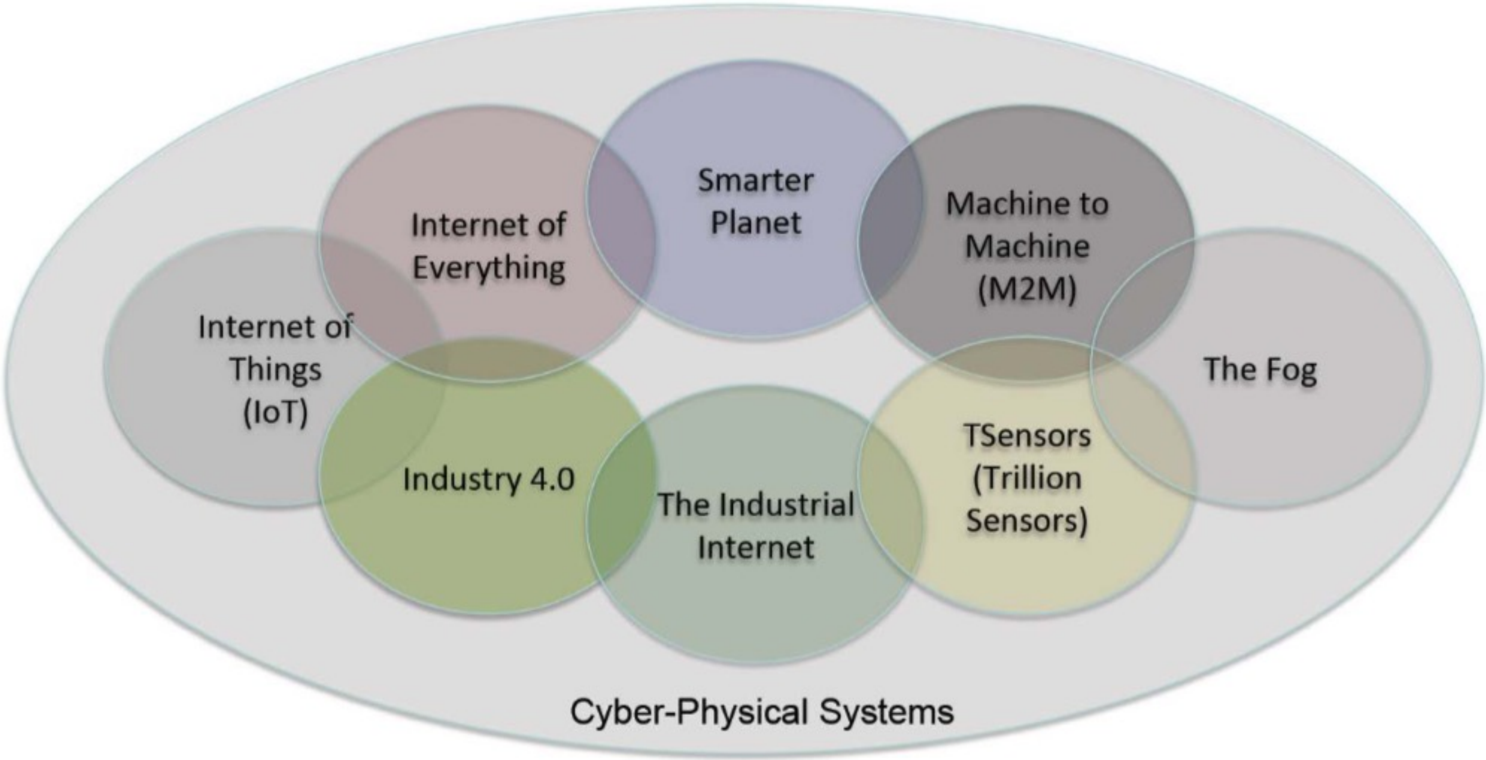
fax machine / printer

prosthesis control

production robot

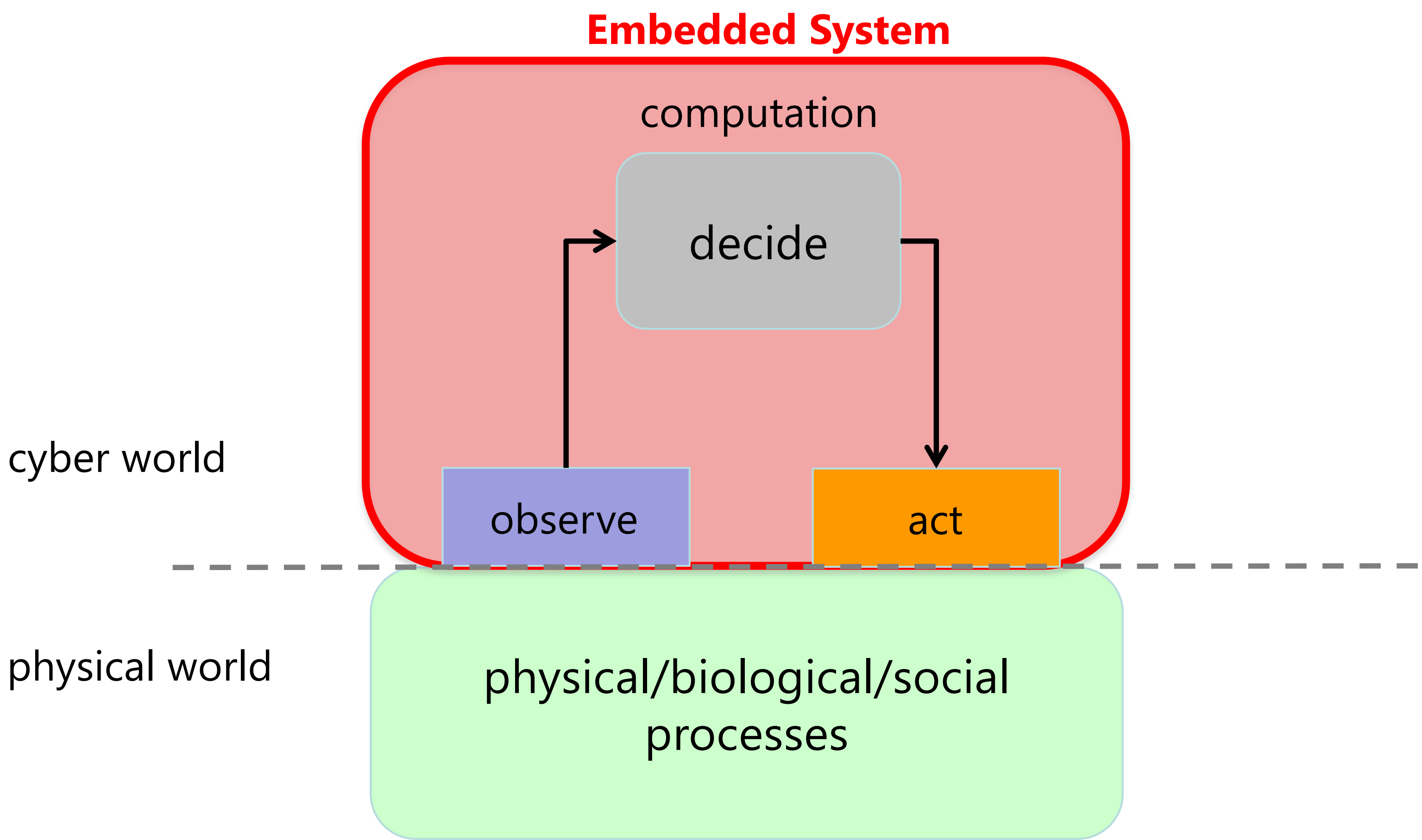
digital tv set

- Cyber-physical system (CPS)
  - integration of computation and physical processes [Lee07]
  - often distributed: integration of computing and communication



[Lee07] E. A. Lee. Computing Foundations and Practice for Cyber Physical Systems: A Preliminary Report. Technical Report No. UCB/EECS-2007-72. 2007.

Abstract View of an Embedded System



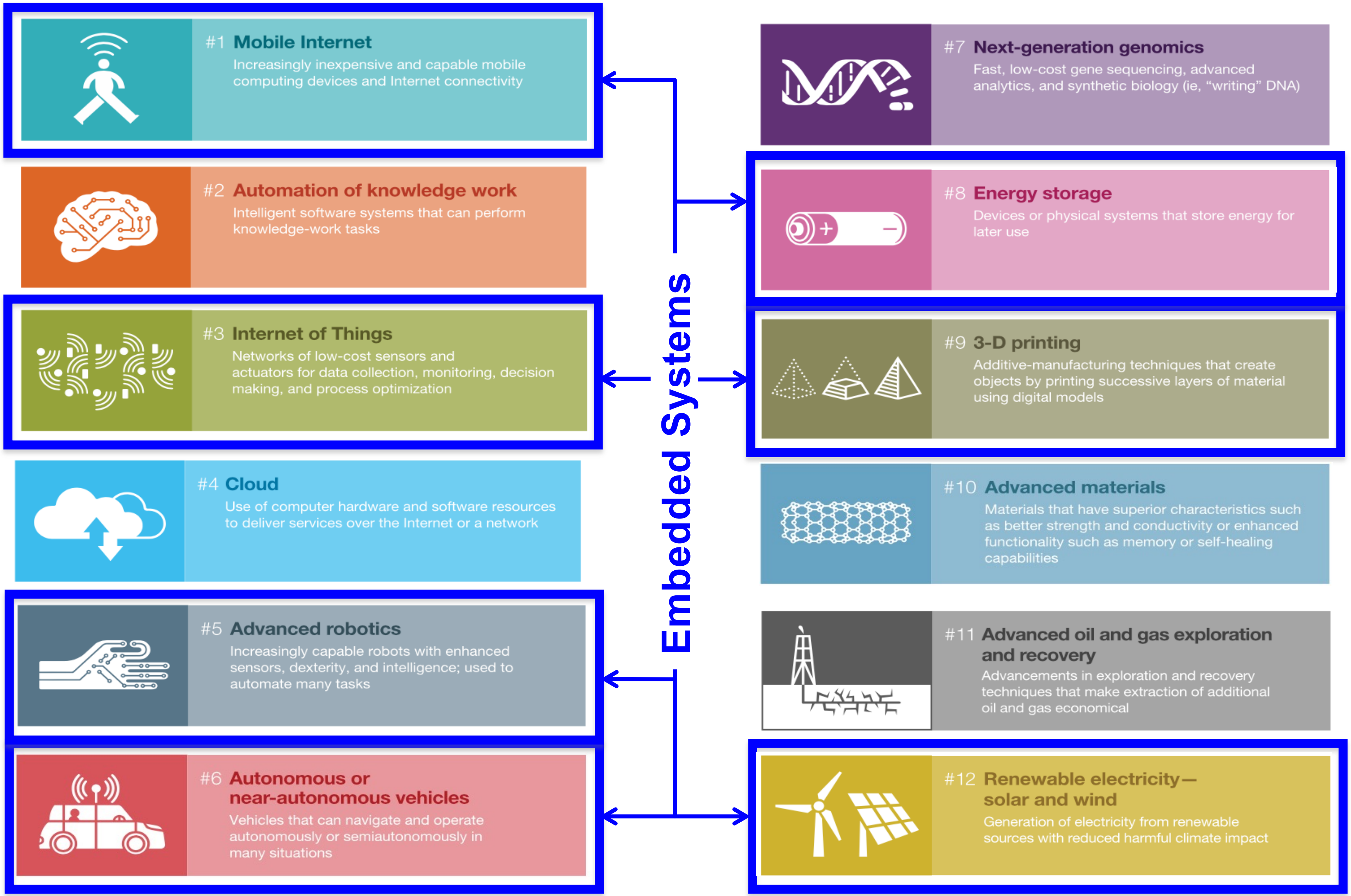
Reactive and Real-time Systems

- Embedded systems are often reactive
  - reactive systems must react to stimuli from the system environment
  - "a reactive system is in continual interaction with its environment and executes at a pace driven by that environment" [Ber+96]

- Embedded systems often have real-time constraints
  - "a real-time constraint is called hard, if not meeting that constraint could result in a catastrophe" [Kop97]; other real-time constraints are called soft
  - for hard-real time systems ...
    - guaranteed system response must be proven, without statistical arguments
    - correct answers that arrive too late are considered wrong

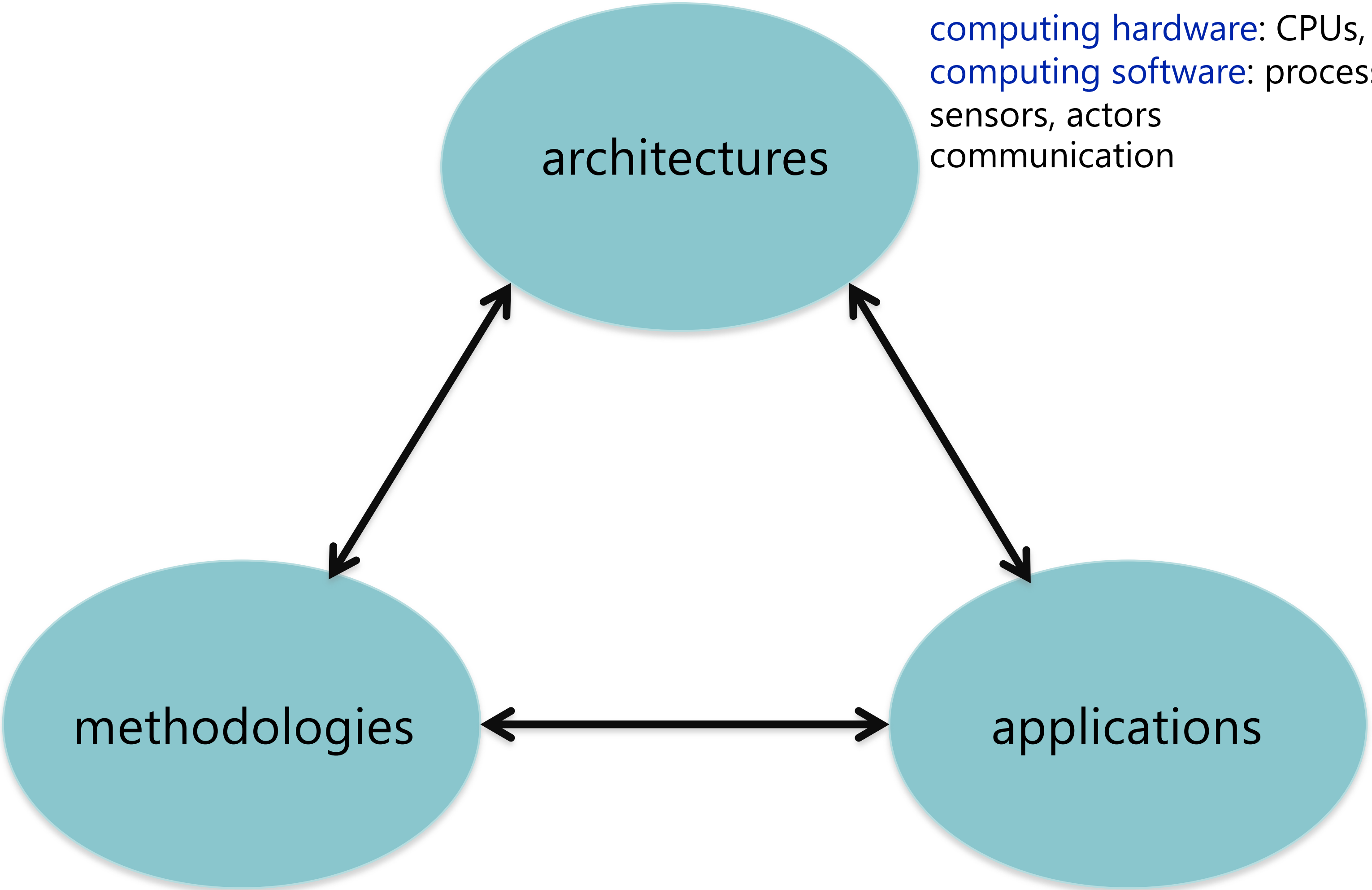
[Ber+96] J.-M. Bergé et al. (Eds.) High-level System Modeling: Specification Languages. Springer. 1995.

[Kop97] H. Kopetz. Real-Time Systems: Design Principles for Distributed Embedded Applications. Springer. 1997.



[Man+13] J. Manyika et al. Disruptive technologies: Advances that will transform life, business, and the global economy. McKinsey Global Institute. 2013

- Embedded system design comprises studying three fields



computing hardware: CPUs, networks, …
computing software: processes, scheduling, …
sensors, actors
communication

modeling and analysis,
synthesis / compilation, verification, …

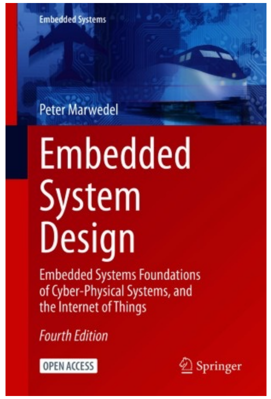
characteristics, specifications,
reference designs, …

Design Goals and Challenges

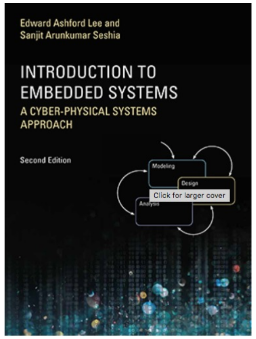
- Design goals
  - functionality
  - deadlines: hard and soft real-time systems, multi-rate systems
  - power and energy consumption
  - cost: manufacturing and development
  - design time
  - dependability
  - ...
- Challenges
  - finding the right amount of hardware needed
  - meeting deadlines
  - minimizing power consumption
  - designing for upgradeability
  - achieving dependable operation
  - mastering restricted development environments
  - ...

- Lecture
  - learn about theoretical foundations and practical aspects of embedded system design
- Exercises
  - work on exercises (paper & pencil) to deepen understanding of the lecture material
- Lab
  - introduction to and practical experience with an embedded compute platform and a real-time operating system (RTOS)

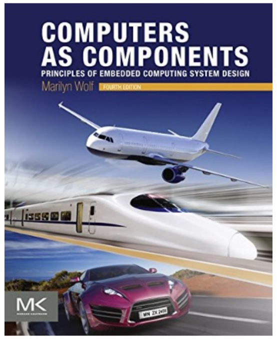
- Introduction
- Specification and modeling
  - models of computation
  - state-based models
  - dataflow-based models
- Target architectures
  - general-purpose processors
  - specialized processors: digital signal processors, microcontrollers, ASIPs
  - FPGAs and ASICs
  - multi-core processors and system-on-chip
- Reactive and real-time systems
  - tasks and task definitions
  - programming paradigms
  - real-time scheduling techniques
  - shared resources
- Performance and energy
  - processor performance, worst-case execution time analysis
  - power and energy

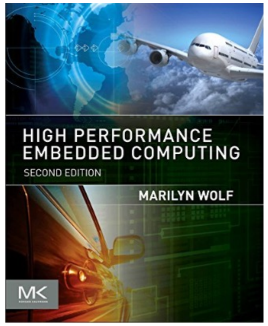


Peter Marwedel: *Embedded System Design*, 4th Ed, Springer, 2021 (Open Access)



Edward A. Lee and Sanjit A. Seshia: *Introduction to Embedded Systems: A Cyber-Physical Systems Approach*, 2nd Ed, MIT Press, ISBN 978-0-262-53381-2, 2017 (Open Access)





Marilyn Wolf: *Computers as Components*, 4th Ed, Morgan Kaufmann, ISBN 978-0-12-805387-4, 2017

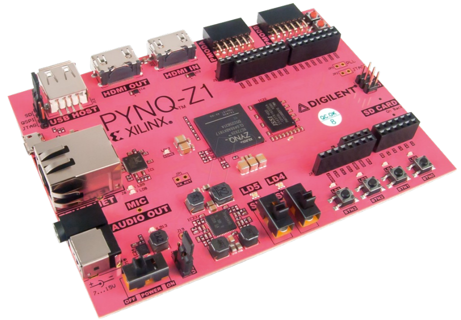
Marilyn Wolf: *High-Performance Embedded Computing*, 2nd Ed, Morgan Kaufmann, ISBN 978-0-12-369485-0, 2014

Uwe Brinkschulte & Theo Ungerer: *Mikrocontroller und Mikroprozessoren*, 3rd Ed, Springer, ISBN: 978-3-642-05397-9, 2010

The lecture slides contain also ideas and material of Lothar Thiele, ETH Zurich.

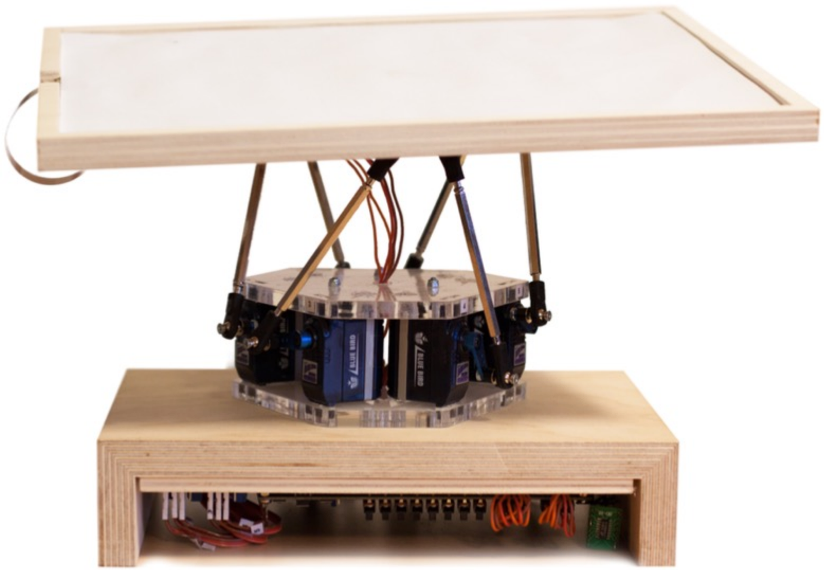
Lab - Topics

- Development platforms / technologies
  - PYNQ with ARM/FPGA System-on-Chip Zynq 7020
    - dual-core ARM Cortex-A9 processor
    - Xilinx 7-series field programmable gate array



  - freeRTOS real-time operating system for microcontrollers
  - Xilinx Vitis software platform for C programming

- Development tasks
  - implement small applications on freeRTOS/PYNQ
  - control a mechatronics system (ball-on-plate)



- Materials and information in PANDA

- Lecture & Exercises
  - Monday 9:15 – 10:45 and Tuesday 10:15 – 11:00
  - exercise sheets provided, try to solve the problems on your own, discussion of solutions in class

- Lab
  - announced in PANDA

- Contact
  - Marco Platzner, platzner@upb.de, 60-5250
  - Lennart Clausing, lennart.clausing@uni-paderborn.de, 60-5396 (lab)

- Grading

  written exam
  - covers material from the lecture, exercises and lab
  - successful lab participation earns a bonus of one or two grade steps (if exam has been passed)
  - nothing to do for study achievement – but you have to register for it (!)