Embedded System Design and Modeling

Introduction to Embedded Systems Design

What are Embedded Systems?

- ▶ Embedded System (Marwedel 2011): Embedded systems are information processing systems embedded into enclosing products

- ▶ Cyber-Physical Systems (Lee & Seshia 2017): A CPS is an integration of computation with physical processes whose behavior is defined by both cyber and physical parts of the system

  - ▶ "cyber" means $\approx$ "control" (from Greek)

- ▶ Key points:
  - ▶ there is a physical process to be controlled
  - ▶ there is some computational device who controls it
  - ▶ the processing is **close** to the physical process:
    - ▶ spatially: done right there (embedded)
    - ▶ behavioral: dedicated / specific to a particular process
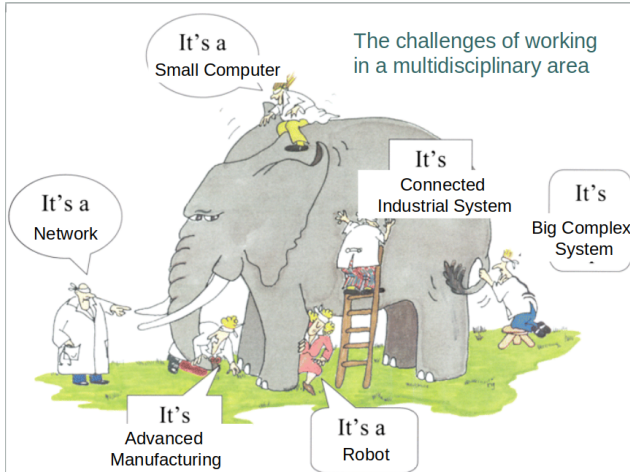
What are Embedded Systems?

- Synonyms (more or less):
  - Embedded Systems
  - Internet of Things (IoT)
  - Industrial Internet
  - Systems of Systems
  - Industry 4.0
  - Internet of Everything (IoE)
  - Smart

  $\approx$ Cyber-Physical Systems

What are Embedded Systems?
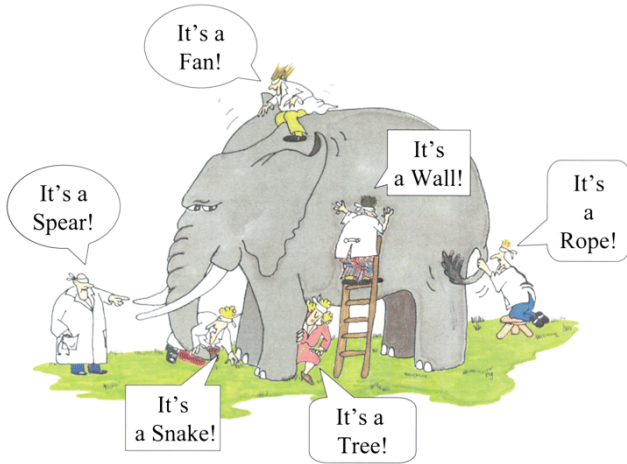
- Image from Lee&Seshia 2017

What are Embedded Systems?

- Image from Lee&Seshia 2017

- ▶ Embedded systems are everywhere:
    - ▶ Automotive (Transportation industry)
    - ▶ Telecommunications
    - ▶ Medicine
    - ▶ Consumer electronics
    - ▶ . . .

Common characteristics

- Embedded systems share common characteristics:
  - must be **dependable**
    - reliability: probability that a system will not fail
    - maintainability: probability that a failed system can be repaired
    - safety: does not cause any harm even in worst-case conditions
    - security: allows authentication and confidentiality of data
  - must be **efficient**
    - low power consumption
    - low weight
    - low cost
    - no unnecessary resources used

Common characteristics

- Embedded systems share common characteristics:
    - must satisfy strict timing constraints
        - most embedded systems operate in real-time
    - must be fault-tolerant

- Aren't embedded systems just "small PC's"? No.

	Embedded	PC-like
Architectures	Frequently heterogeneous very compact	Mostly homogeneous not compact (x86 etc)
x86 compatibility	Less relevant	Very relevant
Architecture fixed?	Sometimes not	Yes
Model of computation (MoCs)	C+multiple models (data flow, discrete events, ...)	Mostly von Neumann (C, C++, Java)
Optim. objectives	Multiple (energy, size, ...)	Average performance dominates
Real-time relevant	Yes, very!	Hardly
Applications	Several concurrent apps.	Mostly single application
Apps. known at design time	Most, if not all	Only some (e.g. WORD)

Figure 1: Embedded Systems vs PC

- Image from Marwedel 2011

- Typical structure of an embedded system (CPS)
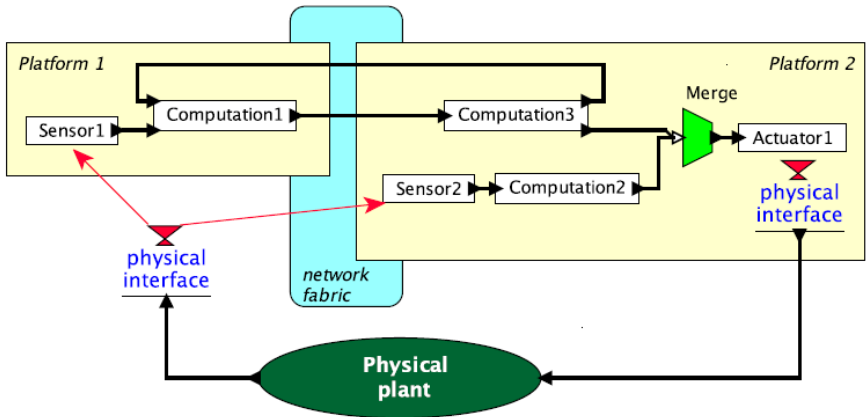
- Image from Lee&Seshia 2017

Structure of an embedded system

- Main components:
  - the physical process (known as the "plant")
  - sensors: acquire information from the process
  - actuators: act on the process
  - computation: may be split between different devices
  - communications: between separate devices

The design process

- Iterative:
  - **Modeling**: "the process of gaining a deeper understanding of a system through imitation. It specifies what a system does."
  - **Design**: "the structured creation of artifacts. It specifies how a system does what it does."
  - **Analysis**: "the process of gaining a deeper understanding of a system through dissection. It specifies why a system does what it does."
  - . . . and iterate again.

The V-Cycle

- ▶ Common System Development Cycle in automotive industry (from a SW point of view):
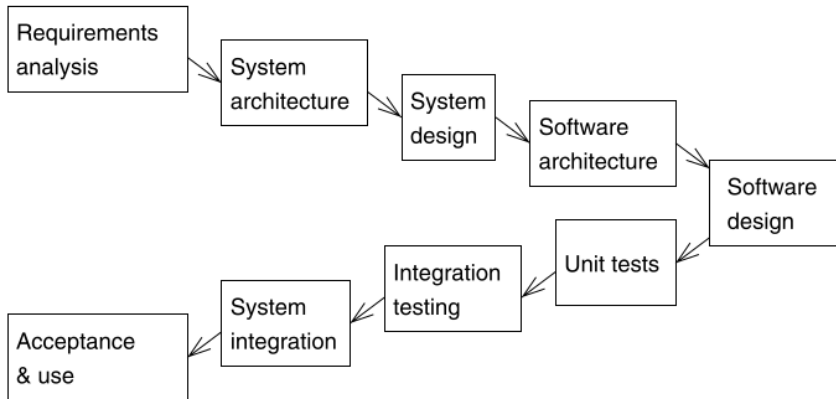
- ▶ Image from Marwedel 2011

The V-Cycle

Steps:

- ▶ Requirements specifications
- ▶ System Architecture & Design
  - ▶ part of the Design and Modelling is done here
- ▶ SW Architecture & Design
  - ▶ part of the Design and Modelling is done here
- ▶ Implementation
- ▶ Tests & Validation
  - ▶ all tests are done against the corresponding documents from the other branch

Other processes

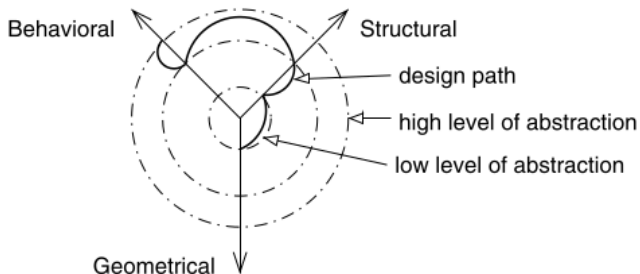- ▶ For System & Software: Waterfall, Agile
- ▶ For Hardware: Gajski's Y-chart

Figure 2: Gajski Y Chart and design path

- ▶ Image from Marwedel 2011