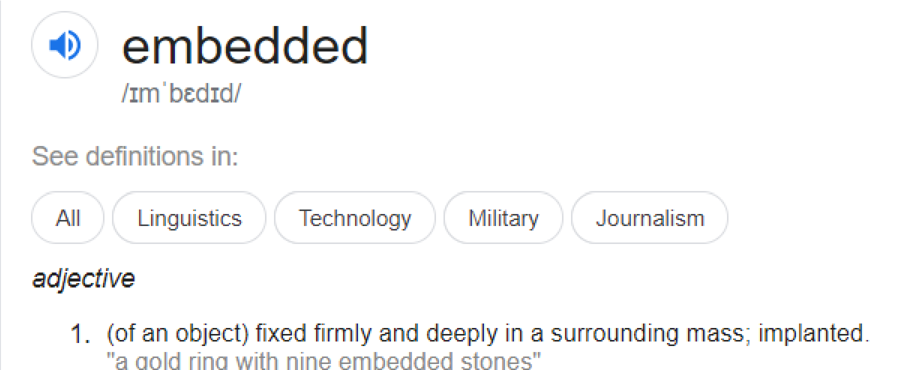
Embedded System Design and Modeling

I. Introduction

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 ≈ "control" (from Greek)



What are Embedded Systems?

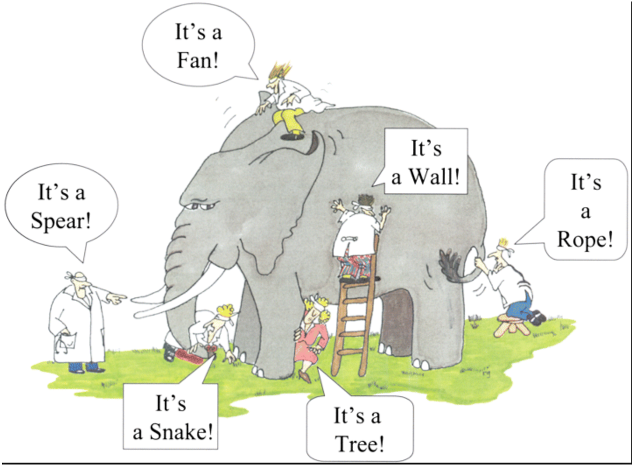
- Key points:
  - there is a physical process to be controlled
    - e.g. the movement of an automatic door, a car window, an elevator, a washing machine
  - there is some computational device who controls it
  - the processing is **close** to the physical process:
    - spatially: done right there (embedded)
    - behavioral: dedicated / specific to a particular process
    - e.g. not with a general purpose computer, not on the cloud

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

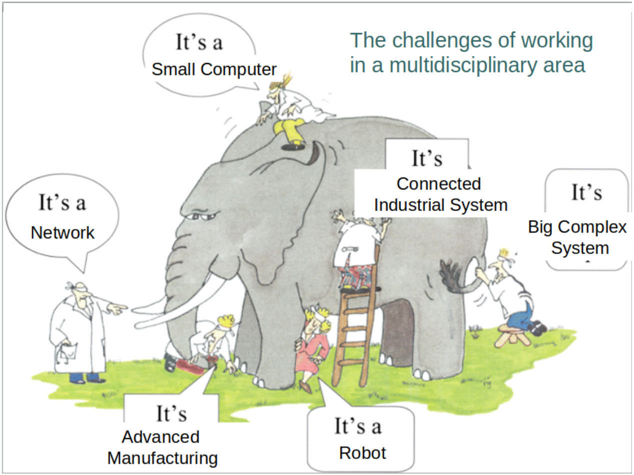
  $\approx$ Cyber-Physical Systems

What are Embedded Systems?



- Image from Lee&Seshia 2017

What are Embedded Systems?



- Image from Lee&Seshia 2017

Found everywhere

- 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
    - sometimes must guarantee response in a given time window
    - requirement example: "If pinch is detected, the motor must be stopped within 60ms" (automatic door closure)
  - must be **fault-tolerant**
    - assume that components may fail
    - detect failures, enter safe mode

Embedded systems vs PC

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

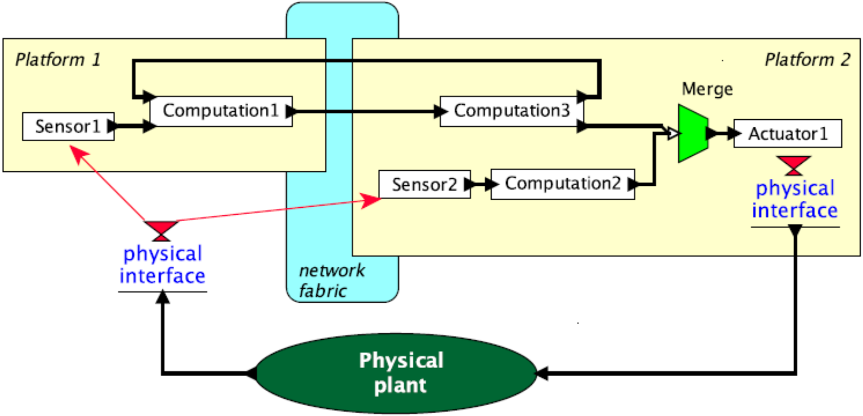
	Embedded	PC-like
Architectures	Frequently heterogeneous very compact	Mostly homogeneous not compact (x86 etc)
x86 compatibility	Less relevant	Very relevant
Architecture fixed?	Sometimes not	Yes
Model of computation (MoCs)	C+multiple models (data flow, discrete events, ...)	Mostly von Neumann (C, C++, 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

Structure of an embedded system

- Typical structure of an embedded system (CPS)



- Image from Lee&Seshia 2017

Structure of an embedded system

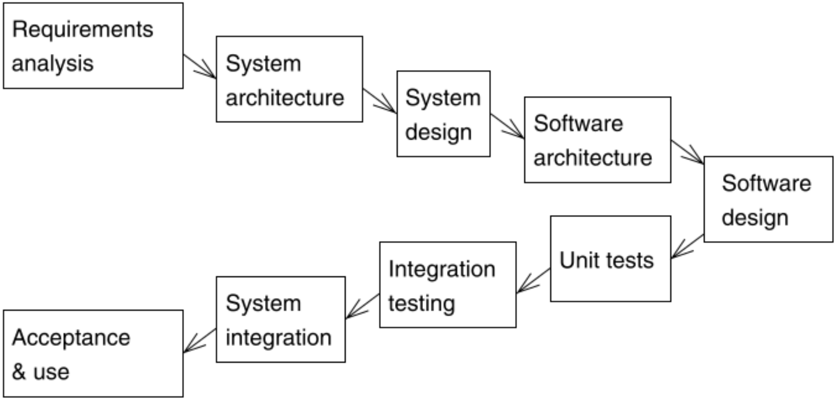
- Main components:
  - the physical process (known as the "plant")
  - sensors: acquire information from the process
  - actuators: act on the process
  - computation: may be split between different devices
  - communications: between separate devices

The design process

- Iterative, multiple steps:
  - **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

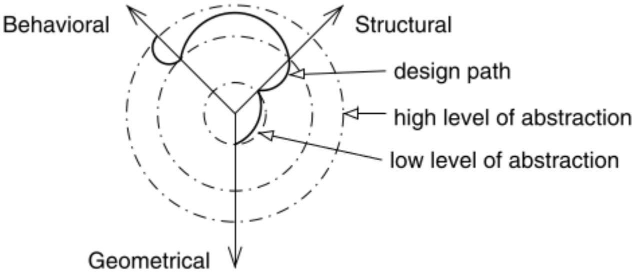


Figure 2: Gajski Y Chart and design path

- Image from Marwedel 2011

What we cover

What we cover in this course:

- Modeling:
  - Modeling continuous dynamics with differential equations
  - Modeling discrete dynamics with finite state machines (FSM)
  - FSM concurrency, hierarchy
- Design:
  - Basics scheduling
- Analysis:
  - ...