# Cyber Physical Systems

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CMPE320

## Definition

- **A cyber-physical system (CPS)** is an integration of computation with physical processes whose behavior is defined by both cyber and physical parts of the system.
- Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.
- For understanding embedded systems, understanding the physical components and the computational components is not sufficient. Understanding their interaction is necessary.

## CPS Application Examples

- Hearth surgery robots: Surgical tools shall move with the motion of the hearth to manage operation without stopping the hearth. It needs
  - to monitor the motion of the hearth,
  - to model the behaviour of the hearth,
  - to manage interaction that does not stop the hearth beats.
- It requires a careful design using extensive modelling of the hearth, the tools, the computational hardware and software.

## Example: City traffic lights

- A non-stop flow of city traffic is possible at all arteries of the city by extensive sensory systems detecting the cars and their movements in the traffic with an expensive infrastructure
- A better approach might be to have the cars themselves cooperate. They track their position and communicate to cooperatively use shared resources such as intersections. Making such a system reliable, of course, is essential to its viability. Failures could be disastrous.

## Example: Flight Control System

- An airplane may refuse to crash by a well-designed flight control system. Even if preventing all possible causes of a crash is not possible, a well-designed flight control system can prevent certain common causes at landing and take off by a well designed cyber physical system.
- In a fly-by-wire aircraft, since a computer mediates the commands from the pilot, the computer can modify the commands. Many modern flight control systems modify pilot commands in certain circumstances. For example, commercial airplanes made by Airbus use a technique called flight envelope protection to prevent an airplane from going outside its safe operating range.
  They can prevent a pilot from causing a stall, for example.

## Features of CP systems

- In all of these examples we have a **physical plant,** which is the physical part of a cyber physical system. Physical part mostly have mechanical, chemical, biological processes, or human operators.
- Next, we have **one or multiple computational platforms** such as mainframe computers, PCs, mini computer boards, microcontrollers, which are interacting to human operators at one side, sensors and actuators at physical plant side.
- Moreover, we have a **communication network fabric** of the computers, to improve the overall behaviour of the system in a desired manner.

# Structure of a cyber-physical system

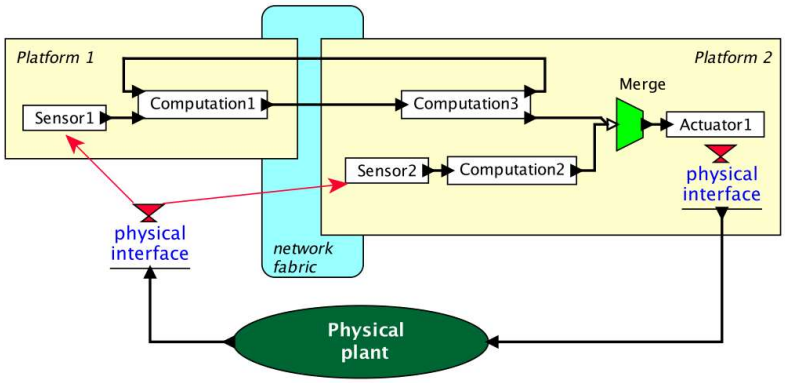
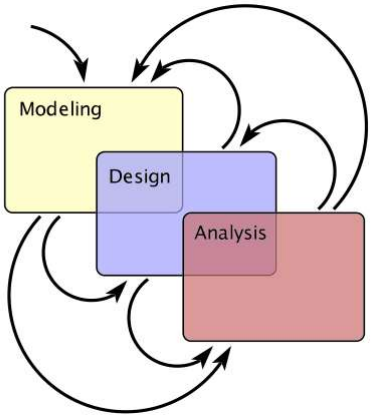



Figure 1.1: Example structure of a cyber-physical system.

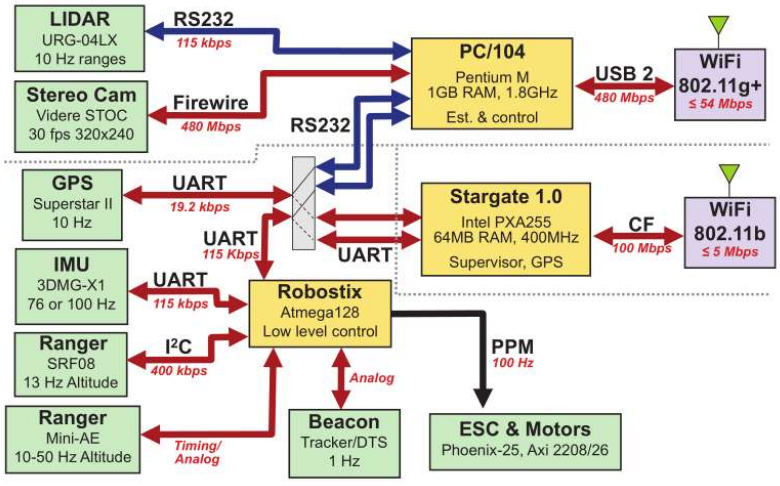
# Iterative process of modeling, design, and analysis



# 1.3 The Design Process

- **Modeling** is the process of gaining a deeper understanding of a system through imitation. Models imitate the system and reflect properties of the system. Models specify what a system does.
- **Design** is the structured creation of artifacts. It specifies how a system does what it does.
- **Analysis** is the process of gaining a deeper understanding of a system through dissection. It specifies why a system does what it does (or fails to do what a model says it should do).

# The STARMAC *Quadcopter* architecture -1



## The STARMAC *Quadcopter* architecture -2

- The hardware architecture of the first generation STARMAC quadrotor is shown in Figure 1.4. At the left and bottom of the figure are a number of sensors used by the vehicle to determine where it is (localization) and what is around it. In the middle are three boxes showing three distinct microprocessors.
- The Robostix is an Atmel AVR 8-bit microcontroller that runs with no operating system and performs the low-level control algorithms to keep the craft flying.
- The other two processors perform higher-level tasks with the help of an operating system. Both processors include wireless links that can be used by cooperating vehicles and ground controllers.

## 1.3.1 Modeling

- The modeling part of the book, which is the first part, focuses on models of dynamic behavior.
- We define a system to be simply a combination of parts that is considered as a whole. A physical system is one realized in matter, in contrast to a conceptual or logical system such as software and algorithms. The dynamics of a system is its evolution in time: how its state changes.
- A **model of a physical system** is a description of certain aspects of the system that is intended to yield insight into properties of the system. In this text, models have **mathematical properties that enable systematic analysis**. The model imitates properties of the system, and hence yields insight into thatsystem.

## Modeling -2

- **A model is itself a system**. It is important to avoid confusing a model and the system that it models.
- A model of a system is said to have high fidelity if it accurately describes properties of the system. It is said **to abstract the system** if it omits details.
- **A cyber-physical system (CPS)** is a system composed of physical subsystems together with computing and networking.

## 1.3.2 Design -1

- Design considers
  - Sensors and Actuators
  - Embedded Processors
    - Memory Architectures
    - Input-Output
    - Multitasking
    - Scheduling

## 1.3.3 Analysis

- A design without specifications cannot be right or wrong, it can only be surprising (Young, 1985)
- The analysis focuses on precise specifications of properties, on techniques for comparing specifications, and on techniques for analyzing specifications and the resulting designs.
  - Temporal Logic
  - Equivalence and Refinement
  - Abstraction
  - Reachability Analysis and Model Checking
  - Quantitative Analysis
  - Security and Privacy.

## 1.4 Summary

- Cyber-physical systems are heterogeneous blends by nature. They combine computation, communication, and physical dynamics. They are harder to model, harder to design, and harder to analyze than homogeneous systems.
- This chapter gives an overview of the engineering principles addressed in this book for modeling, designing, and analyzing such systems.