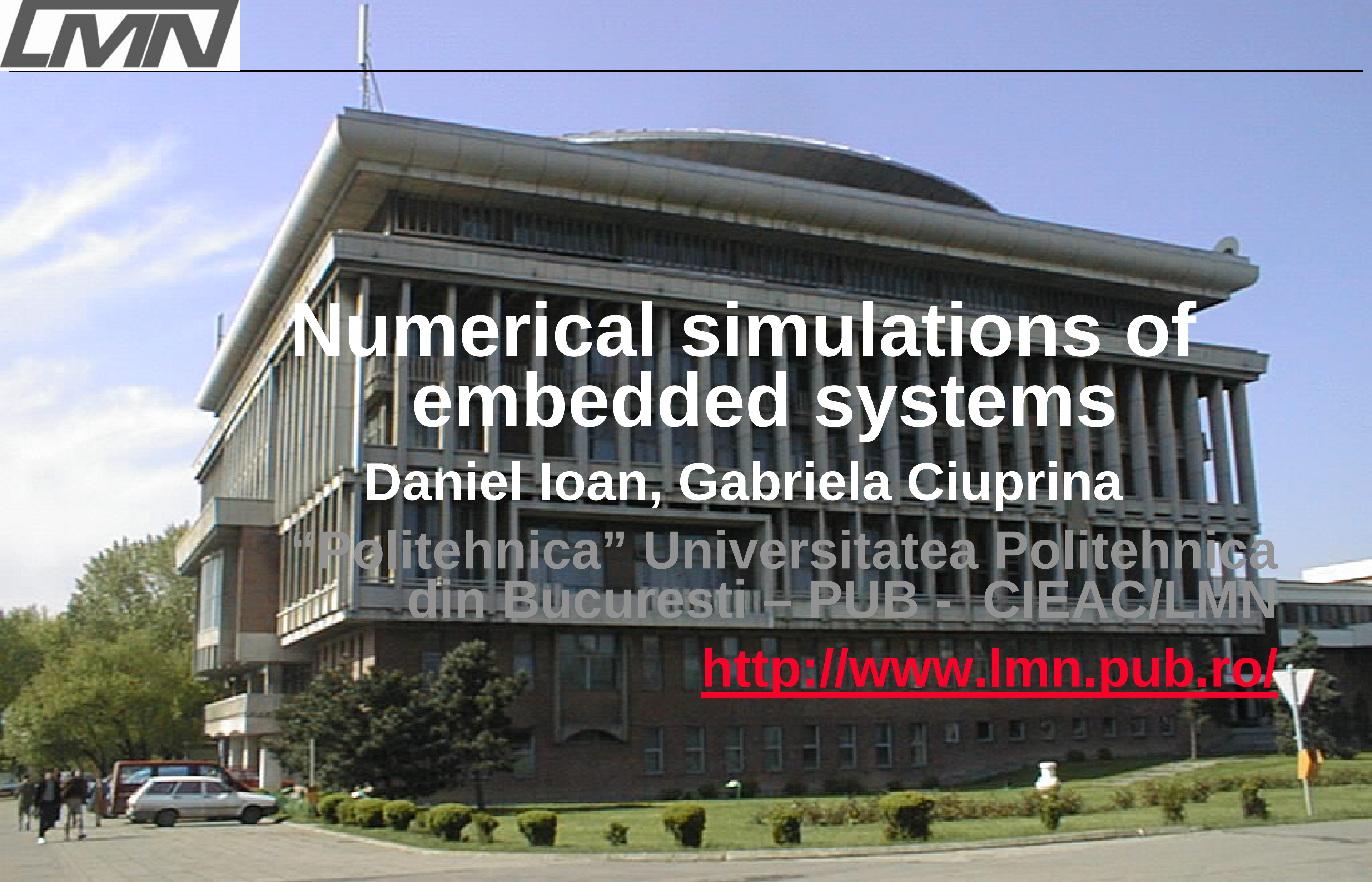


Numerical simulations of embedded systems

Daniel Ioan, Gabriela Ciuprina

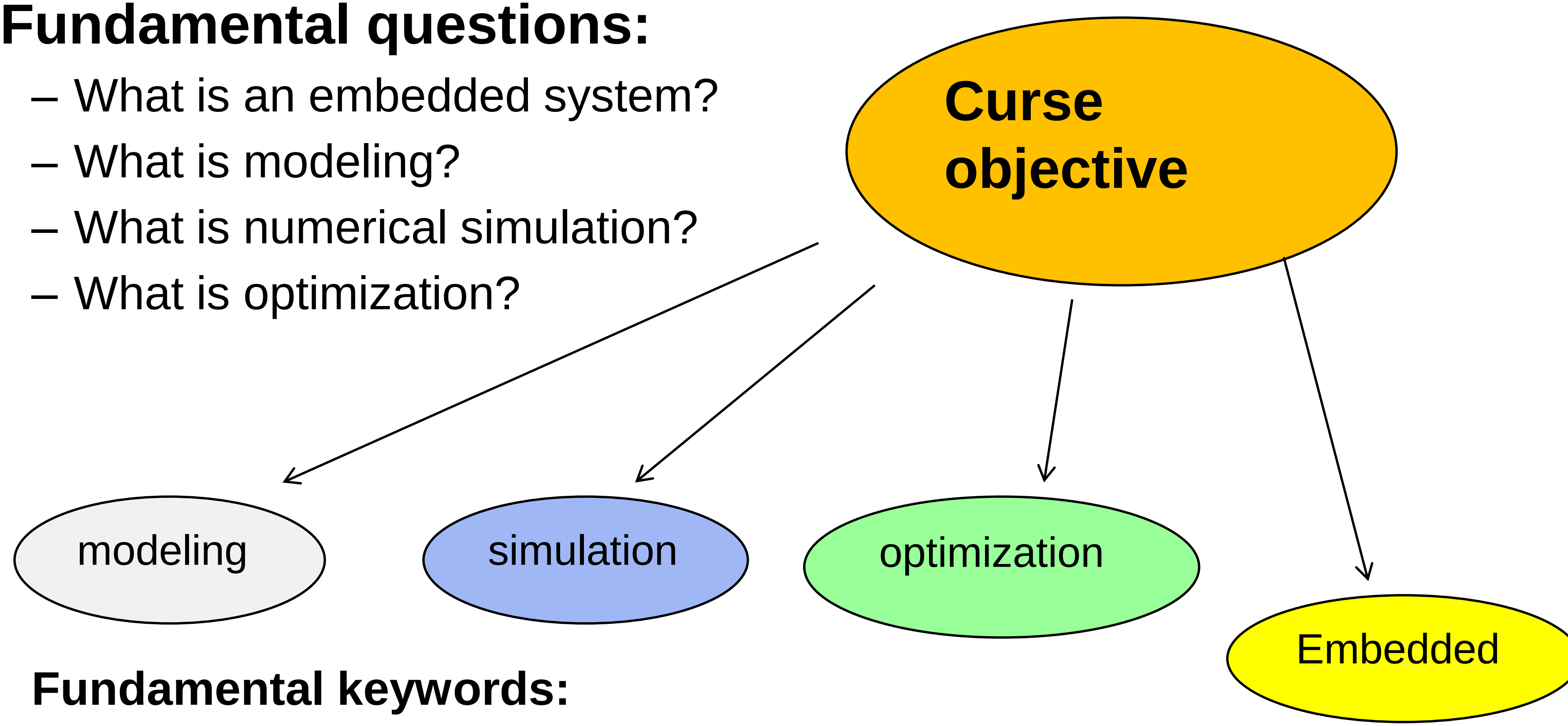
“Politehnica” Universitatea Politehnica din Bucuresti – PUB - CIEAC/LMN

http://www.lmn.pub.ro/

Contents

00. Main objectives of the course:

- Numerical **modeling, simulation** and **optimization** of the **embedded** systems encountered mainly in the automotive industry (Appendix A: official course description).
- **Fundamental questions:**
  - What is an embedded system?
  - What is modeling?
  - What is numerical simulation?
  - What is optimization?



Fundamental keywords:

00.2. Course contents

0. **Introduction**. Embedded systems. Modeling, Simulation, Optimization
1. **Conceptual modeling** of embedded systems. Multipysics and geometric aspects.
2. **Mathematical modeling of distributed** systems.
3. **Mathematical modeling of lumped** systems.
4. **Numerical modeling** of coupled multiphysics systems. Model order reduction.
5. **Computational modeling** of embedded systems on multiprocessor computers. Software environments.
6. **Optimization of embedded systems.**

00.3. Applications / Laboratory

1. Modeling with **MATLAB/Simulink**
2. Simulation of a **clutch lock-up** model
3. A**nti lock braking-system (ABS)**
4. Automotive **suspension**
5. E**lectrical vehicle system**
6. Simulation of automatic **climate control** systems
7. MEMS **accelerometer** with automotive application

00.4. Assessment

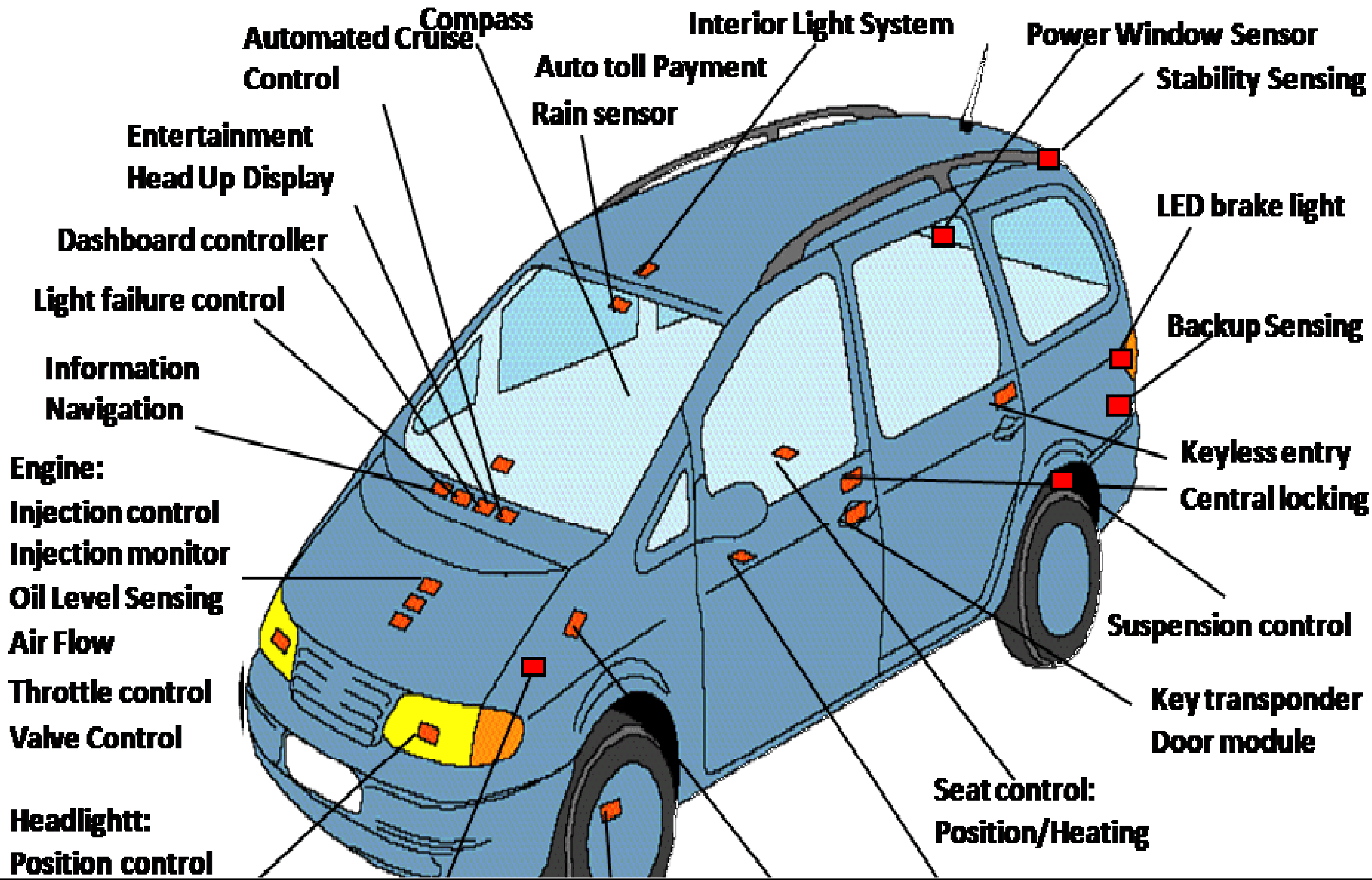
Type of activity	Evaluation criteria	Evaluation methods	Weight in final grade
Course	The level of understanding of concepts and modeling procedures	Oral/written examination	50%
Laboratory	The completeness and the correctitude of the laboratory report, the level of mastering of the software tools used for the modeling, results obtained from the numerical simulations.	Reports	50%

Minimal standard of performance: Correct understanding of the steps of a modeling procedure and their correct use in a study case. Correct answers to the 4 fundamental questions.

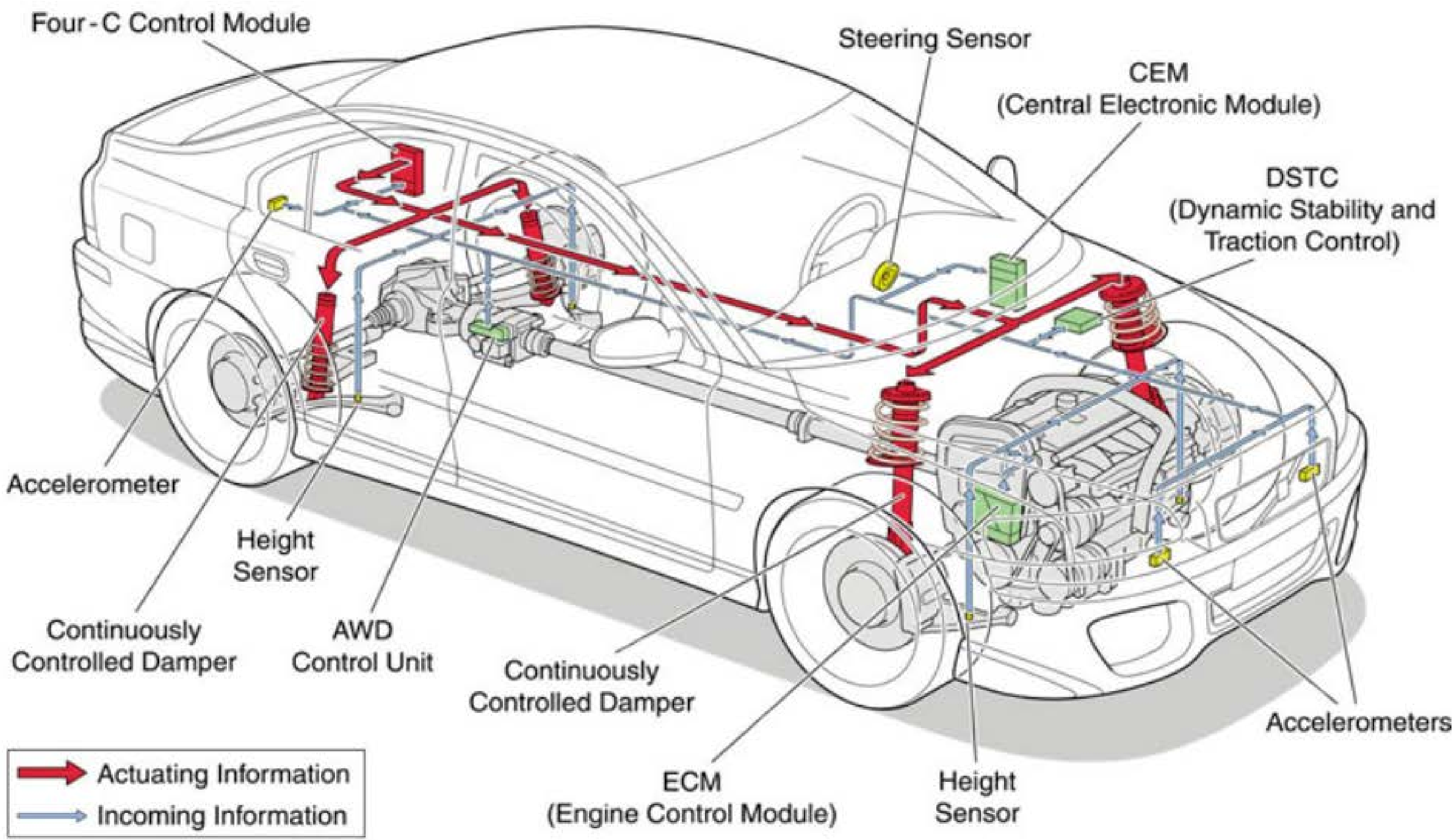
0. Integrated/embedded systems

- **What is an embedded system:** a control system with a dedicated function which integrates several technologies:
  - electric / mechanic (ie mechatronic, MEMS, multiphysics)
  - analog / digital electronics
  - hardware / software
  - devices with distributed parameters / circuits with lumped parameters
- Modern embedded systems are often based on customized **microcontrollers** or ordinary **microprocessors**, especially in more-complex systems. A common standard class of dedicated processors is the **digital signal processor** (DSP).
- In electric vehicles, and hybrid vehicles increasingly use embedded systems to maximize efficiency and reduce pollution. Automotive safety systems include **anti-lock braking system** (ABS), **Electronic Stability Control** (ESC), **traction control** (TCS), **Air-bag** and **automatic four-wheel drive**.

Automotive embedded systems



Automotive embedded systems



https://www.ohlins.com/products/ces/ces-ohlins-racing/

Automotive embedded systems

- **ABS** - Anti-lock braking system
- **ESC** - Electronic stability control
- **ESP** - electronic stability program
- **DSC** - dynamic stability control (DSC)
- **TCS** - traction control system, also known as
- **ASR** (from German: *Antriebsschlupfregelung*)
- **ASS** – Active Suspension System
- **ECU, ECM** – Engine Control Unit/Module
- **Climatronic** - Climate control
- **ADS** - Automated driving system,
- it has several levels of automation

https://en.wikipedia.org/wiki/Automated_driving_system

https://en.wikipedia.org/wiki/Vehicular_automation

- **Connected vechicle: V2I -** Vehicle to Infrastructure; **V2V -** Vehicle to Vehicle; **V2C -** Vehicle to Cloud; **V2P -** Vehicle to Pedestrian; **V2X** Vehicle to Everything

http://autocaat.org/Technologies/Automated_and_Connected_Vehicles/

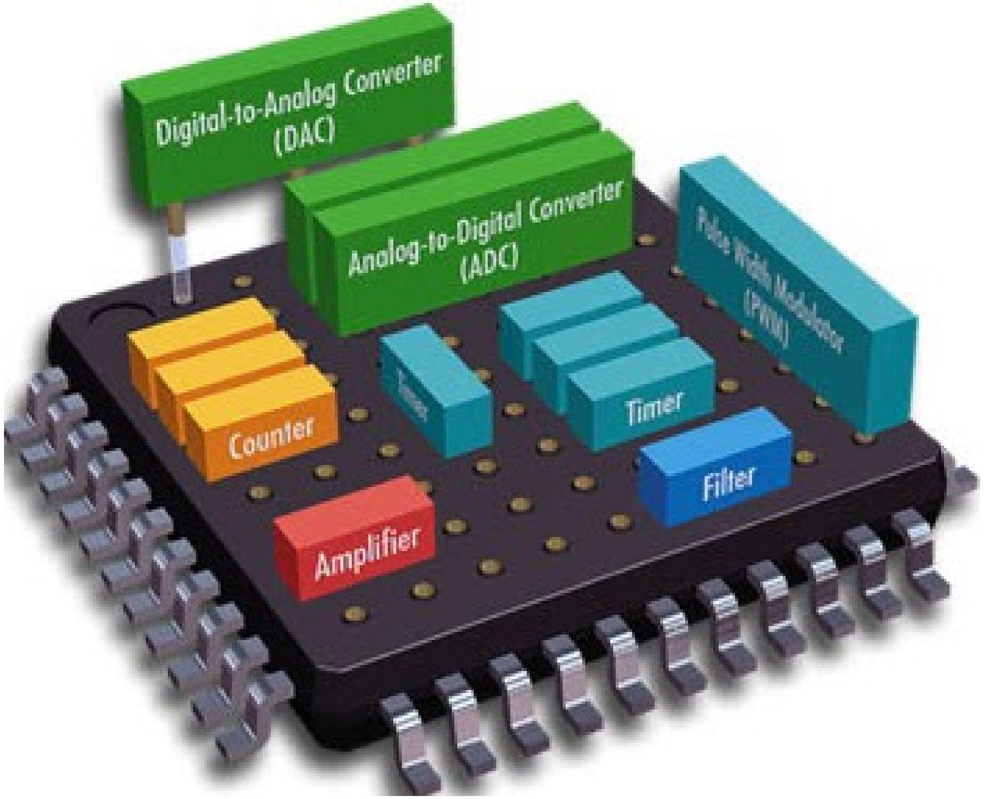
More details regarding auto-moto embedded systems in the Appendix B

Type of embeddings

Embedding: integration (coupling) of several technologies in a unique system.

Types of embeddings:

- Hardware/software;
- Analog/digital integrated circuits;
- Mechanic/electronic (mechatronic);
- Multiphysics (MEMS = micro-electro-mechanic-systems);
- Distributed (field/PDE) – Lumped (circuits/ODE).



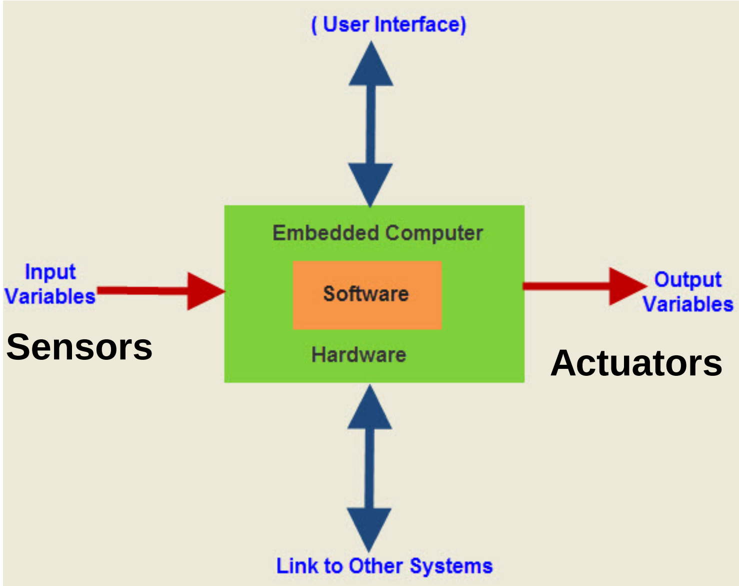
Structure of an embedded system

An embedded system is a particular electronic system that typically has a software that is embedded in computer hardware. It is programmable or non- programmable depending on the application.

It has input signals coming from sensors

and output signals going to actuators.

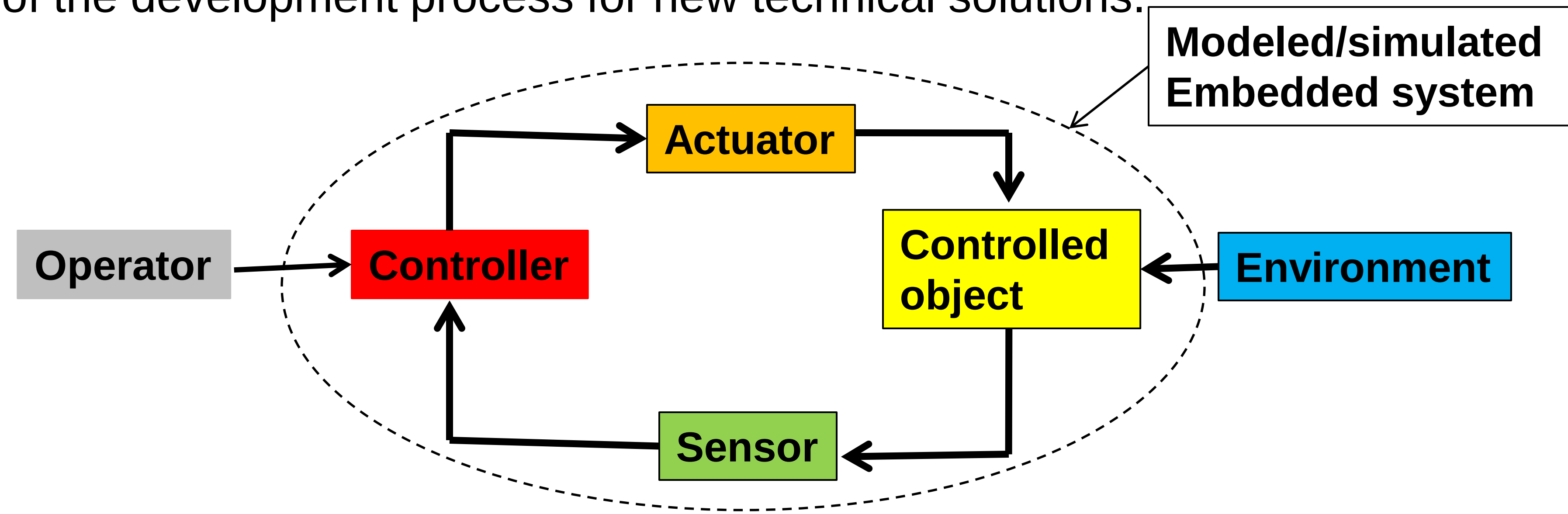
Usually it is included in closed loop, with a feedback.



An Embedded system is a combination of computer hardware and software. The embedded system hardware includes elements like user interface, Input/Output interfaces, display and memory, etc. Generally, an embedded system comprises power supply, processor, memory, timers, serial communication ports and system application specific circuits. See details in the Appendix B.

Main target of the course

- Due to the diversity of design and development methodologies and techniques of these kinds of embedded systems, the present course has not as subject these methodologies and techniques. They are subject of other undergraduate and graduate courses in the area of the Information Technology and Computer Programming.
- The main subject of the present course is the **numerical simulation and modeling of the embedding system**, including sensors, actuators and closed loop with controlled object and environment. It is an essential part of the development process for new technical solutions.



0.2. What is modeling?

Model is a simplified representation of real objects. Modeling is an essential procedure in the engineering, with following 7 steps:

- **Conceptual Modeling (CM)** establishes consistent **geometrical (GM)** and **physical models (PM)** of the device/system, including justified approximations of geometrical and physical nature (CM=PM+GM);
- **Mathematical Modeling (MAT)** formulates the mathematical equations that describe the operation of the device, presenting the conceptual model in a mathematical language, as a problem properly formulated;
- **Analytical–Approximate Modeling (AAM)** determines the approximate analytical relationship between the input and output physical quantities
- **Numerical Modeling (NM)** aims to build an algorithm to obtain the solutions of the mathematical model equations;
- **Computational Modeling (CmpM)** aims to create and test a computer program to implement the numerical algorithm;
- **Model Order Reduction (MOR)** finds the simplest input/output system which approximates the behavior of the modeled device;
- Model **Verification and Validation (VV).**

Electromagnetic and Multiphysics Modeling

- The **electromagnetic modeling** is dedicated to electromagnetic devices, which are devices in which the electromagnetic field play an essential role.

- The **multiphysics modeling** is dedicated to several devices, in which are encountered several physical phenomena and fields: electric, magnetic, solid mechanics, fluid dynamics, thermal, etc. Typically these phenomena are coupled, by an mutual influence, making the analysis more complicated.

- The designers of engineered devices and systems need reasonably complex models, with complexity order of tens. They also need to be parameterized in order to support the process of optimal design.

- This requirement can be achieved only if the analysis and order reduction methods are adequate for the specific characteristics of the model under study. The detailed (field) models are described by PDE, when the simplified (circuit) models are described by ODE.

Discretization methods

The **Numerical Modeling** is based on the discretization of the PDE of mathematical model. The most frequently methods are:

- Finite Elements (FEM);
- Finite Difference (FDM);
- Finite Integration Technique (FIT);
- along with methods based on integral electromagnetic field equations (IEM);
- specifically the boundary elements method (BEM any of these being implemented through the techniques of the Moments Method (MM).

The ODE are solved by numeric qudrature procedures (implicit or explicit).

Each technique has specific characteristics which need a careful study in order to identify the most appropriate method to extract the reduced model for the analyzed device. They use several kind of mesh whose discrete forms are produced starting from various forms of the electromagnetic field equations.

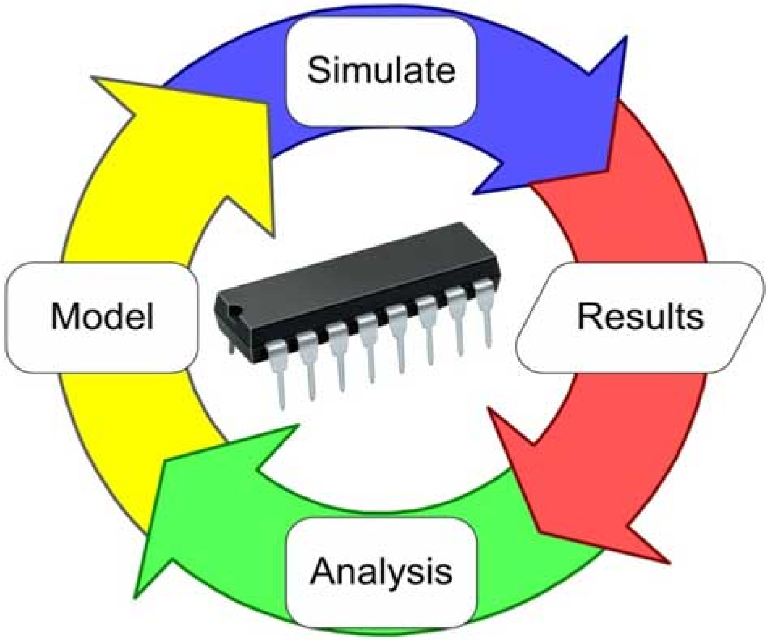
Characteristics of the Numerical Methods for PDE

Method	**Discretization Mesh**	**The Form of Discretized Equations**
FEM – finite element	Unstructured, formed with triangles, quadrilaterals, tetrahedrons, hexahedrons, etc.	Weak form, variational equations
FDM – FIT finite differences or integrals	Grid – mesh with regular topology, latticeal (tensorial product of 1D mesh). Pair of interlaced dual networks in case of FIT.	Differential (FDM) or global equations (FIT)
BEM – Boundary elements	Unstructured 2D mesh, on the domain boundary or on the interfaces between homogenous sub-domains.	Integral equations

0.3. Modeling vs Simulation

Today **computational modeling** is an essential step in the life cycle of many industrial products realized through **CAD, CAE, CAM.** These models are substitutes for traditional expensive prototypes realized to be tested before fabrication. As a result, launching on the market of new advanced products was accelerated, and became less expensive. The substantial comparative advantage makes the use of computational modeling and their simulation a must.

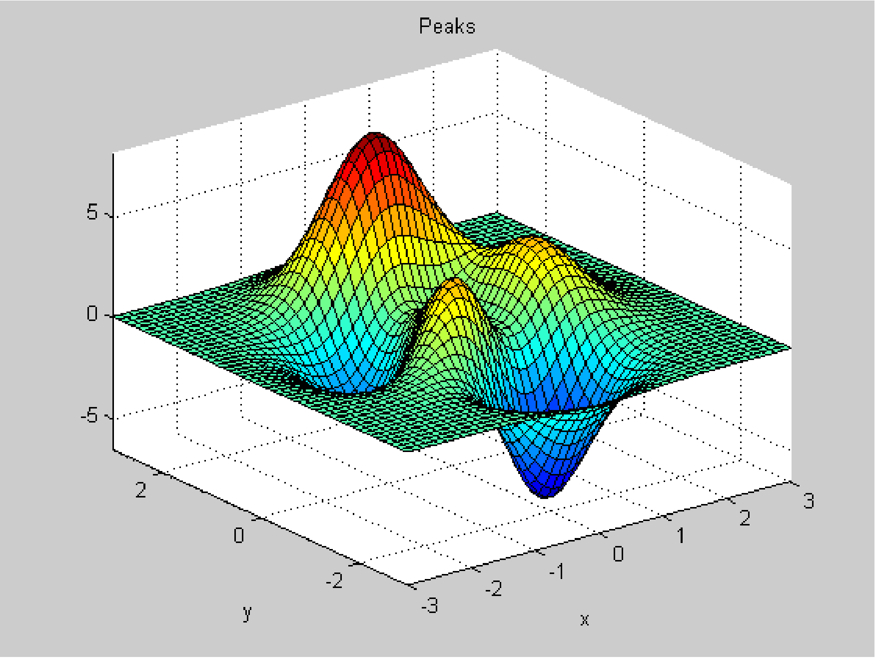
Simulation of a models means running of CAE simulation tools applied to a computational model, for several excitations in order to describe the behavior of the analyzed system, aiming to verify their technical characteristics. So it is foreseen the behavior of real objects.



Simulation can not be done without a previous modeling.

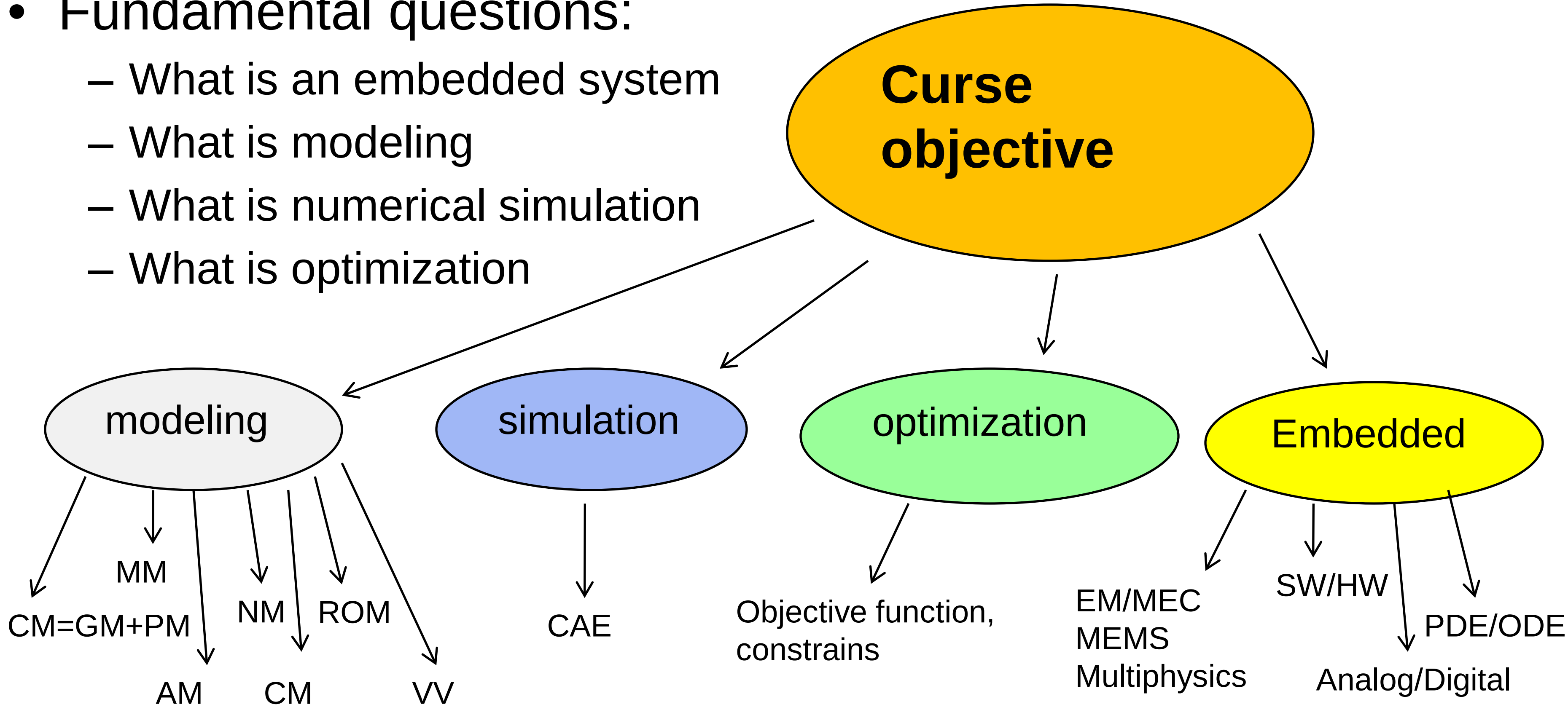
0.4. Optimization

- Embedded systems are described by a series of parameters: **p** = [p1,p2,…,pn], with geometrical or physical meanings.
- Optimization means finding the optimal, numerical values of these parameters which gives a minimal value of an objective (cost) function:
- $f_{min} = \min f(p), \quad f : IR^n \rightarrow IR$
- The parameter space can be IR^n or a sub-domain, defined by a series of restrictions (constrains)
- Optimization is useful in the optimal (re)design of the industrial objects, devices or systems.



0.5. Summary of the introduction

- Numerical **modeling, simulation** and **optimization** of the **embedded** systems encountered mainly in the automotive industry.
- Fundamental questions:
  - What is an embedded system
  - What is modeling
  - What is numerical simulation
  - What is optimization



0.6. Interactive conclusions

- Navigate on Internet with Google, aiming to find the meaning of the most relevant concept, related to “Numerical Simulation of Embedded Systems”.
- As a result, write a memo (min 3 pages) with following structure:
  - Title: Introduction in Numerical Simulation of Embedded Systems
  - Author: name, Group, Date
  - 1. What is an Embedded system
  - 2. What is Numerical Modeling, Simulation, Optimization
  - 3. Conclusion
  - 4. References
- You may use “copy and paste” descriptions or images from Internet, but do not forget to cite their link (http). The conclusions should be original (personal). Save the Memo for the final exam, when you will present it orally.

0.7. References: simulation in automotive industry

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Appendix A – Official description of the course

- Name of subject: Numerical simulations of embedded systems
- Course holder: Prof. Daniel Ioan, Prof. Gabriela Ciuprina
- Seminar/laboratory holder: SL. Dr. Sorin Lup, As Mihai Popescu, As Ruxandra Barbulescu
- Year of study: 1 Semester: 1
- Evaluation type: EX
- Estimated total time (hours per semester of the didactic activities)
- Number of hours per week: 4
- Course: 2 Seminar/Laboratory: 2 Number of hours per semester 56
- Course 28 Seminar/Laboratory 28

General objectives of the course:

- Numerical **modeling, simulation** and **optimization** of the **embedded** systems encountered mainly in the automotive industry.

- Create working abilities with the newest techniques, methods, models and tools for the development and fabrication of products and services in the context of modern companies where the activities are computer aided.

- Create knowhow for modeling and simulations of interactions between various components of embedded electronic systems, mechatronics, multiphysics, MEMS, HD/S with applications in the automotive industry.

Specific objective of the course:

- Efficient use of resources for the modeling and computer simulation of interactions between various components of embedded systems.
- The student will acquire knowhow for the development and (re)design of a embedded systems in accordance with the lifecycle of the project/device.
- Modeling and multiphysic simulation is envisaged, from the software tool, electronics used for control, and elements for the mechanical or thermal actuation.
- Various concepts of the embedding concept will be approached: technology and design of integrated circuits, MEMS, hardware/software embedding/co-design, mechatronic systems. Applications in the automotive industry is mostly considered.

Specific competences acquired

- **General professional competences:** create and develop knowledge related to the newest techniques, methods, models and tools for the development and manufacturing of products.
- **Specific professional competences:** Knowhow in efficient use of resources for the modeling and simulation of interactions between various components of an embedded system.
- **Transversal competences**: This course offers to the students the possibility of understanding how the advanced embedded mechanisms operate, by developing their systemic thinking, and by allowing them to assimilate new concepts and acquire knowhow and communication skills which will help them to chose and process the relevant information from different domains. This subject will help students to develop a multidisciplinary thinking, which will enhance their initiative at their job.

Preconditions and Conditions

Preconditions

- Curriculum: Numerical methods in electrical engineering; Electronics; Signal processing; Digital systems; Electrical actuators.
- Competences: Computer skills for simulations, programming, MATLAB code development, scientific report writing.

Conditions

- For the course: Professors will recommend the students to study a-priori the indicated references for each lecture. Students will be requested to turn off their mobile phones. The teaching method: interactive.
- Laboratory: Computers with MATLAB, Simulink, Comsol will be needed.

  The scientific reports will be edited either in Word or in Latex, with a given template, without plagiarism. Delay in the delivery of the reports will be penalized with 1 point (out of 10) for each day of delay. The deadlines are one week after the lab assembly. The teaching method: individual and supervised study.

Appendix B – Embedded systems in automotive industry

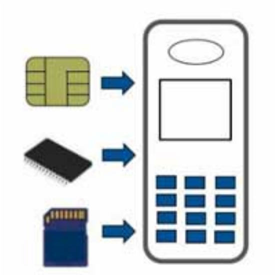
- **Embedded system** is a very broad concept, without a clear, sharp definition.
- In their design are involved several technologies and knowledge, such as: electromagnetic field, electric and electronic circuits, digital and analog circuits, structural mechanics, computational fluid dynamics, thermodynamics, IT (hardware and software), system theory and automatic control.
- Due to the domain’s complexity there are no professionals able to control all these engineering aspects. However professional engineers should adopt a LLL (Long Life Learning) strategy to extend their knowledge an know-how to new, advanced, multidisciplinary domains.

Complexity (performance) of embedded systems

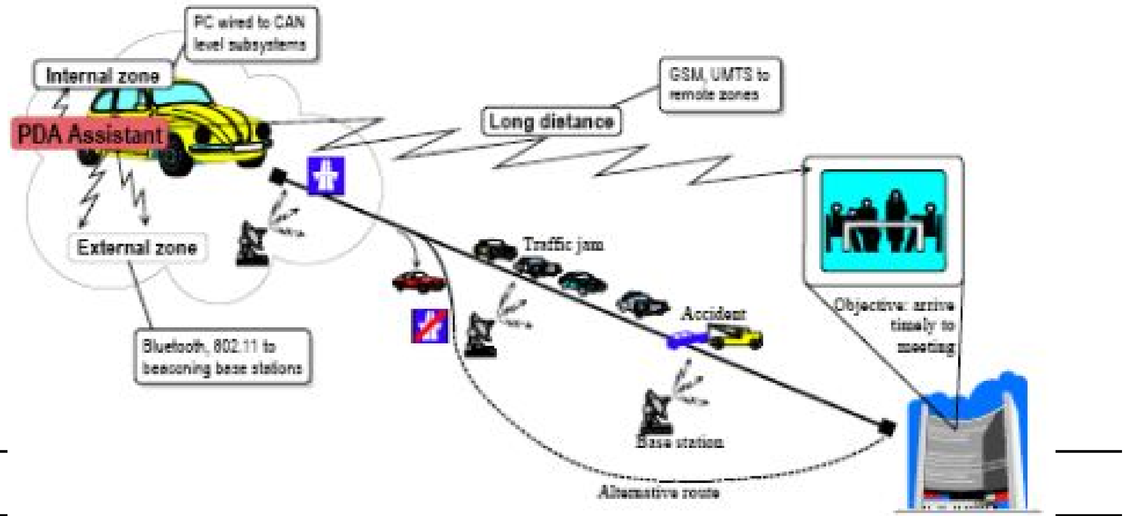
- Stand alone

- Real time

- Networked



- Mobile embedded systems:



- Small scale

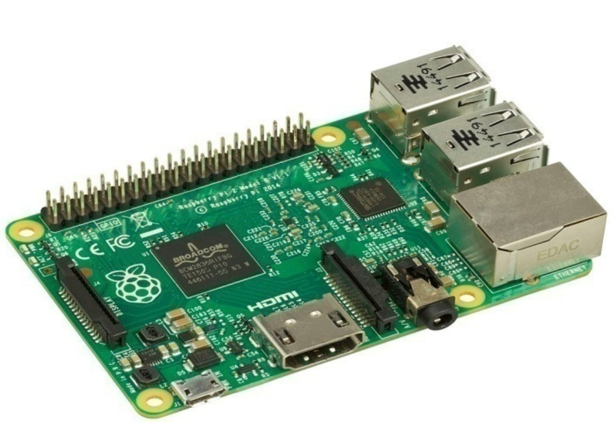
- Medium scale and

- Sophisticated embedded systems.

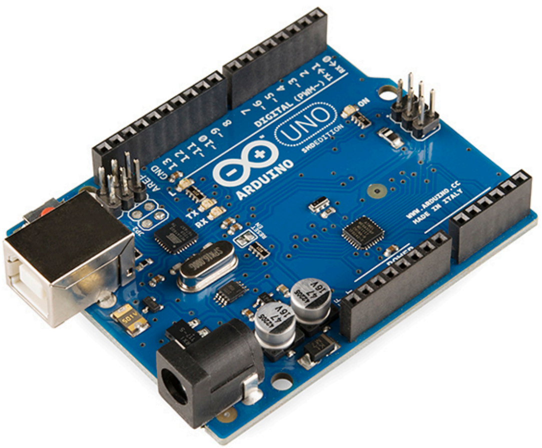
Hardware solutions

- **Ready-made computer boards**: PC/104 and PC/104+ are examples of standards for *ready-made* computer boards intended for small, low-volume embedded and ruggedized systems, mostly x86-based. These are often physically small compared to a standard PC, although still quite large compared to most simple (8/16-bit) embedded systems. They often use DOS, Linux, or an embedded real-time operating system. Sometimes these boards use non-x86 processors.
- In certain applications, where small size or power efficiency are not primary concerns, the components used may be compatible with those used in general purpose x86 personal computers.
- One common design style uses a small system module, perhaps the size of a business card, holding high density BGA chips such as an ARM-based system-on-a-chip processor and peripherals, external flash memory for storage, and DRAM for runtime memory.
- Implementation of embedded systems has advanced so that they can easily be implemented with already-made boards that are based on worldwide accepted platforms. These platforms include Arduino and Raspberry Pi.
- **ASIC and FPGA solutions**: A common array for very-high-volume embedded systems is the system on a chip (SoC) that contains a complete system consisting of multiple processors, multipliers, caches and interfaces on a single chip. SoCs can be implemented as an application-specific integrated circuit (ASIC) or using a field-programmable gate array (FPGA).

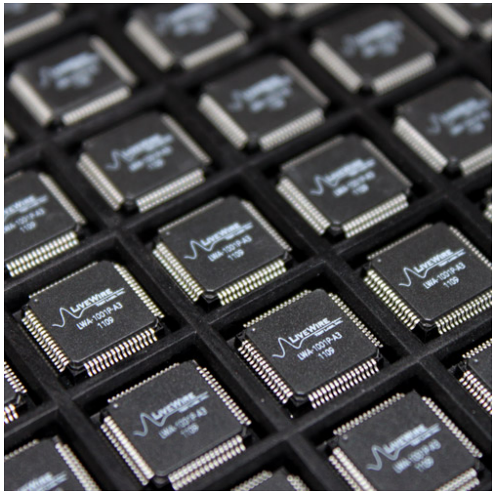
Hardware solutions



Raspberry Pi SoC



Arduino



ASIC

FPGA

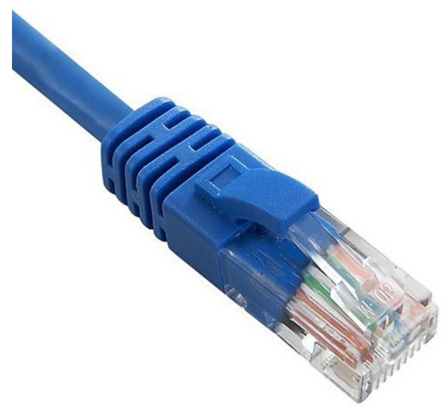
Specific Software Deveopment Tools

- Utilities to add a checksum or CRC to a program, so the embedded system can check if the program is valid.
- For systems using digital signal processing, developers may use a math workbench to simulate the mathematics.
- System level modeling and simulation tools help designers to construct simulation models of a system with hardware components such as processors, memories, DMA, interfaces, buses and software behavior flow as a state diagram or flow diagram using configurable library blocks. Simulation is conducted to select right components by performing power vs. performance trade-off, reliability analysis and bottleneck analysis.
- A model-based development tool creates and simulate graphical data flow and UML state chart diagrams of components like digital filters, motor controllers, communication protocol decoding and multi-rate tasks.
- An embedded system may have its own special language or design tool, or add enhancements to an existing language such as Forth or Basic.
- Another alternative is to add a real-time operating system or embedded operating system
- Modeling and code generating tools often based on state machines

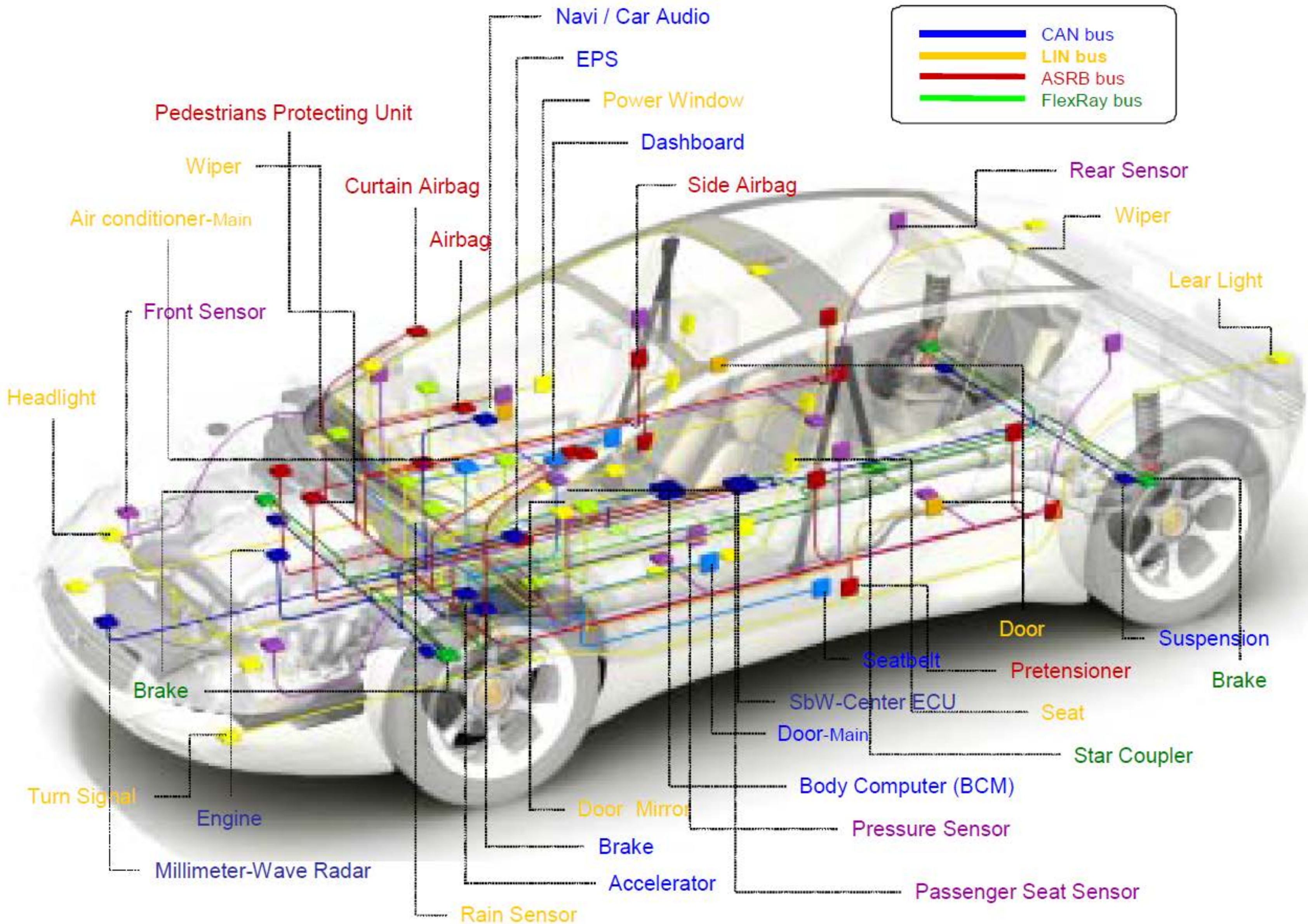
Peripherals

Embedded systems talk with the outside world via peripherals, such as:

- Serial Communication Interfaces (SCI): RS-232, RS-422, RS-485, etc.
- Synchronous Serial Communication Interface: I2C, SPI, SSC and ESSI (Enhanced Synchronous Serial Interface)
- Universal Serial Bus (USB)
- Multi Media Cards (SD cards, Compact Flash, etc.)
- Networks: Ethernet,
- Busses: CAN-Bus, LIN-Bus, PROFIBUS, etc.

Example of several busses



Example of several busses