Embedded Systems

Computer Organization

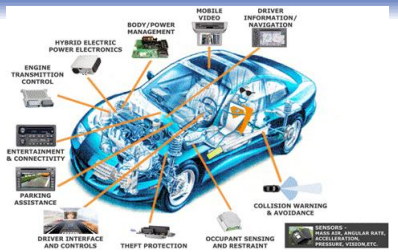
Monday, 17 October 2022

TÉCNICO LISBOA

Summary

- Previous Class
  - Analog-Digital Interface
- Today:
  - Embedded Systems
    - Characteristics
    - Architectures
    - Complete Systems

Embedded Systems



- What is an embedded system?
  - Not always easy to define:
    - "Any sort of device which includes a programmable computer but itself is not intended to be a general-purpose computer"
    - "An embedded system is a computer system with a dedicated function within a larger mechanical or electrical system."
    - "A specialized computer system that is part of a larger system or machine"
    - "An embedded system is a computer that has been built to solve only a few very specific problems and is not easily changed"
    - "An embedded system is some combination of computer hardware and software, either fixed in capability or programmable"
    - "An embedded system contains a computer as part of a larger system and does not exist primarily to provide standard computing services to a user"
  - Keywords: variety, combination, any sort, dedicated, …

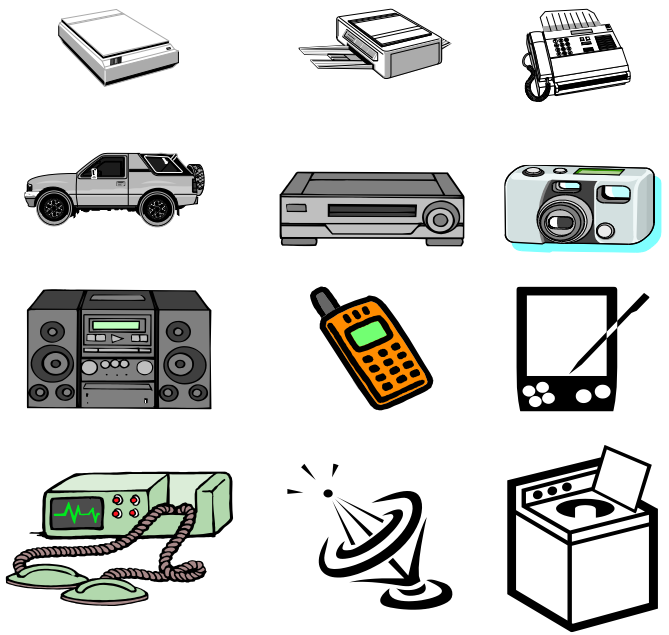
Embedded Systems

- Growing Market
  - Smart homes
  - Internet of Things (IoT)
  - Vehicle networks
  - Wearables
  - Healthcare
  - Security

- Main goals
  - Reliable
  - Energy efficient
    - Low energy, or energy harvesting
  - Cheap
  - Customizable and adaptable
    - adapt to the user's specific needs and evolve with the market

Application Examples

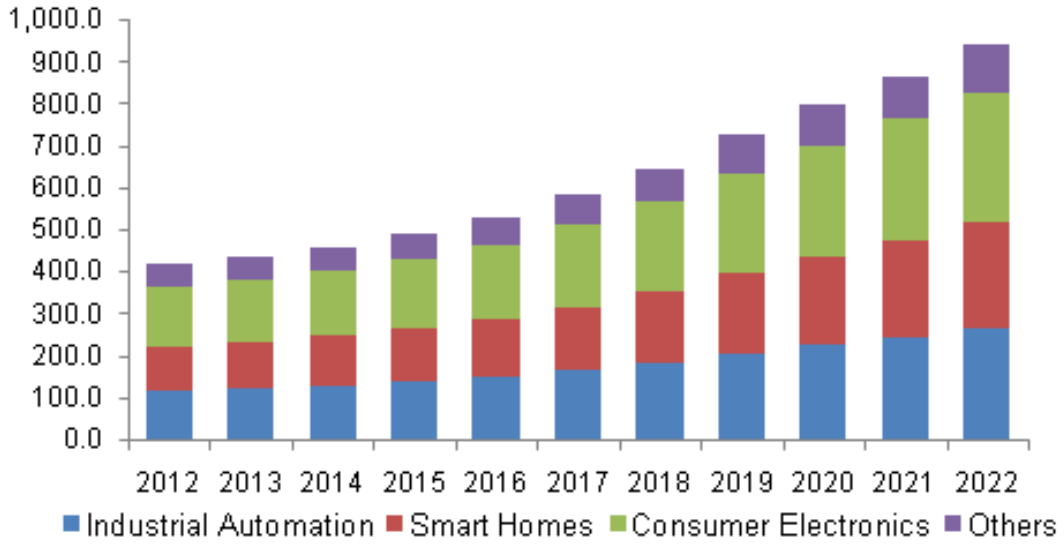
- Personal appliances
  - Phones
  - Watches
  - Smart watches
  - E-health systems
- Computer components
  - Mouse
  - Keyboards
  - Routers
  - Battery charger
  - 3D Printers
- Home appliances
  - Alarms
  - Thermostats
  - Air conditioners
  - Remote controllers
  - Most domestic machines



Application Examples

- Car industry
  - On-board computer
  - Controllers of traction, injection, transmission, break (ABS), etc
  - Air bag
  - Air conditioning
  - Instrumentation
- Entertainment
  - Video games
  - Consoles
  - Toys

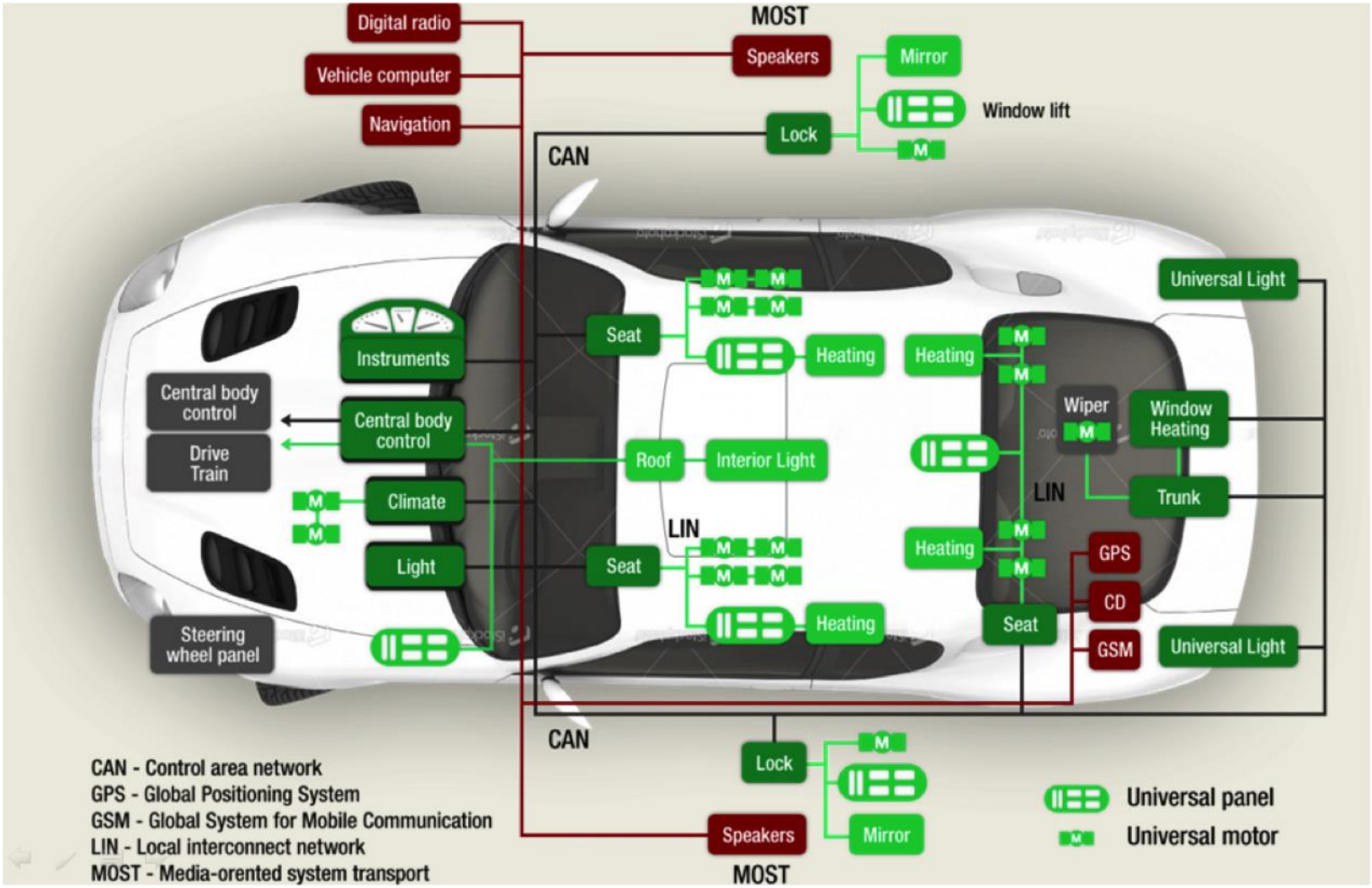
- Industrial applications
  - Industrial robots (manipulators)
  - Belt conveyor systems
  - Lifts
  - Automatic control
  - Instrumentation



Automotive Embedded Systems

- Today's high-end automobile have more than 100 microprocessors:
  - 4-bit microcontroller checks seat belt
  - microcontrollers run dashboard devices
  - 16/32-bit microprocessor controls engine
- Customer's requirements
  - Reduced cost
  - Increased functionality
  - Improved performance
  - Increased overall dependability

An Engineering View



Real Time Systems

- Real time systems have to guarantee that they will respond to an external event within a specified amount of time.
  - Do not have to be fast, but have to be reliably on time.

- System design:
  - Interrupt handling has to be specially careful.
  - Since task scheduling and interrupt handling is performed by the operating system, real time must be supported by the OS (RTOS).
    - Soft real time is usually available (linux, windows), but not hard real time...

Real Time Systems

- Real time systems are classified as:
  - **soft real time**
    - provide a statistical time guarantee. Missing an event is not catastrophic.
      - e.g. TV screen. If a glitch is visible it is not catastrophic.
  - **hard real time**
    - Time guarantee is absolute. Missing a timing deadline will lead to catastrophic results.
      - e.g. Brake sytem of a car. If an event is delayed it may be catastrophic.
  - Soft and hard real time?
    - soft real time systems are optimized for the average case
      - More relaxed designed, cheaper, and easier to design
    - hard real time systems **must** guarantee worst case situations, always.
      - Strict design, strict time

Power and Energy

- Power and Energy
  - Energy provides the ability to work
  - Power is the amount of energy per time interval

    Watts = Joules / second
- Battery provides finite amount of energy
  - and power (i.e. depend on the maximum current that it can output)
- In mobile systems we mainly care about energy
  - Budget energy to prolong battery life

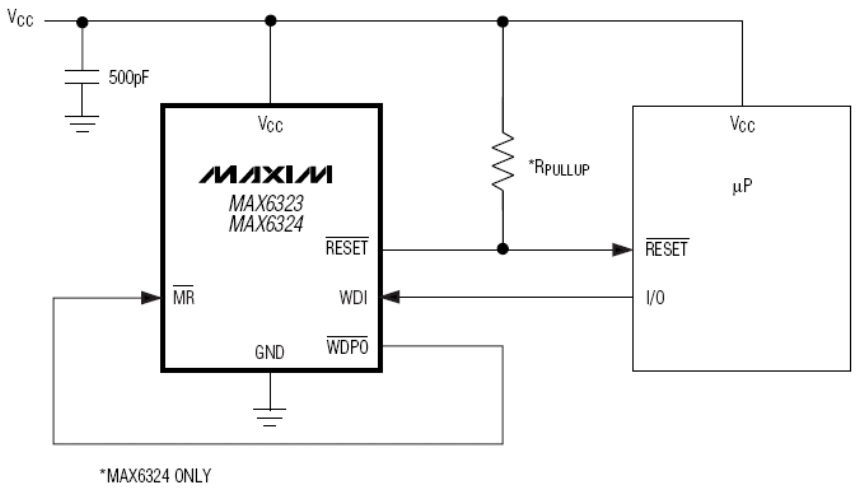
Power and Energy Reduction

- Main power drain sources
  - Computation
  - Wireless transmission
  - Sensors and actuators
  - Memory
- How to reduce power consumption
  - Circuit level
    - Computational architecture, frequency and voltage reduction, turn off circuits, asynchronous circuits, different technologies, …
      - Usually out of our control
  - System level
    - Code, compiler, and OS energy awareness
      - Scheduling, optimize memory access, reduce pipeline stalls, context switching, turning off when idle…

Watchdog Timer

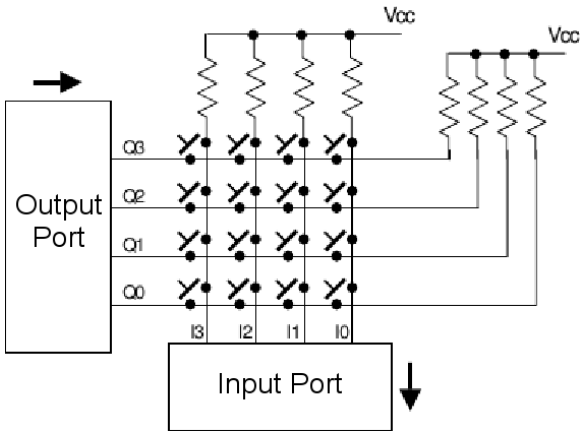
- Watchdog timer
  - Hardware timing device that triggers interruption
    - for system reset, alarm management, or similar operation
      - after a predefined amount of time
  - Can be a stand-alone hardware component or built into the processor itself.
  - Allows for the systems to be put to sleep until next time event
    - embedded system software are many times in the form of endless loops.

```
for(;;) {
        function();
        sleep();
}
```

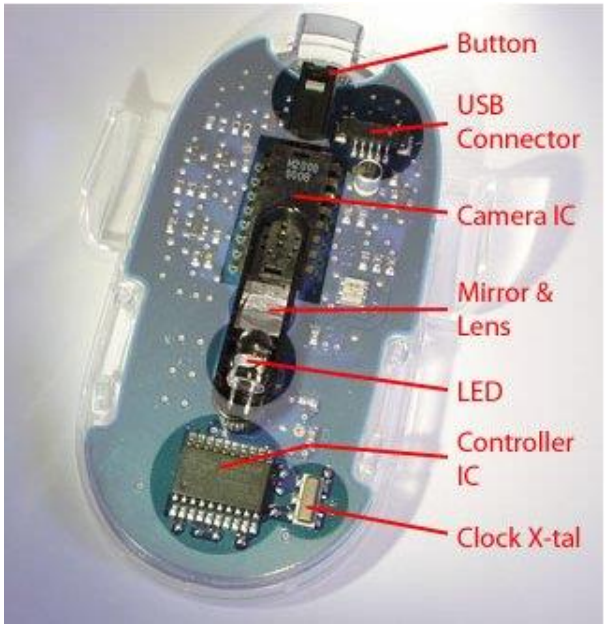


Interface with the User

- Keyboard
  - Embedded system composed by a built-in microcontroller to read the pressed keys; Communicates with the PC using USB.
    - The whole keyboard is read by repetitively testing all lines, with a “fast” frequency (e.g.: 50Hz).

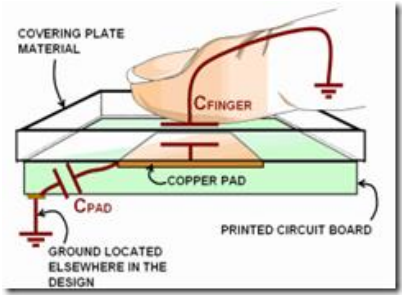


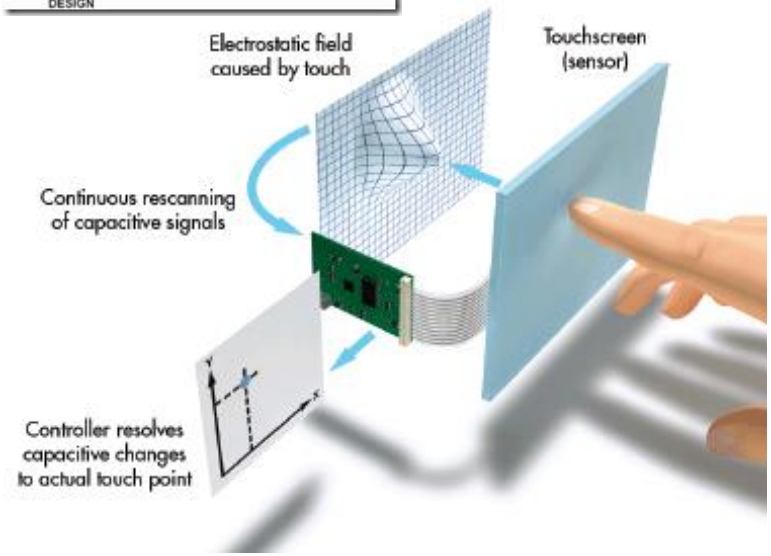
- Mouse
  - The light emitted by a LED/laser is reflected on the table surface and acquired by a small camera
    - The small (simple) camera acquires about 1500 images per second
  - The controller circuit detects the pattern differences and determines the movement direction

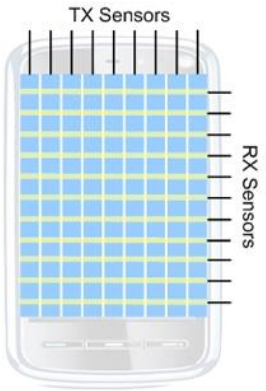


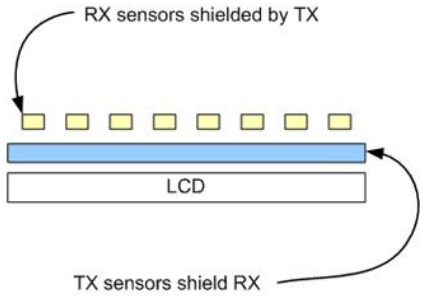
Touch-Screen Displays

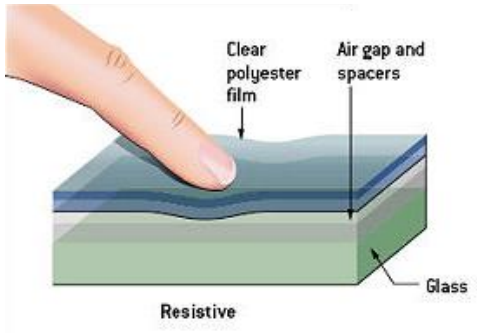
- Most common technologies:
  - Resistive;
    - Cheaper
    - Very resistant and durable
    - Very good resolution;
    - Not affected by cloths, such as gloves
  - Capacitive;
    - Little visibility loss;
    - Not affected by dirt, fat or humidity.

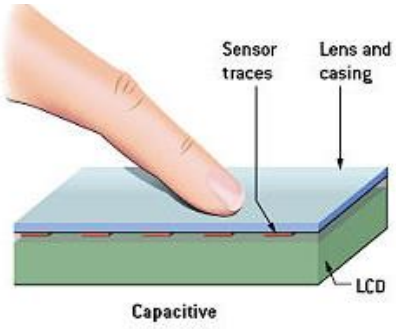










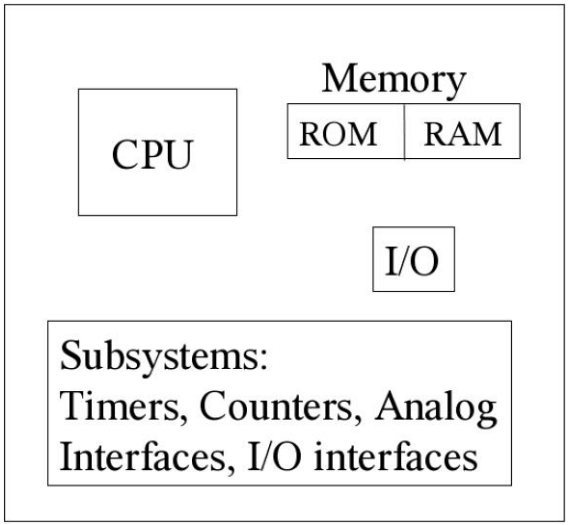


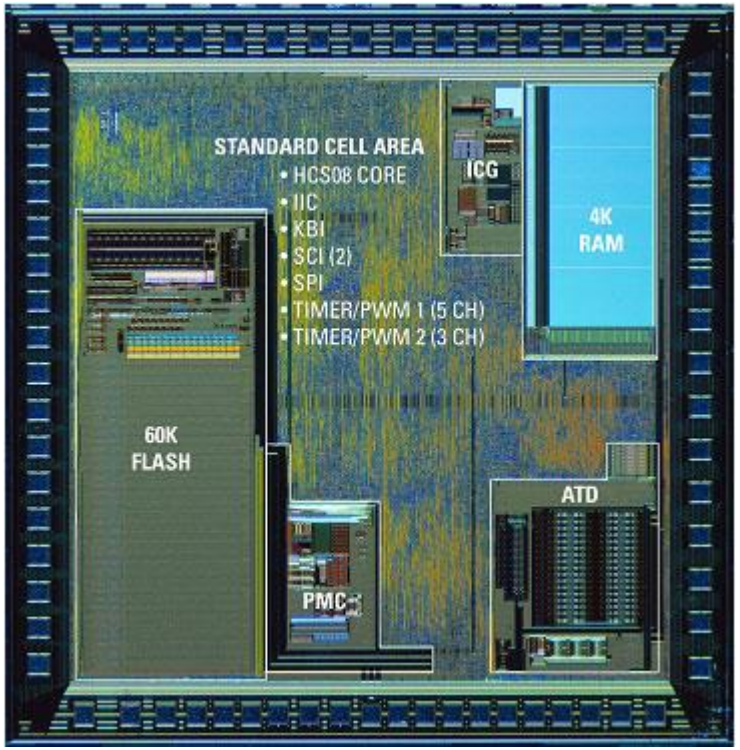
Microprocessor Varieties

- Processing unit particularly suited to the control of simple procedures or devices in embedded systems
- Processor families:
  - General Purpose Processors (GPP)
    - transfer and data manipulation operations (MOVs); conditional execution operations (IF ... ELSE ...)
  - Digital Signal Processors (DSP)
    - microprocessor optimized for digital signal processing
      - Mathematical computation (mainly, multiplications)
  - Microcontrollers
    - includes on-board memory and I/O devices (peripherals) to interface with the outside world
      - Common applications: control, actuators, instrumentation, etc

GPPs versus Microcontrollers

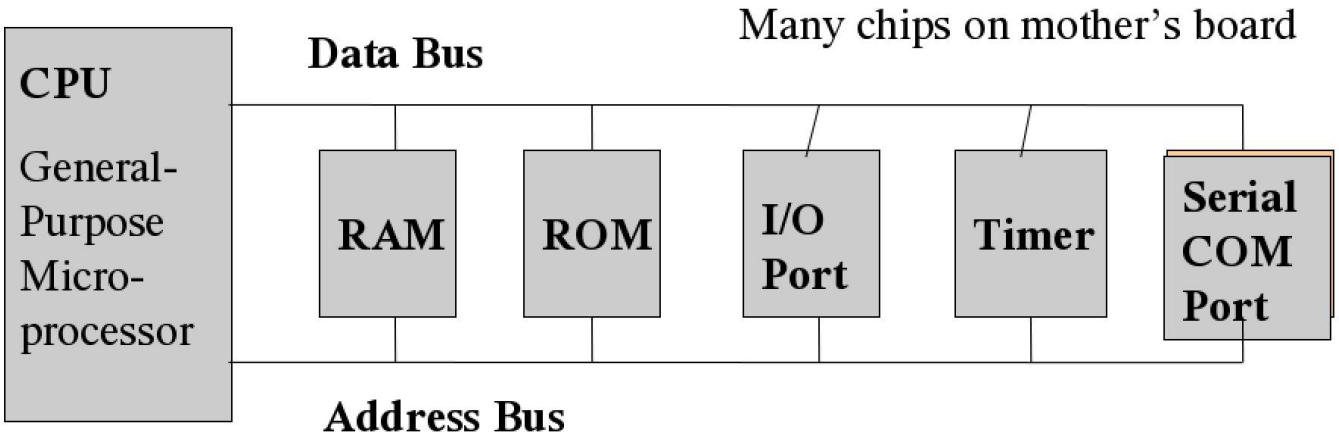
- General Purpose Processors (GPPs)
  - CPU, Memory and IO integrated on a set of chips, on a board or several boards
- Microcontrollers
  - CPU, Memory, IO and peripherals integrated in a single chip





GPPs versus Microcontrollers

- General Purpose Processors (GPPs):
  - High performance CPU, in an independent chip
  - Absence of any RAM, ROM and IO modules in the CPU chip
    - The used memory space should be defined and adjusted according to each particular application
  - Peripherals (timer, serial port, etc.) are external to the CPU chip
- Expansible, versatile and general purpose

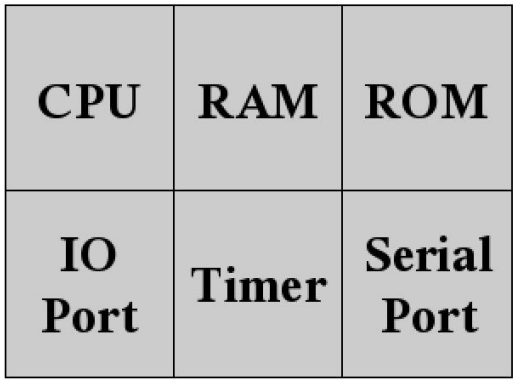


General-Purpose Microprocessor System

GPPs versus Microcontrollers

- Microcontrollers:
  - CPU with few resources (e.g.: 8-bits)
  - RAM, ROM and IO integrated within the CPU chip
    - The available memory space is fixed
  - Peripherals integrated within the CPU chip.

- Suitable for low-cost and constrained (power, HW, etc.) applications



Microcontroller's CPU and Peripherals

- Simple CPU, implemented with:
  - Single-cycle state machine
  - Control unit with a state machine
  - Micro-programmed control unit
  - Very simple pipeline
- *On-chip* peripherals:
  - I/O ports
  - RAM and ROM memories
  - Timer
  - Interrupt controller
  - USART
  - Parallel port; etc.

Microcontrollers Families

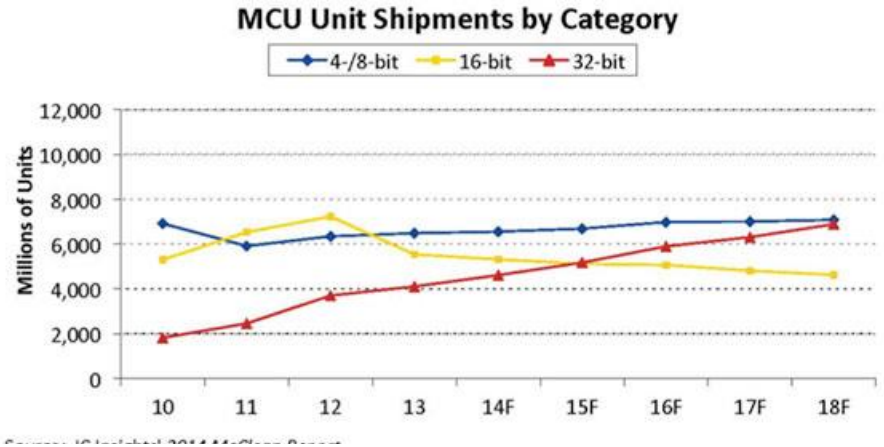
- Most manufacturers offer a wide set of devices, with different performance levels
- Processing power: 4-bits, 8-bits, 16-bits, 32-bits
  - 8-bits microcontrollers are the most widely adopted and used by the majority of the applications
  - 32-bits and 64-bits are only requested by very specialized and reduced markets, with very specific requisites:
    - Communications
    - Signal processing
    - Video processing
    - etc.

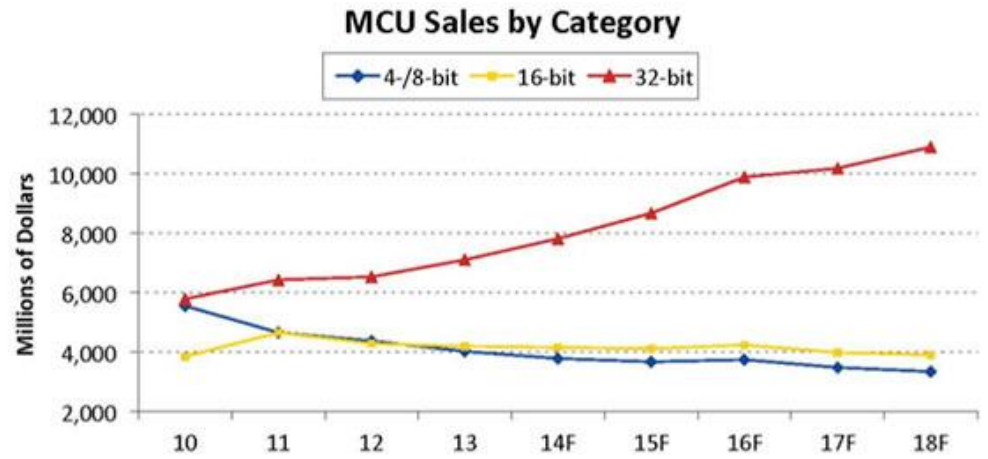
Microcontrollers Families

- Atmel
  - AVR
- ARM
- Intel
  - 8-bit
    - 8XC42
    - MCS48
    - MCS51
    - 8xC251
  - 16-bit
    - MCS96
    - MXS296
- Microchip
  - 12-bit instruction PIC
    - PIC12F508
  - 14-bit instruction PIC
    - PIC16F84
  - 16-bit instruction PIC
- National Semiconductor
  - COP8
- NEC
- Motorola
  - 8-bit
    - 68HC05
    - 68HC08
    - 68HC11
  - 16-bit
    - 68HC12
    - 68HC16
  - 32-bit
    - 683xx
- SGS/Thomson
  - ST62
- Texas Instruments
  - TMS370
  - MSP430
- Zilog
  - Z8
  - Z86E02

Microcontrollers Market

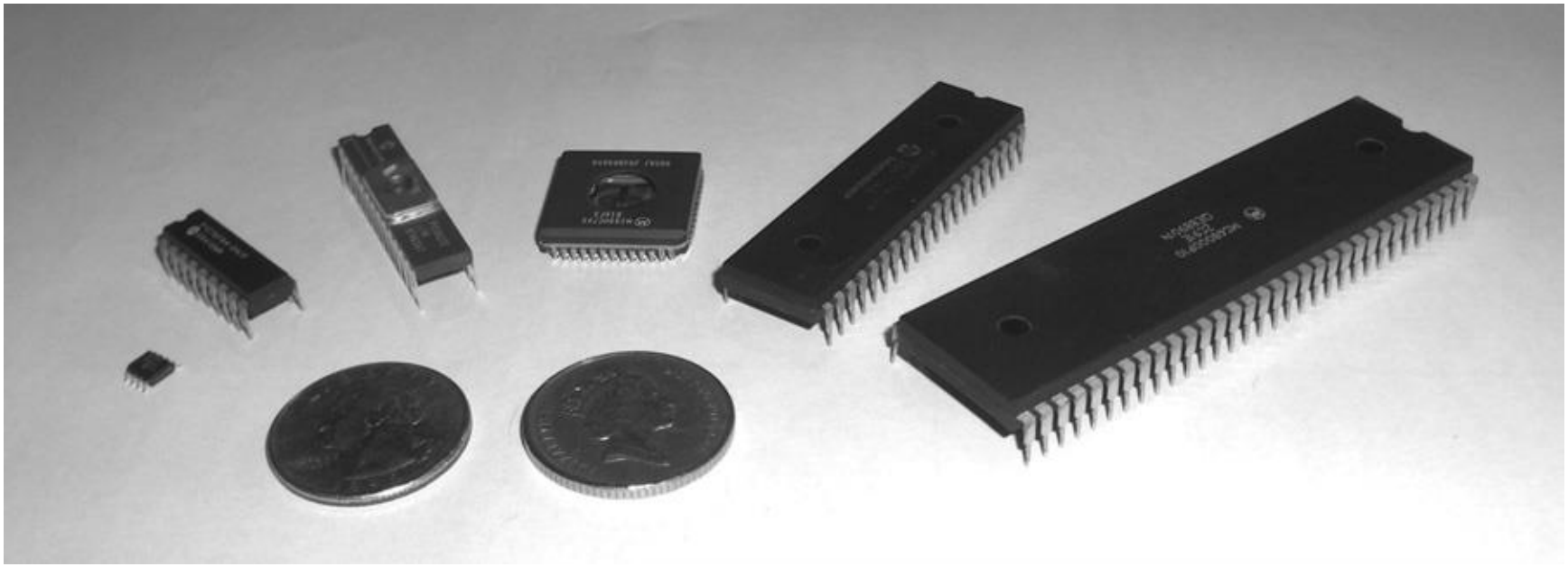
- Market:
  - 8 and 16-bit microcontrollers satisfy more than 75% of the market needs!
- Dominant microcontrollers:
  - Microchip 16Fxx
  - Intel 8051 and derivatives
  - Motorola MC68HC05





Microcontroller Packaging and Appearance

- From left to right: PIC 12F508, PIC 16F84A, PIC 16C72, Motorola 68HC05B16, PIC 16F877, Motorola 68000



Example: Microchip Microcontrollers PIC Family

Vast set of peripherals and protocols:

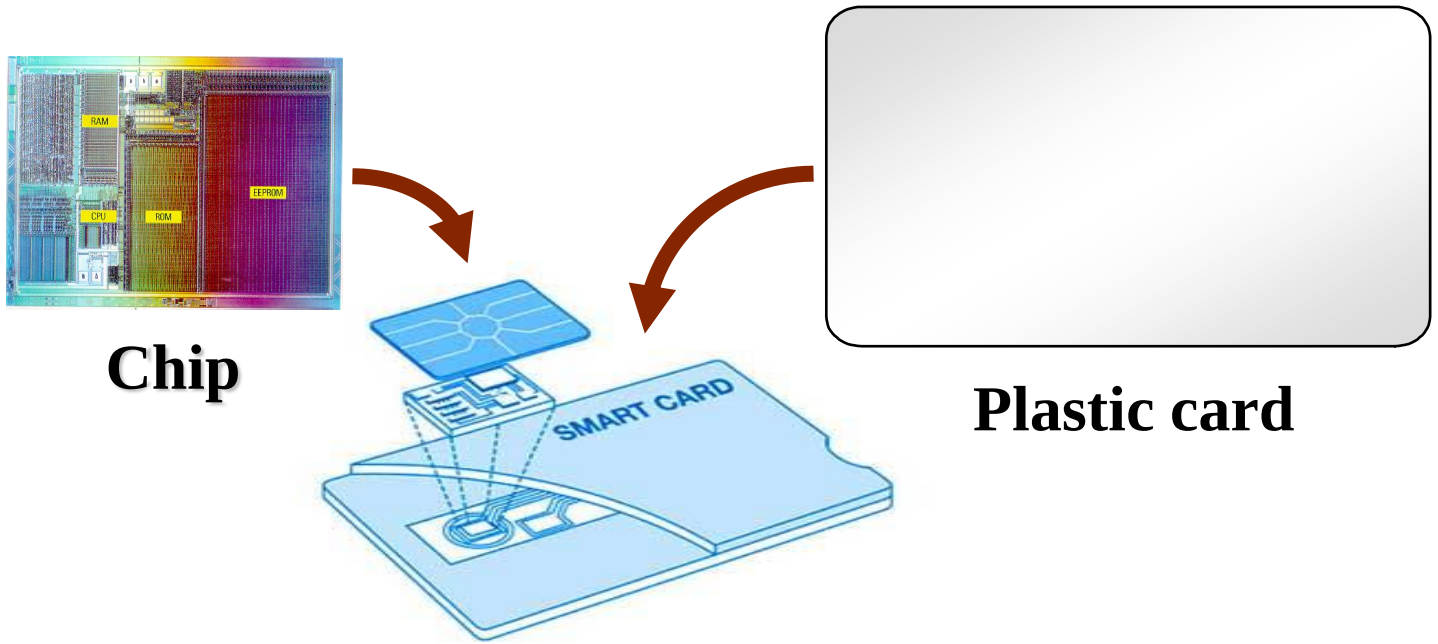
- Communication peripherals and protocols:
  - RS232/RS485
  - SPI
  - I2C
  - CAN
  - USB
  - TCP/IP
  - Ethernet
- Control and timer peripherals:
  - Acquisition and comparison
  - Pulse Width Modulation (PWM)
  - Counters and timers
  - Watchdogs
- Visual peripherals:
  - LED drivers
  - LCD drivers
- Analog peripherals:
  - A/D converters up to 12-bits
  - D/A converters
  - Comparators and signal amplifiers
  - Voltage detectors
  - Temperature sensors
  - Oscillators
  - Voltage references
  - Voltage regulators

Single Board Computers

- F77B MINI2440 + 7 "
  - 150€ (2015)
  - ARM9
    - 400 MHz Samsung
      - S3C2440A ARM920T
  - RAM
    - 64 MB sdram
    - 32 bits Bus
  - Flash
    - 64 MB - 1 GB
  - I/O:
    - Ethernet
    - 7" touch screen
    - SD-Card slot
    - 3,5 mm Stereo Jack
    - USB
  - OS support
    - Windows CE 5 e 6
    - Linux 2,6
    - Android
- Many others:
  - raspberry pi, Intel NUC, …

Smart-Cards

- Appeared in the beginning of the 1970's, but...
  - Only by the beginning of the 1980's were the supporting technologies developed
- Two types of cards:
  - Memory card (without CPU)
  - Card with microprocessor



Smart-Cards

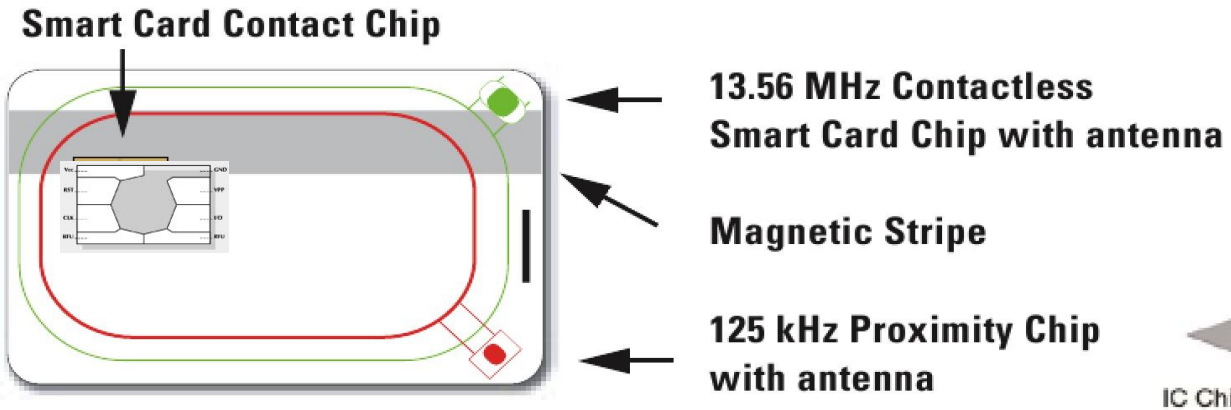
- Applications
  - Information technology
    - Secure access and user authentication
    - Storage of digital certificates and passwords
    - Encryption of critical data
  - Cellular phones (GSM)
    - Subscriber authentication
    - Data storage
  - e-Commerce
    - e-Banking and e-Payments
    - Identification and access control (tickets)
    - Parking
    - Phone credit (decrement of a credit counter)

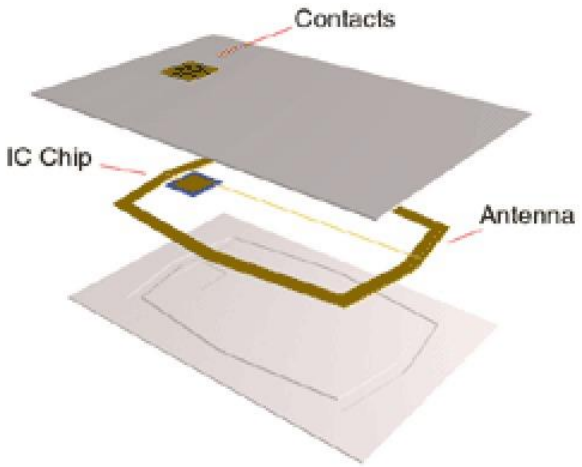
Smart-Cards

- Smart-Cards with microprocessor
  - Processor
    - Usually, 16-bits @ 5-16 MHz
    - Cryptographic co-processors
  - Memory
    - ROM (16 kBytes - 128 kBytes) for the operating system
    - EEPROM (4 kBytes - 64 kBytes) for persistent data
    - RAM (256 Bytes – 4k Bytes) for data
    - ROM size ≈ 4 × EEPROM size ≈ 16 × RAM size
  - File system supported on the installed memory
  - Small silicon area (5mm^2), due to space and energy restrictions

Smart-Cards

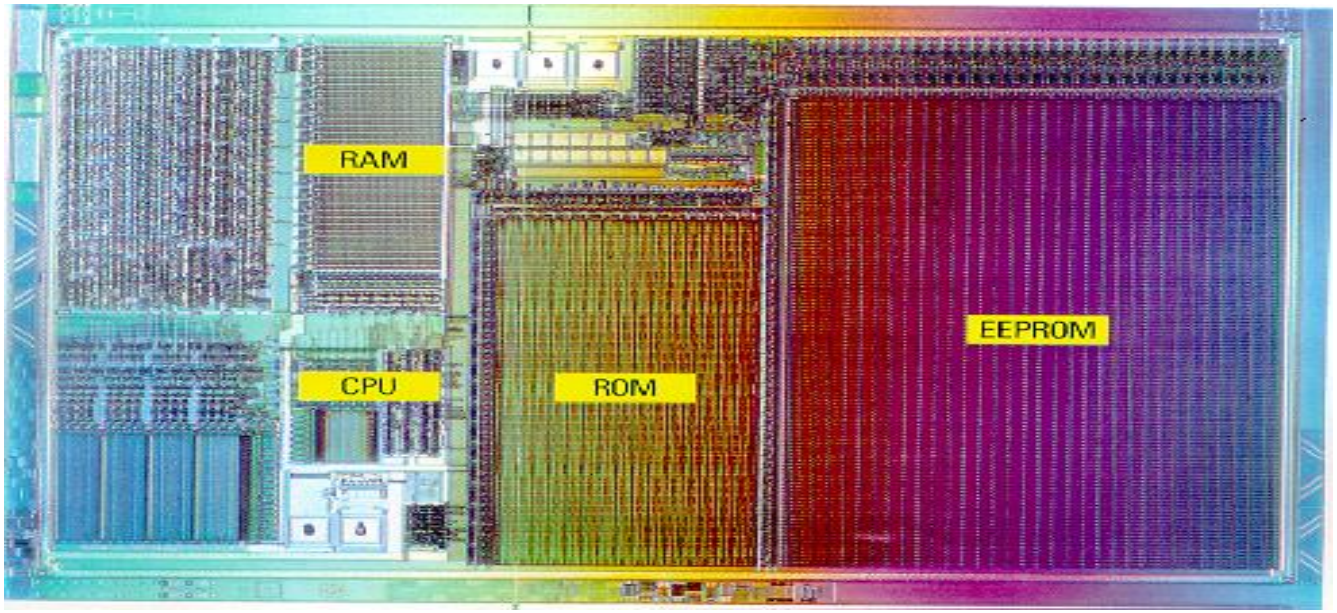
- Communication
  - Contact-based
  - Contact-less (transmission with an antenna)
- Serial protocol, 9600 bps

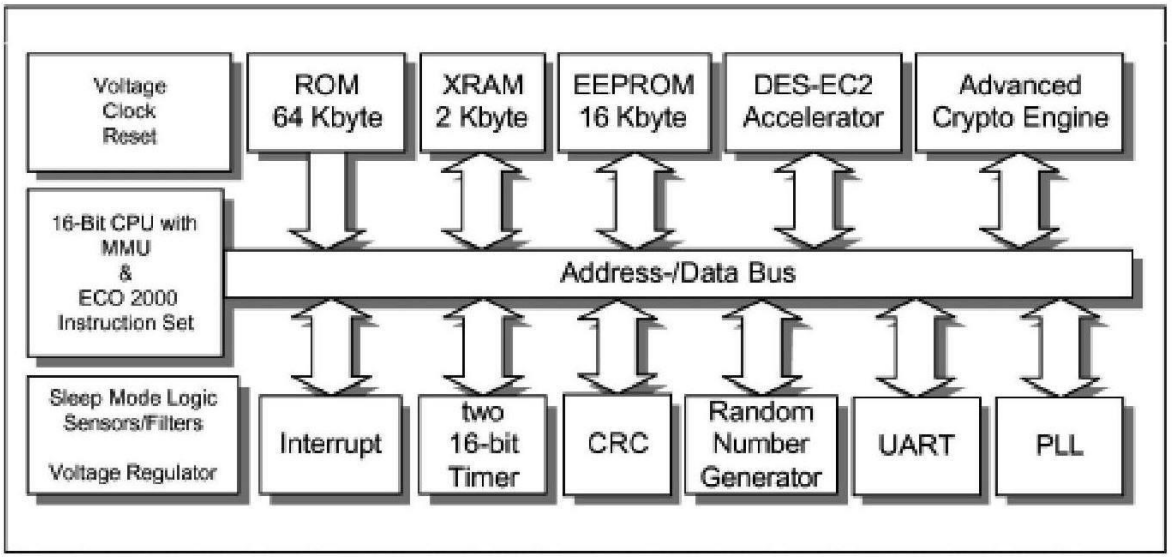




- Power-supply
  - With battery
  - Without battery
    - the CPU is powered with an inductive circuit

Smart-Cards: Infineon SLE66

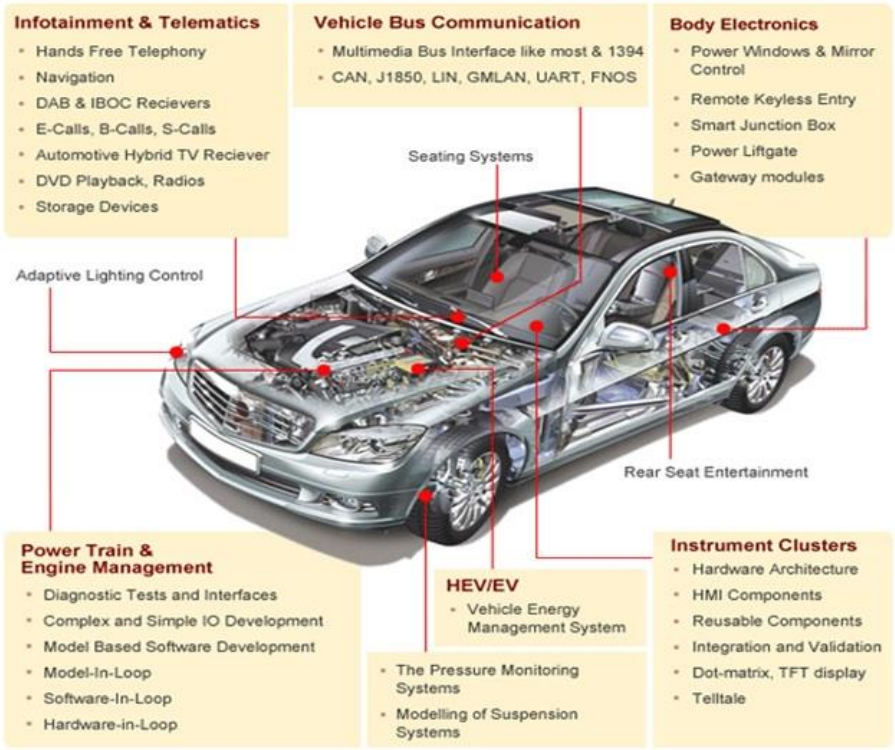




Course: *Ambientes Inteligentes*

- Discuss the concept of Ambient Intelligence
  - and awareness of the multiple fields where it can be applied;
- Recognize the importance of having sensitive and responsive environments
  - that react accordingly to the presence and preferences of people;
- Introduce the main challenges/technologies used in the field
  - Power/energy consumption, communication, security, reliability, interface with sensors and actuators, and interface with people;
- Three main application areas:
  - **Smart homes**/home automation/**intelligent buildings;**
  - **Smart Cities** (and intelligent mobility systems);
  - **Wireless Sensors** and Actuator Networks.

- Cyber-physical and distributed computing
  - Do you know what sensors has your smartphone?
    - Do you know how to use them?
  - Look around
    - What is the most sophisticated distributed computing platform you see?



Course: *Applications and Computation for IoT*

- Introduce the main concepts of embedded systems design
  - Cyber-physical interfacing
  - Design patterns
  - Real-time
  - Fault tolerance
- Practice with real systems

  Arduino/Genuino + Lego Mindstorms

Conclusion

- Microprocessors come in many varieties
  - GPP
  - DSP
  - Microcontrollers
  - Smartcards
- A significant share of the market is targeted to embedded systems:
  - I/O
  - Small
  - Cheap
  - Application oriented
  - Energy restricted

Next Class

- Multiprocessors
  - Programming overheads
  - Shared-Memory Multiprocessor
    - UMA vs NUMA
  - Memory coherence

Embedded Systems

Computer Organization

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