Embedded Systems

Computer Organization

Tuesday, 22 October 2024

TÉCNICO LISBOA

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

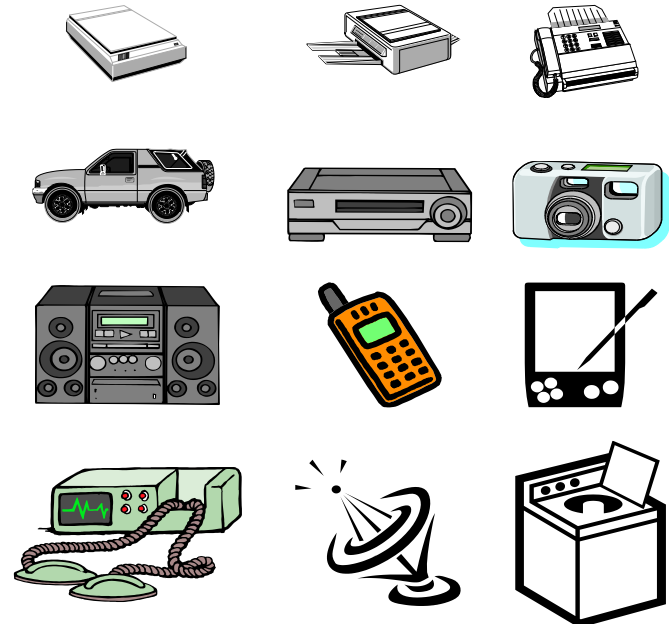# Application Examples

- **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
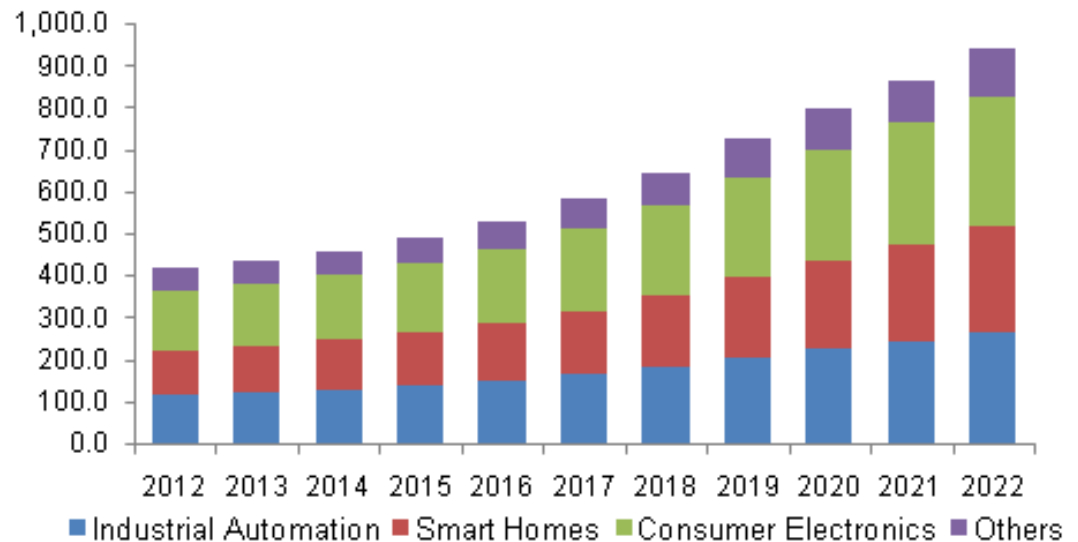
Automotive Embedded Systems

- 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

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8
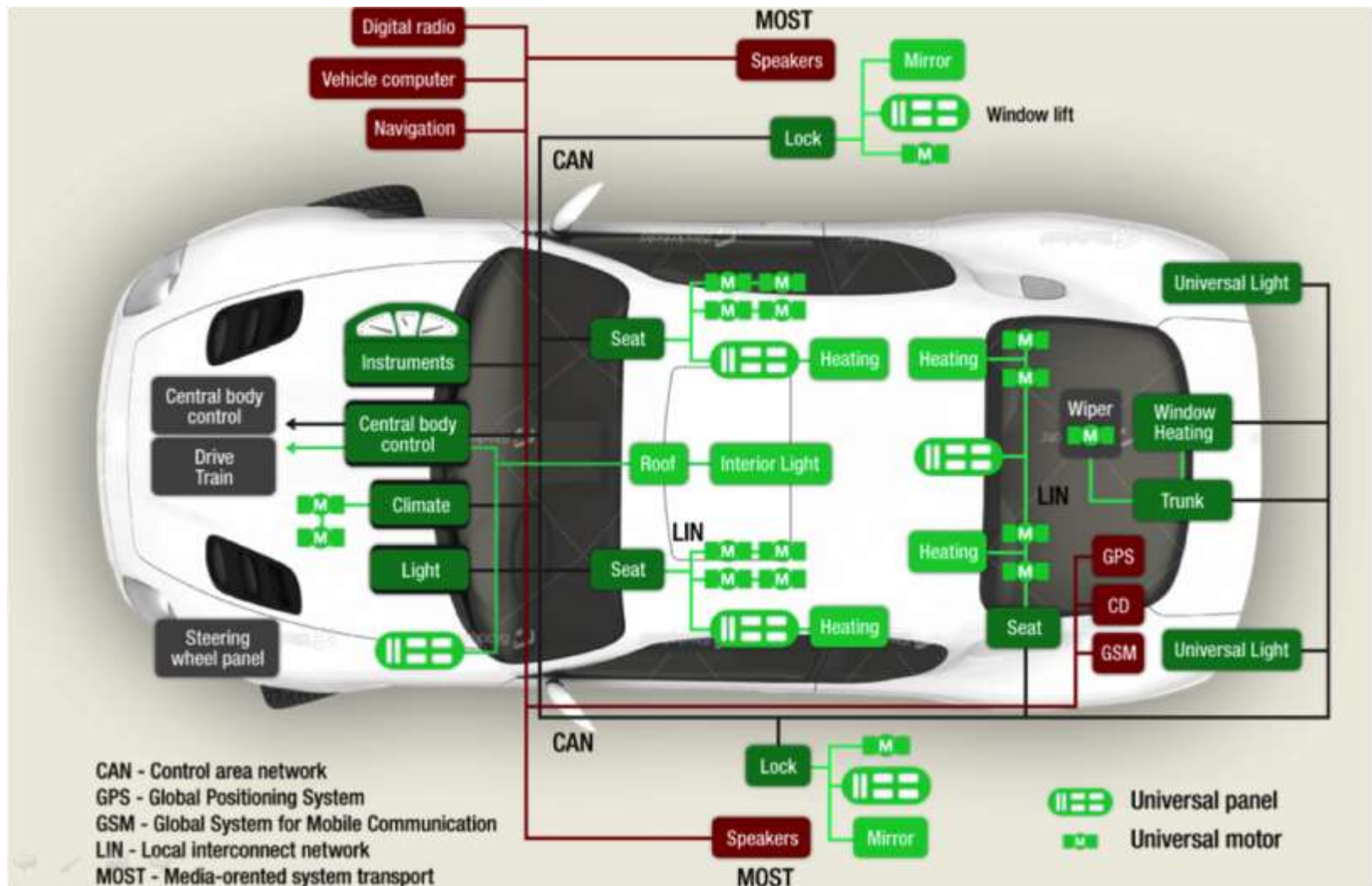
Real Time Systems

- 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…

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
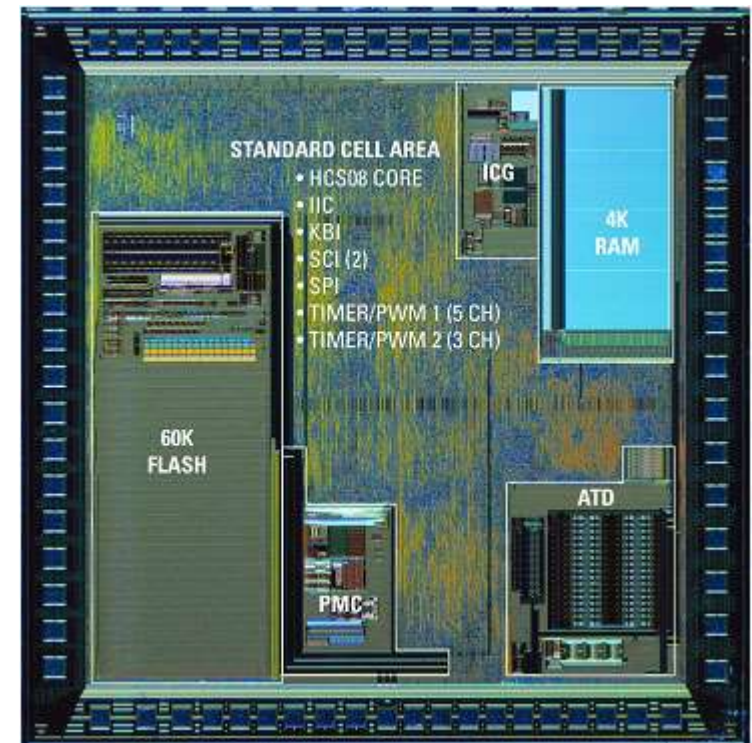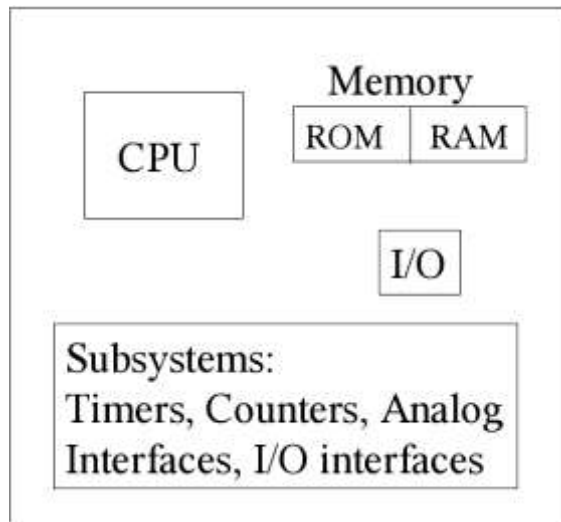
GPPs versus Microcontrollers

- 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
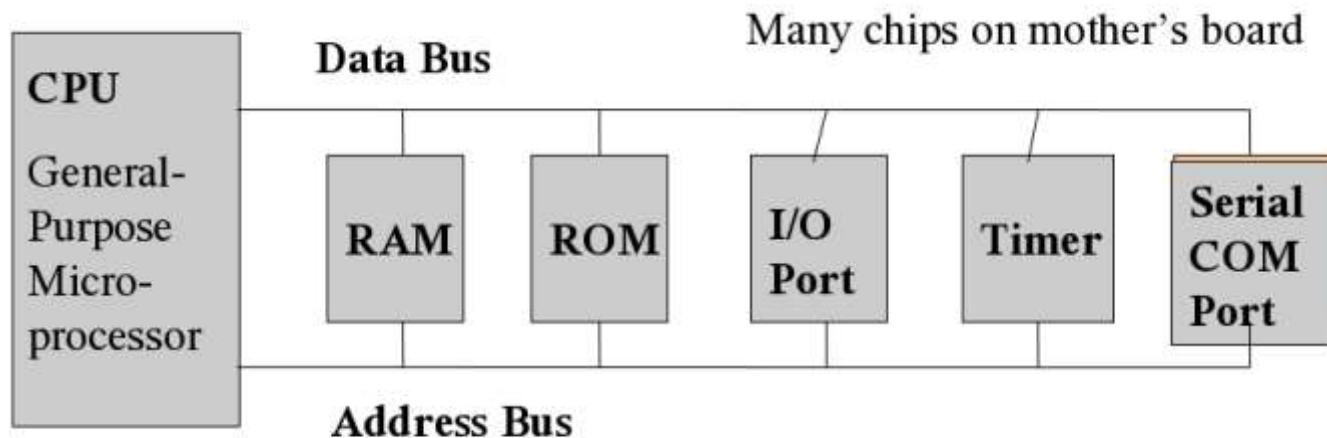
General-Purpose Microprocessor System

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

CPU	RAM	ROM
IO Port	Timer	Serial Port

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

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
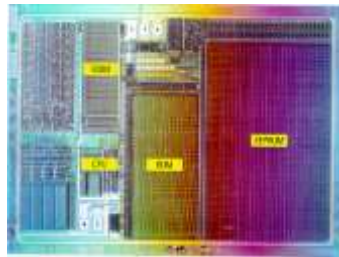
Chip
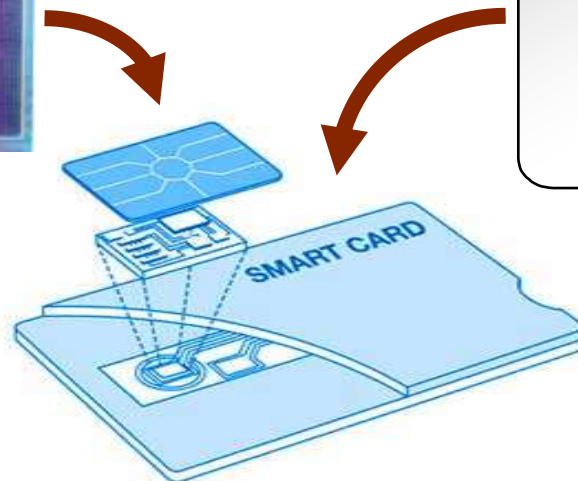
Plastic card

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

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.

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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

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