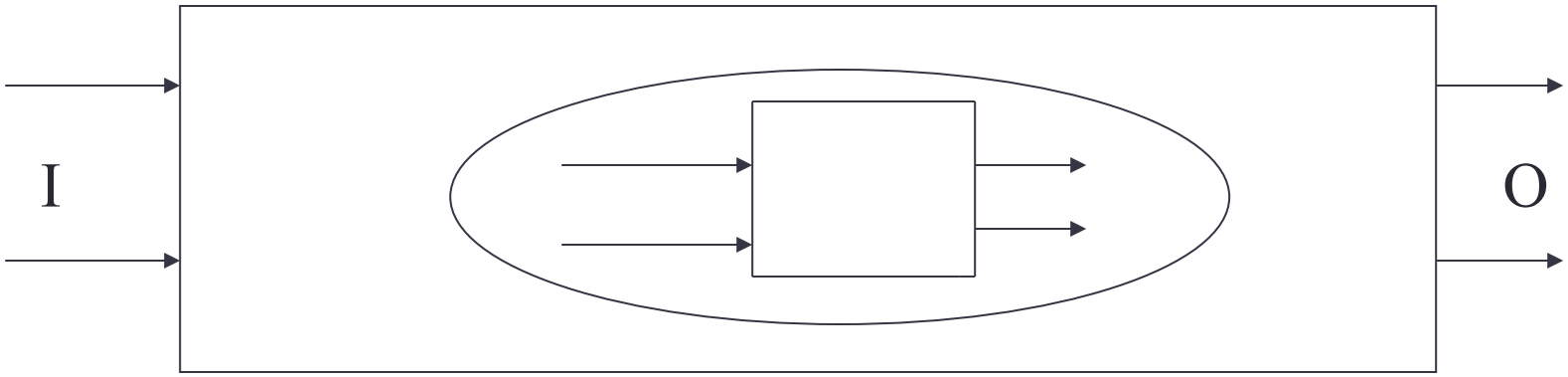
EMBEDDED SYSTEMS

Theory and Design

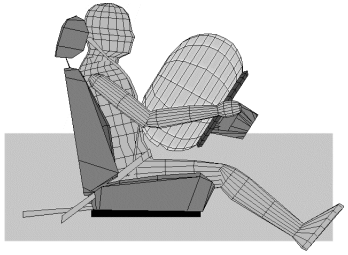
What is an Embedded System

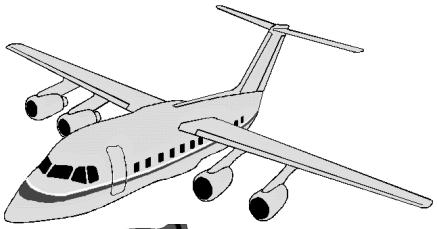
An Embedded System is a microprocessor based system that is embedded as a subsystem, in a larger system (which ***may or may not be a computer system***).

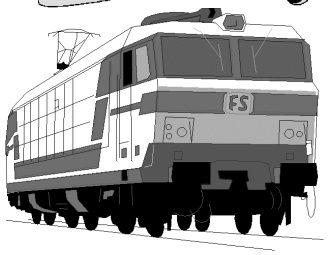


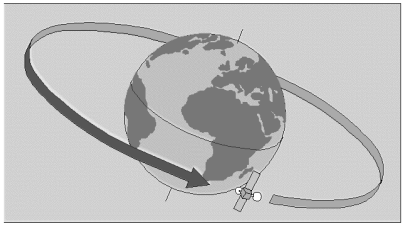
Application areas

- Automotive electronics
- Aircraft electronics
- Trains
- Telecommunication



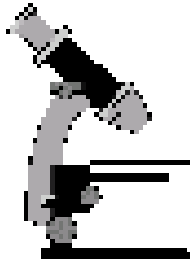




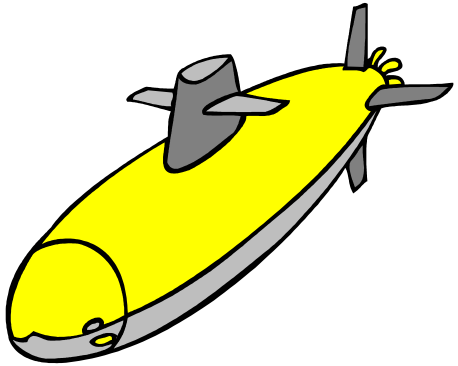


Application areas

- Medical systems



- Military applications

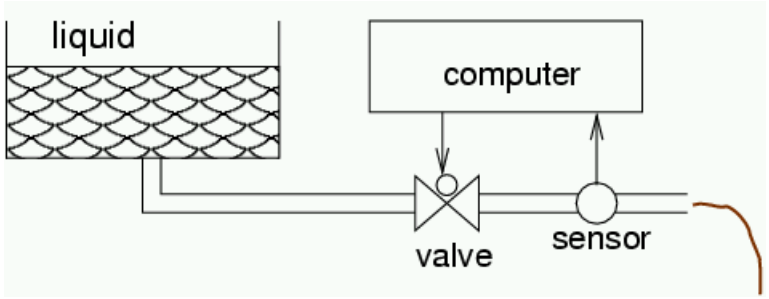


- Authentication

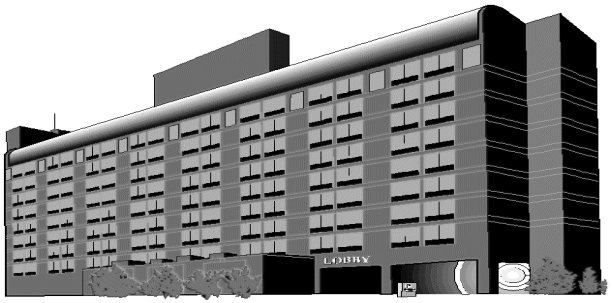
Application areas

- Consumer electronics

- Fabrication equipment



- Smart buildings



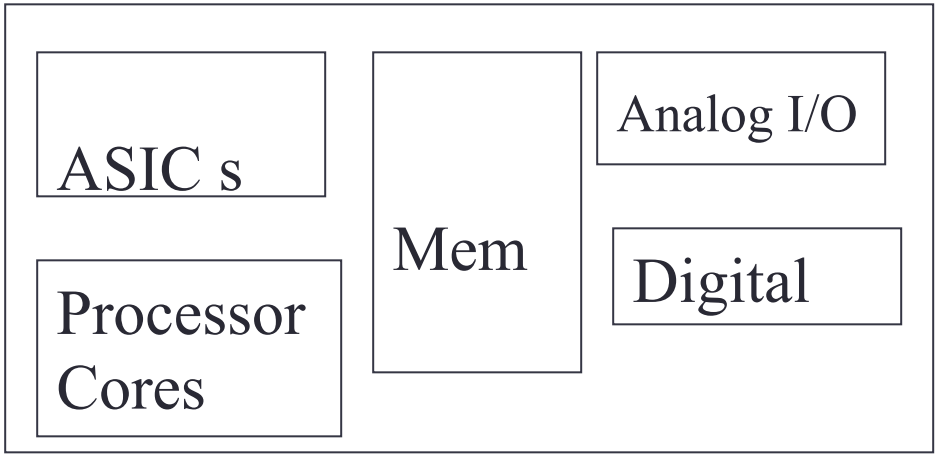
A Brief of Embedded System

- An **embedded system** is a special-purpose system in which the computer is completely encapsulated by or dedicated to the device or system it controls.
- Since the system is dedicated to specific tasks, design engineers can optimize it, reducing the size and cost of the product.
- Embedded systems are often mass-produced, benefiting from economies of scale.

History

- The first recognizably modern embedded system was the Apollo Guidance Computer, developed by Charles Stark Draper at the MIT Instrumentation Laboratory.
- The first mass-produced embedded system was the Autonetics D-17 guidance computer for the Minuteman (missile), released in 1961.
- In 1978 National Engineering Manufacturers Association released the standard for a programmable microcontroller.
- By the mid-1980s, widespread use of embedded systems became feasible with microcontroller.

General Characteristics of Embedded Systems



ASIPs and ASICs form a significant component

- Adv: customization → lower power, cost and enhanced performance
- Disadv: higher development effort (debuggers, compilers etc.) and larger time to market

General Characteristics of Embedded Systems

- **Perform a single task**
  - Usually not general purpose
- **Increasingly high performance and real time constrained**
- **Power, cost and reliability are important considerations**
- **HW-SW systems**
  - **Software is used for more features and flexibility**
  - **Hardware (processors, ASICs, memory etc. are used for performance and security**

Characteristics

- Some also have real-time performance constraints.
- An embedded system very often is physically built-in to the device it is controlling.
- The software written for embedded systems is often called firmware, and is stored in read-only memory or Flash memory chips rather than a disk drive.

Characteristics

- **User interfaces -** range from no user interface at all to full user interfaces similar to desktop operating systems in devices such as PDAs.
- **Complexity –** from simple embedded devices use buttons, LEDs to full graphical screen, with touch sensing or even World Wide Web interface (TCP/IP required)

Characteristics

- **CPU platform**
  - two distinct categories: microprocessors (μP) and microcontrollers (μC). μC have built-in peripherals on the chip, reducing size of the system.
  - CPU architectures used: ARM, MIPS, Coldfire/68k, PowerPC, x86, PIC, 8051, Atmel AVR, Renesas H8, SH, V850, FR-V, M32R, Z80, Z8
  - For small, low-volume embedded and ruggedized system. PC/104 and PC/104+ are used. They often use DOS, Linux, NetBSD, QNX, or VxWorks.
  - High-volume embedded systems use system on a chip (SoC), an application-specific integrated circuit (ASIC), or field-programmable gate array (FPGA) to execute the firmware.

Characteristics

- **Peripherals**
  - Serial Communication Interfaces (SCI): RS-232, RS-422, RS-485 etc
  - Synchronous Serial Communication Interface: I2C, JTAG, SPI, SSC and ESSI
  - Universal Serial Bus (USB)
  - Networks: Controller Area Network, LonWorks, etc
  - Timers: PLL(s), Capture/Compare and Time Processing Units
  - Discrete IO: aka General Purpose Input Output (GPIO)

Characteristics

- **Tools**
  - Generally, compilers, assemblers, and debuggers are used to develop embedded system software.
  - An in-circuit emulator (ICE) is a hardware device that replaces or plugs into the microprocessor, and provides facilities to quickly load and debug experimental code in the system.
  - For systems using digital signal processing, developers may use a math workbench such as MathCad or Mathematica to simulate the mathematics.
  - Software tools can come from several sources:
    - Software companies that specialize in the embedded market
    - Ported from the GNU software development tools
    - Sometimes, development tools for a personal computer can be used if the embedded processor is a close relative to a common PC processor.

Characteristics

- **Debugging**
  - at different levels, ranging from assembly- or source-level debugging with an in-circuit emulator or in-circuit debugger, to output from serial debug ports or JTAG/ Nexus interfaces, to an emulated environment running on a personal computer.
  - As the complexity of embedded systems grows (e.g. cellphones, PDAs), higher level tools and operating systems (Linux, NetBSD, OSGi or Embedded Java) are migrating into machinery where it makes sense.

Application Specific Characteristics

- Application is known before the system is designed
- System is however made programmable for
  - Feature upgrades
  - Product differentiation
- Often application development occurs in parallel to system development
  - Hw-Sw partitioning should be as delayed as possible
- For upgrades design reuse is an important criterion
  - IP reuse, object oriented development

Design Metrics

- Unit cost – the $ cost for each unit excluding development cost
- NRE cost: $ cost for design and development
- Size: The physical space reqd. – determined by bytes of sw, number of gates and transistors in hw
- Performance: execution time or throughput of the system
- Power: lifetime of battery, cooling provisions
- Flexibility: ability to change functionality without heavy NRE cost

Design Metrics (contd.)

- Time to market = Time to prototype + Time to refine + Time to produce in bulk
- Correctness: Test and Validation
- Safety:

- Often these metrics are contradictory – hence calls for optimization
- Processor choice, partitioning decisions, compilation knowledge
- Requires expertise in hw and sw both

Major Subtasks of Embedded System Design

- Modeling the system to be designed and constraints
  - Experimenting with different algorithms and their preliminary evaluation
  - Factoring the task into smaller subtasks and modeling their interaction
- Refinement
- HW-SW partitioning
  - Allocating the tasks into hw, sw running on custom hw or general purpose hw
- Scheduling – allocation of time steps for several modules sharing the same resource
- Implementation: Actual hw binding and sw code generation
- Simulation and Validation
- Iterate if necessary

What is Co-design?

- Traditional design
  - SW and HW partitioning done at an early stage and development henceforth proceeds independently
- CAD tools are focussed towards hardware synthesis
- For embedded systems we need several components
  - DSPs, microprocessors, network and bus interface etc.
- HW-SW codesign allow hw and sw design to proceed in parallel with interactions and feedback between the two processes
- Evaluation of trade offs and performance yields ultimate result

CAD for Embedded Systems

- Co-design: Joint optimization of hw and sw to optimize design metrics
- Co-synthesis: Synthesizes designs from formal specifications
- Rapid prototyping and design space exploration
- Many of the tasks are interrelated
- Intermediate evaluation is not easy as a later decision in one path affects the other

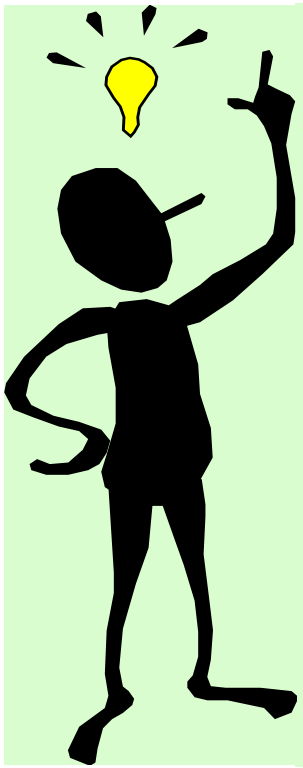
A Mix of Disciplines

- Application Domain (Signal processing, control …)
- Software Engg. (Design Process plays an important role)
- Programming Language
- Compilers and Operating System
- Architecture – Processor and IO techniques
- Parallel and Distributed Computing
- Real Time Systems

Importance of Embedded Software and Embedded Processors

"... the New York Times has estimated that the average American comes into contact with about 60 micro-processors every day...." [Camposano, 1996]

Latest top-level BMWs contain over 100 micro-processors [Personal communication]



Most of the functionality of embedded systems will be implemented in software!

Views on embedded System

- It is estimated that each year embedded software is written five times as much as 'regular' software
- The vast majority of CPU-chips produced world-wide today are used in the embedded market ... ; only a small portion of CPU's is applied in PC's
- ... the number of software-constructors of Embedded Systems will rise from 2 million in 1994 to 10 million in 2010;
  ... the number of constructors employed by software-producers 'merely' rises from 0.6 million to 1.1 million.

[Department of Trade and Industry/ IDC Benelux BV: Embedded software research in the Netherlands. Analysis and results, 1997 (according to: www.scintilla.utwente.nl/shintabi/engels/thema_text.html)]