Introduction to Embedded Systems

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Outline

1. Definition of embedded systems
2. History and applications
3. Characteristics of embedded systems
   - Purposes and constraints
   - User interfaces
   - Processors for embedded systems
   - Development issues
What is an embedded system?

- **Definition (from Wikipedia)**
  - An embedded system is a special-purpose system in which the computer is completely encapsulated by the device it controls. Unlike a general-purpose computer, such as a personal computer, an embedded system performs one or a few pre-defined tasks, usually with very specific requirements.

- **General view**
  - Embedded system is a computing system embedded into a larger product
Smartphone as an embedded system

Smartphone = Hardware + Software

Hardware Components:
- CPU
- Memory
- Network
- eMMC
- GPU
- Sensor

Software Components:
- Application SW
- System SW
- OS kernel
Early history

☐ One of the very first embedded systems was the Apollo Guidance Computer
  ▪ Developed by Charles Stark Draper at MIT

☐ An early mass-produced embedded system was the Autonetics D-17 guidance computer for the Minuteman missile, released in 1961

☐ Since 1960s, embedded systems have come down in price and there has been a dramatic rise in processing power and functionality
  ▪ An early microprocessor, the Intel 4004, was designed for calculators and other small systems
Typical applications

- Vehicles
  - Ignition Systems, Engine Control, Antilock Braking System,

- Consumer Electronics
  - TVs, STBs, appliances, toys, automobiles, cell phones …

- Industrial Control
  - robotics, control systems…

- Medical devices and systems
  - Infusion Pumps, Dialysis Machines, Prosthetic Devices, Cardiac Monitors, …

- Networks
  - routers, hubs, gateways, …

- Office Automation
  - fax machines, photocopiers, printers, monitors, …
Characteristics of embedded systems

- Dedicated purposes
- Real-time requirements
  - Deadlines and periods
- Mass production
- Harsh operating conditions
- Limited resources
  - Limited processing power and memory
  - Many systems are battery-powered
- Portability and mobility
Examples

99% of CPUs are used in embedded systems
Examples

Electronics: >30% of cost, >90% of innovation

Powertrain control:
> 100 embedded software components

Mars, December 3, 1999
Lander lost due to embedded software design error
$184 million development cost

$4 billion development cost
> 50% system integration and validation
Largest private industrial project (1995)

Ariane 5, French Guyana, June 4, 1996
$800 million embedded software failure
User interfaces in embedded systems

- Embedded systems range from no user interface at all, in systems dedicated only to one task, to complex graphical user interfaces that resemble modern computer desktop operating systems
  - Simple embedded devices use buttons, LEDs, graphic or character LCDs (HD44780 LCD for example) with a simple menu system
  - More sophisticated devices use a graphical screen with touch sensing or screen-edge buttons

Buttons

Character LCD

LEDs

7-segment LED
User interfaces in embedded systems

Some systems provide user interface remotely with the help of a serial (e.g. RS-232, USB, I²C, etc.) or network (e.g. Ethernet) connection

- A good example of this is the combination of an embedded web server running on an embedded device (such as an IP camera) or a network router
- The user interface is displayed in a web browser on a PC connected to the device, therefore needing no software to be installed
Processors for embedded systems

- General purpose processors (mostly low power)
  - A microprocessor is a single chip CPU
  - ARM, Intel Atom, Motorola’s 680x0

- Microcontrollers (μC)
  - Include on-chip peripherals (ROM, RAM and I/O ports) as well as CPU, thus reducing power consumption, size and cost
  - Motorola’s 6811, Intel’s 8051, Zilog’s Z8 and PIC 16X

- SoC (System-on-Chip)
  - Integrates all components of a computer or other electronic system into a single chip
  - It may contain digital, analog, mixed-signal, and often radio-frequency functions—all on a single chip substrate
  - Used for very high volume products
  - SoCs can be implemented as an application-specific integrated circuit (ASIC) or using a field-programmable gate array (FPGA)
ARM-based Processors

ARM11 MPCore

ARM-based SoC (Mobile AP)
North/Southbridge Layout in Intel Chipsets

- The northbridge is used to manage data communications between a CPU and a motherboard within Intel chipsets.
- The southbridge typically implements the slower capabilities of the motherboard.
- Increasingly the northbridge functions have migrated to the CPU chip itself, beginning with memory and graphics controllers:
  - For Intel Sandy Bridge and AMD Accelerated Processing Unit processors introduced in 2011, all of the functions of the northbridge reside on the CPU.
Cross Development Environment

- When doing embedded development, there is always a split between the host, the development workstation, which is typically a powerful PC and the target, which is the embedded system under development
  - They are connected by various means: almost always a serial line for debugging purposes, frequently an Ethernet connection, sometimes a JTAG interface for low-level debugging
Cross Development Environment

- Cross compilation

![Diagram showing cross compilation process]

- Source code
- Native toolchain
- Cross-compiling toolchain
- x86 binary
- ARM binary

Compilation machine

Execution machine
Cross Development Environment

**Native build**
used to build the normal gcc of a workstation

**Cross-native build**
used to build a toolchain that runs on your target and generates binaries for the target

**Cross build**
used to build a toolchain that runs on your workstation but generates binaries for the target

The most common case in embedded development

**Canadian build**
used to build on architecture A a toolchain that runs on architecture B and generates binaries for architecture C
Debugging Embedded Systems

- Embedded debugging may be performed at different levels, depending on the facilities available.

- Interactive resident debugging, using the simple shell provided by the embedded operating system (e.g. Forth and Basic)

- External debugging using logging or serial port output to trace operation using either a monitor in flash or using a debug server like the Remedy Debugger which even works for heterogeneous multicore systems
Debugging Embedded Systems

- An in-circuit debugger (ICD), a hardware device that connects to the microprocessor via a JTAG or Nexus interface
  - This allows the operation of the microprocessor to be controlled externally, but is typically restricted to specific debugging capabilities in the processor

- An in-circuit emulator (ICE) replaces the microprocessor with a simulated equivalent, providing full control over all aspects of the microprocessor
  - A complete emulator provides a simulation of all aspects of the hardware, allowing all of it to be controlled and modified, and allowing debugging on a normal PC
  - The downsides are expense and slow operation, in some cases up to 100X slower than the final system
Debugging Embedded Systems

- For SoC designs, the typical approach is to verify and debug the design on an FPGA prototype board
  - Tools such as Certus are used to insert probes in the FPGA RTL that make signals available for observation
  - This is used to debug hardware, firmware and software interactions across multiple FPGA with capabilities similar to a logic analyzer

- Because an embedded system is often composed of a wide variety of elements, the debugging strategy may vary
  - For instance, debugging a software- (and microprocessor-) centric embedded system is different from debugging an embedded system where most of the processing is performed by peripherals (DSP, FPGA, co-processor)
  - An increasing number of embedded systems today use more than one single processor core
  - A common problem with multi-core development is the proper synchronization of software execution
  - In such a case, the embedded system design may wish to check the data traffic on the busses between the processor cores, which requires very low-level debugging, at signal/bus level, with a logic analyzer, for instance
Debugging Embedded Systems

- Real-time operating systems (RTOS) often support tracing of operating system events
  - A graphical view is presented by a host PC tool, based on a recording of the system behavior. The trace recording can be performed in software, by the RTOS, or by special tracing hardware
  - RTOS tracing allows developers to understand timing and performance issues of the software system and gives a good understanding of the high-level system behavior
  - Commercial tools like RTXC Quadros or IAR Systems exist