Department of Electrical and
Computer Engineering

EEL 4742C: Embedded Systems

Introduction

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Introduction

- What are embedded systems?
- In which application(s) did this field start?

Introduction

- What are embedded systems?
- **Answer #1:** Anywhere we use a computer (CPU, memory, IO, etc.) where the product is not a computer
- **Answer #2:** Any system that has a computer (CPU, memory, IO, etc.) in it. The computer components need to be fast enough to meet the product's demand; beyond that, there's no benefit in having faster computer components

- In which application(s) did this field start?
- Embedded systems started with industrial controls and automation
- E.g: chemical processing, paper manufacturing, oil and gas processing, manufacturing line
- E.g: search on YouTube: How is Coke made?

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Introduction

- What are examples of embedded systems that we encounter everyday?

- They're hidden in plain sight…

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Introduction

- In the home: microwave oven, fridge, oven, TV, wireless router, camera, alarm clock, calculator, electronic door lock
- In the car: engine control unit, infotainment system, remote control
- In the classroom: system that controls lights, projection screen and projector
- In the office bldg: fire alarm system, elevator, door access, AC system
- In the city: vending machine, ATM machine, parking meter, toll collector, subway turnstile access

- Embedded systems are everywhere…

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Design Points

Performance vs. cost equation

- Reduce the cost as long as performance is met
- No benefit for having faster computer components
- E.g: we don't need a quad-core CPU in the microwave!

Wide range of performance…

- Embedded computers are like fish in the sea… there exist tiny fish up to huge whales!
- Four-function calculator needs a slow CPU
- Modern TV supporting Internet needs a fast CPU
- Smartphones and tablets moved to desktop-class once 64-bit CPUs were used since around 2013 (no longer considered embedded systems!)

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Design Points

Wide range of cost…

- Door lock microcontroller costs less than a dollar
- Modern TV microcontroller costs tens or >$100

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Design Points

Real-time performance…

- Tasks should be done on time for the system to work properly
- E.g: airplane control, car's engine, cruise control
- Different levels of real-time (soft: okay to miss a few deadlines, hard: catastrophe occurs if a deadline is missed)
- Operating System (OS) concepts are used
- A unit of computation (thread, process) are assigned priorities
- The OS schedules the threads so that all the deadlines are met
- Such an OS is called a Real-Time OS (RTOS)
- One idea: Placing important code in a fast memory so that loading this code is fast

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Design Points

Safety Critical Systems

- Embedded systems are used in safety-critical applications
- E.g: airplane control, car's engine and throttle control
- How do we know the system will function correctly every time?
- One idea is lockstep computing: two CPU compute the same code in parallel so that errors are detected

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Embedded Technology

Scenario about 10-15 years ago…

- In my project, I have multiple chips
- A CPU chip, a memory chip, an analog-to-digital converter chip, a timer chip, a communication chip, etc.
- Annoyance: I have to interface all these chips together
- Reliability: using external wires introduces more bugs (interference, broken wires)

- What would I do today?

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Embedded Technology

- Today, we use a microcontroller unit (MCU) which has all of these components in one chip!

- **Moore's Law:** The number of transistors on a chip doubles every 1.5 to 2 years
- It allowed us having faster PC and phones every year
- Also enabled having relatively cheap MCUs that integrate multiple parts
- Therefore, we can build a project using fewer chip

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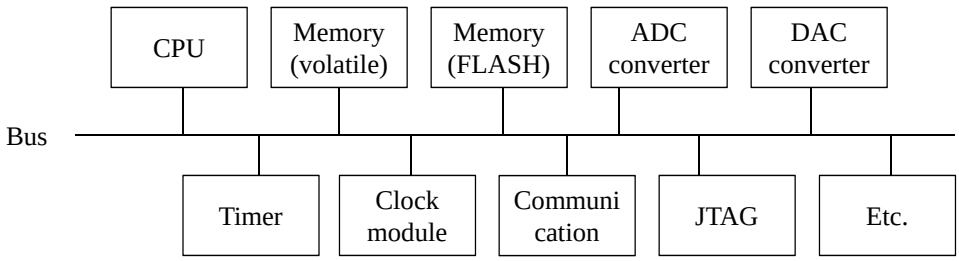
Microcontroller Organization



- All of the above are inside the microcontroller (on the same chip)
- All the modules (other than CPU, memory) are called **peripherals**
- MCU offerings have a great variety of peripherals (we choose the one that suits our project)
- Note: In MCUs, peripherals are inside the MCU chip
- In desktops, peripherals are outside the tower (mouse, keyboard, monitor)

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Type of Chips

Alternatives to microcontrollers…

FPGA (Field Programmable Gate Array)

- A chip with a circuit that can be reconfigured
- Programmed in Verilog or VHDL
- E.g: Basys board used in EEE 3342C lab

ASIC (Application Specific Integrated Circuit)

- A chip designed for a specific product
- Large expense upfront; justified for large volumes
- Strips down non-needed functions; optimizes power consumption

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Types of MCUs

Ultra-Low Power Microcontrollers

- Draws milliAmps; can go down to microAmps with low-power modes
- Can run on battery power for 10 years
- CPU speed up to 16 MHz (not very fast)
- 8-bit or 16-bit CPU
- Small memory in KBs (KiloBytes)
- Good for: electronic door lock, vending machine, sensing temperature, parking stub dispenser, some senior design tasks etc.
- Not good for: image and video processing, very fast tasks
- E.g: MSP430 we'll study
- MSP430 is well-known in ultra-low power applications

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Types of MCUs

Performance Microcontrollers

- 32-bit or 64-bit CPU
- CPU clock rate reaches or exceeds 1 GHz
- Possibly dual core
- Larger memory in MBs (MegaBytes)
- Applications: image processing, high-speed networking, any application that needs high performance
- Eg: ARM CPUs

- At the high end, there are the **single-board computers**
- They approach the performance of PCs; possible to run a full OS
- E.g: Raspberry Pi

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Other Microcontroller Platforms

- Atmega
- Microchip
- Renesas
- Freescale (formerly Motorola)
- ARM
- AVR
- Intel microcontrollers

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Survey of Embedded Engineers

- A large-scale survey in North America asks embedded engineers about their projects
- Results in the next few slides

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Survey of Embedded Engineers

To which field does your embedded project belong?

- Industrial controls & automation
- Consumer electronics
- Communication / networks
- Medical
- Automotive
- Military
- Computer peripherals (mouse, keyboard)
- Video / imaging
- Transportation (airport, bus, taxi)
- Security, audio, electronic instruments…

Which of these showed up in the responses?

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Survey of Embedded Engineers

To which field does your embedded project belong?

- Industrial controls & automation 33%
- Consumer electronics 23%
- Communication / networks 23%
- Medical 15%
- Automotive 15%
- Military 15%
- Computer peripherals (mouse, keyboard) 11%
- Video / imaging 8%
- Transportation (airport, bus, taxi)
- Security, audio, electronic instruments…

All of them… the percentages show the frequency of the answers

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Survey of Embedded Engineers

Resource allocation

- Software
- Hardware

What percentage corresponds to each answer choice?

Programming language

- C
- C++
- Assembly language
- Java

Do embedded projects use an Operating System (OS)?

- Yes
- No

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Survey of Embedded Engineers

Resource allocation

- Software 60%
- Hardware 40%

Programming language

- C 60%
- C++ 20%
- Assembly language 5%
- Java 2%

Do embedded projects use an Operating System (OS)?

- Yes 70%
- No 30%

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Survey of Embedded Engineers

Main processor in the embedded project

- 64-bit CPU
- 32-bit CPU
- 16-bit CPU
- 8-bit CPU

What percentage corresponds to each answer choice?

CPU clock rate

- 10-99 MHz
- 100-250 MHz
- 250-999 MHz
- 1 GHz
- 2+ GHz

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Survey of Embedded Engineers

Main processor in the embedded project

- 64-bit CPU 6%
- 32-bit CPU 62%
- 16-bit CPU 16%
- 8-bit CPU 13%

CPU clock rate

- 10-99 MHz 40%
- 100-250 MHz 16%
- 250-999 MHz 22%
- 1 GHz 13%
- 2+ GHz 4%

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Embedded System Example

- A washing machine is a good embedded system example

Input/Output	Type
Panel switches	
Knob buttons	
Door sensor	
Water temperature sensor	
Display LEDs	
Water valve	
Motor speed	

For each signal, decide whether **input or output** and whether **analog or digital**

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Embedded System Example

- A washing machine is a good embedded system example

Input/Output	Type
Panel switches	Digital input: on/off
Knob buttons	Analog input
Door sensor	Digital input: on/off
Water temperature sensor	Analog input
Display LEDs	Digital output (each segment is on/off)
Water valve	Digital output: on/off
Motor speed	Analog output: e.g: Pulse-Width Modulation (PWM)

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