Lecture 2:

**Embedded Systems: An Introduction**

Adapted from ECE456 course notes, University of California (Riverside), and EE412 course notes, Princeton University

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Winter-Spring 2008

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Topics for Today

- An introduction to embedded systems
- Embedded systems vs. self-contained systems
- Embedded system design considerations
Self-Contained vs. Embedded System

- **Digital System**: provide information processing service
  - as a self-contained unit (e.g., desktop PC)
  - as part of a larger system (e.g., digital control system for manufacturing plant)
Self-Contained vs. Embedded System

- **Self-contained systems (A.K.A. computer)**
  - PC’s
  - Laptops
  - Servers

- **Embedded computing systems**
  - Computing systems embedded within larger units.
  - Provide dedicated service to that unit

- Hard to define. Nearly any computing system other than a desktop computer
What is an embedded system?

Avionics

Communication

Automobile

Consumer Electronics

Office Equipments

Household Appliances
A “Short List” of Embedded Systems

- Anti-lock brakes
- Auto-focus cameras
- Automatic teller machines
- Automatic toll systems
- Automatic transmission
- Avionic systems
- Battery chargers
- Camcorders
- Cell phones
- Cell-phone base stations
- Cordless phones
- Cruise control
- Digital cameras
- Disk drives
- Electronic card readers
- Electronic instruments
- Electronic toys/games
- Factory control
- Fax machines
- Fingerprint identifiers
- Home security systems
- Life-support systems
- Medical testing systems
- Modems
- MPEG decoders
- Network cards
- Network switches/routers
- On-board navigation
- Pagers
- Photocopiers
- Plant control
- Point-of-sale systems
- Portable video games
- Printers
- Satellite phones
- Scanners
- Smart ovens/dishwashers
- Speech recognizers
- Stereo systems
- Teleconferencing systems
- Televisions
- Temperature controllers
- Theft tracking systems
- TV set-top boxes
- VCR’s, DVD players
- Video game consoles
- Video phones
- Washers and dryers

And the list goes on and on
Function classification

- Monitoring and control functions for the overall system (e.g., vehicle control)
- Information-processing functions (e.g., telecommunication system, Multimedia, etc.)

Different application type have different requirements and characteristics.
Some Application Domains

- CONSUMER PRODUCTS
  - Appliances, Games, A/V, Intelligent home devices
- TRANSPORTATION
  - Autos, Trains, Ships, Aircrafts
- PLANT CONTROL
  - Manufacturing, Chemical, Power Generation
- NETWORKS
  - Telecommunication, Defense

Local
- e.g., appliance

Locally distributed
- e.g., aircraft control over a LAN

Geographically distributed
- e.g., telephone network
Parts of an Embedded System

- USER
- MEMORY
- PROCESSOR
- I/O
- HARDWIRED UNIT:
  - Application-specific logic
  - Timers
  - A/D and D/A conversion
- ENVIRONMENT
- ACTUATORS
Parts of an Embedded System (cont.)

- **Sensors**: input data (e.g., accelerometer for airbag control)
- **Actuators**: mechanical components (e.g., step motors)
- **Processors**: Data conversion, storage, processing, decision-making
- Can be on-chip or on-board systems
  - SoC
- Can be bus-based or network-based systems
  - NoC
Characteristics of Embedded Systems

- Sophisticated functionality.
- Real-time operation.
- Throughput.
- Low power.
- Reliability.
- Low manufacturing cost.
- Time-to-market.
Functional Complexity

- Some systems are single-functioned
  - Executes a single program, repeatedly

- Often have to run sophisticated algorithms or multiple algorithms (Cell phones, Tele. Switches, DVD Players).
  - Example: A DVD player
    - DVD, video CD, audio CD, JPEG image CD, MP3 CD, MPEG-4, DivX 3.11/4.x/5.x

- Often provide sophisticated user interfaces.
  - Multiple levels of user menus
  - Support for multiple languages
  - Graphics
  - Speech, handwriting
Real-Time Operation

- Embedded systems are reactive
  - Continually reacts to changes in the system’s environment.
  - Sensor and actuator
  - User-interface and sensors
  - Reactive systems are often real-time
Real-time operation

- Must finish operations by deadlines.
  - *Hard real time*: missing deadline causes failure.
    - Drive-by-wire systems
  - *Soft real time*: missing deadline results in unhappiness!
    - Printers

- Many systems are multi-rate: must handle operations at widely varying rates.
  - Example: Audio and Video in a multimedia app.

- Real-time vs. non-real-time systems.
Throughput

- In real-time operation the critical factor is *latency*
  - Latency (response time): Time between task start and end

- Throughput
  - The other important performance metric.
  - Tasks per second.

- Example:
  - Camera A processes an image in 0.25 seconds: 4 images per second.
  - Camera B processes an image in 0.25 seconds but processes 8 images per second.
    - By capturing a new image while previous image is being stored.
    - *Throughput Speedup* of B over A = 8/4 = 2.

- Throughput can be more than latency seems to imply due to concurrency.
- Real-time operation still depends on latency.
Power Consumption

- Power-limited vs. power-unlimited systems
- Power consumption is critical in battery-powered devices.
  - Excessive power consumption increases:
    - System cost (more powerful batteries and cooling)
    - System size and weight.

- Now it is critical in all computing systems
  - Ever increasing chip density
Reliability

- **Reliability**: $R(t)$ probability that no fault occurs (i.e. system survives) during time $t$.

- Important in all digital systems.
- Extremely important in safety-critical systems.
  - Avionic systems
  - Medical systems
  - Plant control systems
Time-to Market

- Time required to develop a product to the point it can be sold to customers
- Market window
  - Period during which the product would have highest sales
- Average time-to-market constraint is about 8 months
- Delays can be costly
Delayed Market Entry

- **Simplified revenue model**
  - Product life = 2W, peak at W
  - Time of market entry defines a triangle, representing market penetration
  - Triangle area equals revenue

- **Loss**
  - The difference between the on-time and delayed triangle areas

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Design & Co-design of Embedded Systems 20
NRE and Unit Cost Metrics

Costs:

- Unit cost: the monetary cost of manufacturing each copy of the system, excluding NRE cost
- NRE cost (Non-Recurring Engineering cost): the one-time monetary cost of designing the system

\[
\text{total cost} = \text{NRE cost} + \text{unit cost} \times \# \text{ of units}
\]

\[
\text{per-product cost} = \frac{\text{total cost}}{\# \text{ of units}} = \left( \frac{\text{NRE cost}}{\# \text{ of units}} \right) + \text{unit cost}
\]

• Example
  - NRE=$2000, unit=$100
  - For 10 units
    - total cost = $2000 + 10*$100 = $3000
    - per-product cost = $2000/10 + $100 = $300

  *Amortizing NRE cost over the units results in an additional $200 per unit*
NRE and Unit Cost Metrics

- Compare technologies by costs -- best depends on quantity
  - Technology A: NRE=$2,000, unit=$100
  - Technology B: NRE=$30,000, unit=$30
  - Technology C: NRE=$100,000, unit=$2

- For 100 copies: a=$120, b=$330, c=$1002
- For 1,000,000 copies: a=$100, b=$30.03, c=$2.1

• But, must also consider time-to-market
Some Other Properties

- **Size:**
  - The physical space required by the system
  - Power consumption, Packaging cost,…

- **Flexibility:**
  - The ability to change the functionality of the system without incurring heavy NRE cost.
Design Challenge – Optimization

- **Obvious design goal:**
  - Construct an implementation with desired functionality.

- **Key design challenge:**
  - Simultaneously optimize numerous design objectives.

- The design objectives are at odds!
Conflicting Design Objectives

- Reliability requires redundancy
  - More energy consumption
  - More weight and size
- Real-time operation may need applying ASIC modules
  - More NRE cost
  - Time-to-market
Conflicting Design Objectives

- Constrained objectives: the design objectives MUST be met.
  - Reliability
  - Real-time operation
- Optimized objectives: the design objectives should be Improved as much as possible
  - Power-consumption
  - throughput
Design Methodology

- A procedure for designing a system
  - Requirements
  - Specification
  - Architecture
  - Components
  - System Integration

- A Design Methodology should provide func. and non-func. design objectives.
What We Learned Today

- Embedded computers are all around us.
  - Many systems have complex embedded hardware and software.
- Embedded systems pose many design challenges: design time, deadlines, power, etc.
- The design objectives are conflicting.
  - Design methodologies should help us to manage the design process.
- Course web-page is now established
  - At CE course page

- Books are ready