Introduction to Embedded Systems

Jin-Soo Kim (jinsookim@skku.edu)
Computer Systems Laboratory
Sungkyunkwan University
http://csl.skku.edu
Embedded Systems Everywhere
What are Embedded Systems?
Definition

- **Embedded System (ES):** any device that includes a programmable computer but is not itself a general-purpose computer.

  - Take advantage of application characteristics to optimize the design
Embedding a Computer

- CPU
- Mem
- Input
- Output
- Analog

Embedded computer
Where are the CPUs?

- Estimated 98% of 8 billion CPUs produced in 2000 used for embedded applications
- Smartphone shipments (101M) surpass PCs (2010Q4)

Source: DARPA/Intel (Tennenhouse)
Embedded Processors

- **Microcontroller (μC or MCU)**
  - A small computer on a single IC containing a processor core, memory, and I/O peripherals

- **Microprocessor**
  - A general-purpose CPU in a single chip

- **SoC (System-on-a-Chip)**
  - More integration than MCU
  - Mostly, require external memory
Early History (1)

- MIT Whirlwind computer (Late 1940’s)
  - Originally designed to control a flight simulator for training bomber crews
  - The first computer that operated in real time
  - 5000 vacuum tubes
Early History (2)

- Intel 4004 (1971)
  - The first microprocessor (4-bit)
  - Originally designed for use in a calculator
  - The first complete CPU on one chip
  - The first commercially available microprocessor
  - 2300 transistors @ 108KHz
Early History (3)

- Automobiles used microprocessor-based engine controllers starting in 1970’s
  - Control fuel/air mixture, engine timing, etc.
  - Multiple modes of operation: warm-up, cruise, hill climbing, etc.
  - Provides lower emissions, better fuel efficiency
Keyboard
Mouse
Hard Disk Drive
Digital Still Camera

Canon EOS3 uses three microprocessors for auto-focus, etc.
iPhone 3G
Digital TV

Programmable CPUs + hardwired logic for video/audio decode, etc.
Automobile

- A high-end automobile
  - > 100 microprocessors
  - 4-bit microcontroller checks seat belt
  - Microcontrollers run dashboard devices
  - 16/32-bit microprocessor controls engine
Want More?

You name it!

- 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
- Curbside check-in systems
- 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
- 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 ...
Challenges
ES Characteristics (1)

▪ Single-functioned
  • Executes a single program, repeatedly

▪ Sophisticated functionality
  • Often have to run sophisticated algorithms or multiple algorithms
    - Cell phone, laser printer
  • Often provide sophisticated user interfaces
ES Characteristics (2)

- Reactive and real-time operation: Must finish operations by deadlines
  - Continually reacts to changes in the systems environment
  - **Hard real-time**: missing deadline causes failure
  - **Soft real-time**: missing deadline results in degraded performance
  - Many systems are multi-rate: Must handle operations at widely varying rate
ES Characteristics (3)

- **Low cost**
  - **Manufacturing cost**
    - The monetary cost of manufacturing each copy
  - **NRE (Non-Recurring Engineering) cost**
    - The one-time monetary cost of designing the system
  - Many embedded systems are mass-market items that must have low manufacturing cost
  - Limited memory, microprocessor power, etc.
ES Characteristics (4)

- Low power
  - Power consumption is critical in battery-powered devices
  - Excessive power consumption increases system cost even in wall-powered devices
ES Characteristics (5)

- Designed to tight deadlines by small teams
  
  - Often designed by a small team of designers
  - Often must meet tight deadlines
    - 6-month time-to-market is common
    - Can’t miss back-to-school window for calculator
  
  - Many design alternatives
  - Hard to develop and debug
Challenges in ES Design (1)

▪ How much hardware do we need?
  • Powerful CPU? Big memory?

▪ How do we meet our deadlines?
  • Faster hardware or cleverer software?

▪ How do we minimize power?
  • Turn off unnecessary logic? Reduce memory accesses?

▪ Time-to-market?
Challenges in ES Design (2)

- Does it really work?
  - Is the specification correct?
  - Does the implementation meet the spec?
  - How do we test for real-time characteristics?
  - How do we test on real data?
  - Does it work reliably?

- How do we work on the system?
  - Observability, controllability?
  - What is our development platform?
Challenges in ES Design (3)

- Optimizing design metrics
  - Improving one may worsen others
  - Expertise with both software and hardware is needed to optimize design metrics
  - A designer must be comfortable with various technologies in order to choose the best for a given application and constraints