Introduction to Embedded Systems

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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

Embedding computer

analog

analog
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 5S

Apple M7 Co-processor
Apple A7 Application Processor & 1GB LPDDR3 DRAM
Qualcomm MDM9615M LTE Modem

SK Hynix 16GB NAND Flash
Qualcomm PM8018 RF Power Management IC

TriQuint TQM6M6224 Dual-band PA duplexer

Apple 338S1216 Power Management IC
Qualcomm WTR1605L LTE/HSPA+/CDMA2K/TDSCDMA/EDGE/GPS Transceiver

TI 343S0645 Touchscreen Interface
Broadcom BCM5976 Touchscreen Controller

TriQuint TQM6M6224 Dual-band PA duplexer
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!**

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Example</th>
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<tbody>
<tr>
<td>Anti-lock brakes</td>
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<td>Auto-focus cameras</td>
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<td>Automatic teller machines</td>
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<td>Automatic toll systems</td>
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<td>Automatic transmission</td>
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<td>Avionic systems</td>
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<td>Battery chargers</td>
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<td>Camcorders</td>
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<td>Cell phones</td>
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<td>Cell-phone base stations</td>
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<td>Cordless phones</td>
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<td>Cruise control</td>
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<td>Curbside check-in systems</td>
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<td>Digital cameras</td>
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<td>Disk drives</td>
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<td>Electronic card readers</td>
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<td>Electronic instruments</td>
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<td>Electronic toys/games</td>
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<td>Factory control</td>
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<td>Fax machines</td>
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<td>Fingerprint identifiers</td>
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<td>Home security systems</td>
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<td>Life-support systems</td>
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<td>Medical testing systems</td>
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<td>Modems</td>
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<td>MPEG decoders</td>
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<td>Network cards</td>
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<td>Network switches/routers</td>
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<td>On-board navigation</td>
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<td>Pagers</td>
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<td>Photocopiers</td>
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<td>Point-of-sale systems</td>
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<td>Portable video games</td>
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<td>Printers</td>
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<td>Satellite phones</td>
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<td>Scanners</td>
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<td>Smart ovens/dishwashers</td>
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<td>Speech recognizers</td>
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<td>Stereo systems</td>
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<td>Teleconferencing systems</td>
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<td>Televisions</td>
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<td>Temperature controllers</td>
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<td>Theft tracking systems</td>
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<td>TV set-top boxes</td>
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<td>VCR’s, DVD players</td>
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<td>Video game consoles</td>
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<td>Video phones</td>
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<td>Washers and dryers</td>
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Solid State Drives (SSDs)
SSD Architecture
## Commercial SSDs

From enuri.com (As of March 4, 2014)
1\$-per-GB?

News

SSD Per-GB Cost to Fall Below $1 in Second Half of 2012 - Market Observers.
SSDs to Gain Considerable Market Share This Year, Says DRAMeXchange

[03/07/2012 08:53 PM]
by Anton Shilov

The $1-per-GB price has been for a long time considered as a holy grail for solid-state drives as it is widely believed that at such price points SSDs will start to be adopted by mainstream users.

According to DRAMeXchange, a division of TrendForce market research firm, the price per GB will be even lower than $1 in the second half of the year, which will unleash growth potential for SSDs.

After SSDs based on NAND flash memory manufactured using the latest - 19nm, 20nm and similar - process technologies enter mass production in the second half of 2012, unit cost may fall below $1-per-GB, the pricing sweet spot the market has been anticipating. When this occurs, DRAMeXchange expects ultrabook/thin notebook makers will transition from adopting hybrid HDD solutions to pure SSD solutions, and mainstream capacity will increase to 128GB.

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