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

input

output

analog

analog

mem

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

Motor Driver

Flash-ROM

Controller

Buffer (RAM)
Digital Still Camera

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

Semiconductor insights™

- **SST**: SST25VF080B
  - 1 MB Serial Flash

- **Samsung**: LIS331 DL
  - Accelerometer

- **ST Microelectronics**: SMP3i
  - SMARTi Power Management IC

- **Skyworks**: SKY77340
  - Power Amp. Module

- **Infineon**: UMTS Transceiver

- **TriQuint**: TQM666032
  - WCDMA/HSUPA Power Amp.

- **TriQuint**: TQM676031
  - WCDMA/HSUPA Power Amp.

- **TriQuint**: TQM616035
  - WCDMA/HSUPA Power Amp.

- **Wolfson**: WM6180C
  - Audio Codec

- **Infineon**: PMB2525
  - Hammerhead II GPS

- **Linear Technology**: LTC4088-2
  - Battery Charger/USB Controller

- **NXP**: Power Management

- **Infineon**: Digital Baseband Processor

**Notes**: iPhone 3G uses a variety of semiconductor components from different manufacturers to create its integrated circuit.
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 ...
Solid State Drives (SSDs)
HDDs vs. SSDs

2.5” HDD       Flash SSD  
(101x70x9.3mm)

1.8” HDD       Flash SSD  
(78.5x54x4.15mm)
SSD Architecture
## Commercial SSDs

*From enuri.com (As of March 5, 2013)*

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Interface</th>
<th>Capacity</th>
<th>Sequential Read (MB/s)</th>
<th>Sequential Write (MB/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandisk</td>
<td>Extreme SSD Pro</td>
<td>Sata III</td>
<td>256 GB</td>
<td>520</td>
<td>390</td>
</tr>
<tr>
<td></td>
<td>840 Series Pro</td>
<td>Sata III</td>
<td>240 GB</td>
<td>550</td>
<td>510</td>
</tr>
<tr>
<td></td>
<td>510 Series Pro</td>
<td>Sata III</td>
<td>120 GB</td>
<td>540</td>
<td>500</td>
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<tr>
<td></td>
<td>460 Series Pro</td>
<td>Sata III</td>
<td>960 GB</td>
<td>540</td>
<td>500</td>
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<tr>
<td></td>
<td>550 Series Pro</td>
<td>Sata III</td>
<td>960 GB</td>
<td>540</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>530 Series Pro</td>
<td>Sata III</td>
<td>480 GB</td>
<td>530</td>
<td>490</td>
</tr>
</tbody>
</table>

### Technical Specifications
- **Interface**: Sata III
- **Dimensions**: 2.5" x 88.9 x 9.5 mm
- **Form Factor**: 2.5" x 88.9 x 9.5 mm

*From enuri.com (As of March 5, 2013)*
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