Lecture 1: Introduction
What is an embedded system?
How do we build embedded systems?
Homework 1 (4 Weeks Long)

Concept Design

Part Selection Schematics

Printed Circuit Board Layout

Manufacturing

Board Assembly Testing

• Define Requirements
• Define Constraints
• Online searches (octopart.com, digikey.com, mouser.com, etc.)
• Altium Designer for Schematic input
• Altium Designer PCB Editor

• Send Gerber Files to Board House
• Sunstone, 4PCB, CircuitBoards

• Soldering in our lab!
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1. Concept
2. Design
3. Part Selection
4. Schematics
5. Printed Circuit Board Layout
6. Manufacturing
7. Board Assembly
8. Testing

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Lab 0 / Homework 1

- Introduction to PCB Design
- Check-out canvas for details and submission
- Four-part homework
  1. Choose a MCU and make schematic using *Altium Designer*
  2. Layout PCB and verify it
  3. Get your board manufactured by circuitboard.com
  4. Assemble your board.
- First part due this Friday, *Jan 10th at 11:59pm!*
- You have to pay for manufacturing & parts.

1. Altium is installed on all computers in the Digital Lab, Analog Lab, and Computer Class Room
2. Walkthrough available: [http://goo.gl/j12h76](http://goo.gl/j12h76)
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Zero Credit for LATE homework!
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere

Open Automotive Alliance
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere
Embedded, everywhere
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Embedded, everywhere
Embedded, Everywhere - Fitbit

A picture of a Fitbit wearable device is shown, along with images of the Fitbit app on a mobile phone. The app displays various fitness metrics, including activity tracking and calorie consumption. The text and images together illustrate how Fitbit devices and their mobile application can be integrated into daily life to track physical activity and monitor health.
Embedded, Everywhere - Nest Protect
Embedded, Everywhere - WattVision on Kickstarter

Wattvision - The Smart Energy Sensor

Wattvision is a revolutionary sensor and app that gives you real-time feedback on your energy use so you can save money and the planet.
What is driving the embedded everywhere explosion?
Technology Trends

Design Questions

Course Administrativa
Bell’s Law of Computer Classes:
A new computing class roughly every decade

“Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry.”

Adapted from D. Culler
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Moore’s Law:
IC transistor count doubles every two years

![Transistor Count Chart]

- Intel 10-Core Xeon Westmere-EX: 2,600,000,000 (2011) 32 nm
- AMD Tahiti: 4,310,000,000 (2011) 28 nm
- Xilinx Virtex-7: 6,800,000,000 (2011) 28 nm

Photo Credit: Intel
Moore’s Law:
IC transistor count doubles every two years

Intel 10-Core Xeon Westmere-EX  2,600,000,000 2011 32 nm
AMD Tahiti  4,310,000,000 2011 28 nm
Xilinx Virtex-7  6,800,000,000 2011 28 nm

Photo Credit: Intel
Moore’s Law:
IC transistor count doubles every two years

Intel’s next-generation Broadwell CPUs delayed due to yield problems
14nm chips will now begin production in Q1 of 2014.

by Andrew Cunningham - Oct 16 2013, 6:45am MDT

During the company's third quarter earnings call yesterday, CEO Brian Krzanich announced that production of Intel's next-generation Broadwell CPUs would be delayed slightly due to manufacturing issues. CNET reports that a "defect density issue" in the new 14nm manufacturing process was causing lower-than-expected yields and that Intel's first round of fixes didn't improve the yields by the expected amount. Krzanich expressed "confidence" that the issue had been fixed, that it was just a "small blip in the schedule," and that the CPUs would begin mass production in the first quarter of 2014 rather than the fourth quarter of 2013 as expected. Broadwell's successor, codenamed Skylake and due in 2015, will apparently not be affected by the delay.

Broadwell is a "risk" on Intel's CPU roadmap, a refined version of the current Haswell architecture.

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Learn more.

Ars deathwatch 2014: Companies on the edge of relevance
These five companies won't die, but they may not escape 2014 in one piece.

Nvidia, steering wheels, drones, and keyboards at CES
Moore’s Law and the future
Moore’s Law and the future
Moore’s 2nd Law (Rock’s Law):
Chip fabrication costs doubles every four years

Cost in $ Million

<table>
<thead>
<tr>
<th>Process Node (nm)</th>
<th>Leader</th>
<th>Follower</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>139</td>
<td>94</td>
</tr>
<tr>
<td>130</td>
<td>196</td>
<td>135</td>
</tr>
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<td>90</td>
<td>283</td>
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<td>45</td>
<td>547</td>
<td>394</td>
</tr>
<tr>
<td>32</td>
<td>796</td>
<td>581</td>
</tr>
<tr>
<td>22</td>
<td>1354</td>
<td>999</td>
</tr>
</tbody>
</table>
Flash memory scaling:
Rise of density & volumes; Fall (and rise) of prices
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Rise of density & volumes; Fall (and rise) of prices
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Rise of density & volumes; Fall (and rise) of prices
300mm Wafer Capacity

- Samsung: 19
- SK Hynix: 12
- Micron: 14
- Intel: 11
- TSMC: 10
- Toshiba: 9

IC Insight
Memory: 36%
Foundry: 28%
Logic: 12%
Micro: 10%
Analog: 10%
Other: 4%
MEMS Accelerometers: Rapidly falling price and power
MEMS Accelerometers:
Rapidly falling price and power

10(mA)
MEMS Accelerometers: Rapidly falling price and power

ADXL345

[Analog Devices, 2009]
MEMS Accelerometers: Rapidly falling price and power

**ADXL345**

[Analog Devices, 2009]

- Price: 10 mA
- Power: 25 µA @ 25 Hz
MEMS Accelerometers: Rapidly falling price and power

ADXL345
[Analog Devices, 2009]

10(µA) @ 10 Hz @ 6 bits
[ST Microelectronics]
MEMS Accelerometers: Rapidly falling price and power

10(mA)

Price

Power

ADXL345
[Analog Devices, 2009]

25 μA @ 25 Hz

10 μA @ 10 Hz @ 6 bits
[ST Microelectronics]
MEMS Accelerometers:
Rapidly falling price and power

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[ST Microelectronics]
MEMS Gyroscope Chip

J. Seeger, X. Jiang, and B. Boser
MEMS Gyroscope Chip

J. Seeger, X. Jiang, and B. Boser
MEMS Gyroscope Chip

0.01 Å Sense

1 µm Drive

J. Seeger, X. Jiang, and B. Boser
Energy harvesting and storage: Small doesn’t mean powerless...

Thermoelectric Ambient Energy Harvester

RF [Intel]

Clare Solar Cell

Shock Energy Harvesting CEDRAT Technologies

Thin-film batteries

Piezoelectric [Holst/IMEC]

Electrostatic Energy Harvester [ICL]

Thermoelectric Ambient Energy Harvester
Bell’s Law, Take 2: Corollary to the Laws of Scale

Photo credits: Intel, U. Michigan
Bell's Law, Take 2:
Corollary to the Laws of Scale

Photo credits: Intel, U. Michigan
Bell’s Law, Take 2: Corollary to the Laws of Scale

Intel® 4004 processor
Introduced 1971
Initial clock speed
108 KHz
Number of transistors
2,300
Manufacturing technology
10µ

UMich Phoenix Processor
Introduced 2008
Initial clock speed
106 kHz @ 0.5V Vdd
Number of transistors
92,499
Manufacturing technology
0.18 µ

Photo credits: Intel, U. Michigan
Bell’s Law, Take 2: Corollary to the Laws of Scale

Intel® 4004 processor
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Number of transistors
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Initial clock speed
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UMich Phoenix Processor
Introduced 2008
Initial clock speed
2.66 GHz
Number of transistors
582,000,000
Manufacturing technology
65nm

Quad-Core Intel® Xeon® processor
Quad-Core Intel® Core™2 Extreme processor
Introduced 2006
Intel® Core™2 Quad processors
Introduced 2007
Initial clock speed
2.66 GHz
Number of transistors
582,000,000
Manufacturing technology
65nm

15x size decrease
40x transistors
55x smaller λ

Photo credits: Intel, U. Michigan
Outline

Technology Trends

Design Questions

Course Administrivia
Learning happens when assumptions are challenged and invalidated, so…
Mobile phones: the most successful technology ever

U.S. Cell Phone Subscriber Growth 1990-2015

© Bridge Ratings LLC
What happened elsewhere now happens on the phone

Preferred Cell Phone Services

- Music Downloading: 37%
- AM/FM Receiver: 15%
- TV Viewing: 11%
- News/Sports: 28%
- Concierge Services: 23%
- Internet Browsing: 12%
- Audio Streaming: 8%
- Music Playback: 14%
- Text Messaging: 57%
- Weather Reports: 17%
- Traffic Reports: 39%

© Bridge Ratings LLC
What happened elsewhere now happens on the phone

Self-expression
Participating in hobbies and interests

Discovery
Seeking news and information

Preparation
Planning for upcoming activities

Accomplishing
Managing finances, health, and productivity

Shopping
Seeking a product or a service

Socializing
Interacting with other people

“Me time”
Seeking relaxation or entertainment (for example, by watching a funny video, reading a gossip website, playing solitaire, or even window shopping for fun)

PERCENTAGE OF ALL INTERACTIONS (EXCLUDES E-MAIL, SMS MESSAGES, AND VOICE CALLS)

AVERAGE MINUTES PER MONTH PER USER (METERED)

410
19%

864
46%

61
13%

47
9%

21
4%

22
7%

126
61%

12%

11%

7%
What happens when you press the power switch on your mobile phone?
Mobile phone system architecture

- Switch/Filters
- Radio & PLLs
- Digital Baseband
- PA
- Low-Noise LDOs
- SUPA
- Loop Control
- Analog Baseband & PMU or APU
- Bluetooth Module
- Modem Section
- PMU
- LED Drive
- Application Processor
- PowerWise™
- Keypad
- Memory Card/Stick
- Level Shift
- Processor/Main Board
- External Interface
- TV; FM Tuner
- GPS
- Peripherals
- Battery
- Charging & Protection
- Fuel Gauge
- Energy System
- Camera
- LED Flash
- Audio Subsystem
- MPL/PMU
- Flip Section
- Display Drive & Power
- Lighting Mgmt
- Graphics Accelerator
- Display
Why study 32-bit MCUs and FPGAs?
MCU-32 and PLDs are tied in embedded market share

Source: iSuppli
Why study the ARM architecture (and the Cortex-M3 in particular)?
Lots of manufacturers ship ARM products
What differentiates these products from one another?
The difference is...
The difference is...

Peripherals!!
The difference is...

Peripherals!!

Peripherals!!
The difference is...

Peripherals!!
An embedded systems design example:
Turning the mobile phone into an EKG
Integrating power, data, and processing
Integrating power, data, and processing
Integrating power, data, and processing
Outline

Technology Trends

Design Questions

Course Administrativa
Instructional Staff
(see homepage for contact info, office hours)

Thomas Schmid
thomas.schmid@utah.edu

Andrzej Forys
andrzej.forys@utah.edu

Anh Luong
anh.n.luong@utah.edu
Prerequisites

- CS/ECE 3700 (Digital System Design) OR CS/ECE 3810 (Computer Organization)
  - Digital Systems
  - Computer Architectures
  - CPU organizations
  - Memory systems
  - Pipelining
  - Hardware Description Language (Verilog)
- CS 2000 (Introduction to Program Design in C)
  - CS 1410 (Introduction to Object-Oriented Programming)
  - CS 4400 (Computer Systems)
  - C programming
  - Algorithms (e.g. sort) and data structures (e.g. lists)

- Graduate Students: Enrolled in graduate program.
Course Syllabus (tentative)

• See course homepage:
  - http://wiesel.ece.utah.edu/redmine/projects/ece5780-s13/wiki

• Assignments & Discussions on Canvas
  - https://utah.instructure.com/courses/178704

• Roughly
  - 50%: Lab-centric
  - 50%: Project-centric

• Labs
  - Schematics + PCB Design
  - FPGA + Hardware Tools
  - MCU + Software Tools
  - Memory + Memory-Mapped I/O
  - Interrupts
  - Timers and Counters
  - Serial Bus Interfacing / USB
  - Data Converters (e.g. ADCs/DACs)
Labs

- Start next week
- Tutorials to familiarize you with Altium, ARM, Microsemi tools
- Should be fun
  - Learn how to sense/control physical world
  - Build hardware (including PCBs)
- Should be instructive
  - Program in Verilog
  - Program in C, and assembly
  - Learn debugging skills
  - Learn how to interface peripherals to the CPU/MCU
- Are challenging and time-consuming - plan ahead
Lab Organization

- 3 Sessions, Digital Lab MEB 2265
  - Session 1: Monday 2pm - 5pm
  - Session 2: Wednesday 11:50am - 2:50pm
  - Session 3: Friday 8:35pm - 11:35pm
- TAs will be there to help you with the labs
- You can work in teams of 2
  - *Try to have a mixed team CS/CE/EE/ME*
- You have to have a CADE account!
- There is a local printer in the lab. 400 Page Limit!
Lab 1 - 7

- Will be covered in next lecture

- You can check out the hardware from MEB 1381
  - 1x Microsemi SmartFusion A2F-EVAL
  - 1x A2F-BREAKOUT board
  - 2x USB cables

- Keep it for the whole semester at no cost (unless you break it!)
- Digital Logic Analyzer Saleae Logic 16, one per team!

- Be careful not to short the board
- Some testpoints are VCC, others are GND!!!
- Use antistatic mats and connectors in lab when handling the boards (ask TA if you don’t understand this)
Open-ended Project

- Goal: learn how to build embedded systems
  - By building an embedded system
  - Work in teams
  - Pick a problem of your own interest
  - Meet with instructors to discuss other ideas

- Should be related to the class and emphasize topics

- Scope of project must grow with size of team

- Encourage to have a mixed team of CS, CE, EE, ME
Last Year Projects

See http://wiesel.ece.utah.edu/redmine/projects/ece5780-s12-groups

- 3D PCB Maker
- Adaptable Motor Controller
- Audio Digital Effects and Recording System
- Fish Bait
- FPGA Implementation of 4-QAM Transceiver
- High-Altitude Balloon Sensor
- MotoLogger
- Pet Pipe
- Project Levitate
- ringtactoe
- Smart Facilities
- 3D LED Cube
- WiFi Embedded Sniffing Encryption Cracker
- X-Mas Sweater
See http://wiesel.ece.utah.edu/redmine/projects/ece5780-s12-groups

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- X-Mas Sweater
Exams

- Midterm 1 (~ February 27, 2014)
  - Emphasize problem solving fundamentals

- Midterm 2 (Date TBD, Late in Semester)
  - Cumulative topics

- Minute Quizzes
  - Short, Random
  - Over previous day’s material
<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labs</td>
<td>28%</td>
<td>7 labs, 4% each</td>
</tr>
<tr>
<td>Project</td>
<td>30%</td>
<td>Group project demonstrating understanding of major topics.</td>
</tr>
<tr>
<td>Exams</td>
<td>22%</td>
<td>Two exams: Midterm 1 (10%); Midterm 2 (12%)</td>
</tr>
<tr>
<td>Quizzes</td>
<td>10%</td>
<td>Approximately four 1-minute quizzes given at random (coin-flip)</td>
</tr>
<tr>
<td>Homework</td>
<td>10%</td>
<td>Two or three homework assignments weighted roughly equally.</td>
</tr>
</tbody>
</table>
Thinking ahead:
Letters of recommendation for graduate school

- Grad school apps will require supporting letters
- Faculty write letters and read “coded” letters
- Strong letters give evidence of research ability
- Weak letters are vague and give class standing
- Strong letters can really help your case
- Weak letters are useless (or even worse)

- Want a strong letter?
  - Do well in this class
  - Pull off an impressive project
  - Continue class project as independent research over Summer or F’14
Demo of ADFX

http://www.youtube.com/watch?feature=v=b6phcj4tcQg