Computer Engineering

Logic Design

EE
- Elect
- Mag
- Circuits
- Solid
- State
- Signals
- & Sys
- Program
- Probability
- Comp
- Arch

CS
- Disc
- Math
- Algor
- & Data
- Str
- Theory
- of Comp

Comp Eng
Computer Engineers

An undergrad program that hits the sweet spot between EE and CS that involves designing computers!
– i.e. Fun Stuff!

CS

Computer Engineering!

EE

Engineering and Computer Science

• Computers are Everywhere
• Create, Innovate
• Serve Humanity by Improving
  – Environment
  – Safety
  – Productivity
  – Communications
  – Energy Availability and Efficiency
  – Health
Ultimately

- **Engineering requirement**
  - what we build must work
- **Ethical requirement**
  - what we create must help
  - lots of dimensions for this responsibility
- **Skill requirements**
  - science: math, physics, chemistry, materials, CS, ...
  - engineering: state of the art, current practice, technology trends, manufacturing, testability, maintenance, life cycle costs, ...
  - art: creative component that is clearly evident in the great engineers
CE - A student perspective

• Undergraduate program
  – joint offering by ECE and SoC
    • some required courses, electives, &
      a senior project or thesis
      – details http://www.ce.utah.edu
      – numerous faculty involved in CE research
        » check the ECE & SoC web pages to explore
          further
  • Graduate programs
    – both MS and Ph.D. offered separately by
      ECE and SoC

Computer Engineering Curriculum

• Design and build computer systems
  – software and hardware design skills
• System software
  – compiler, operating system, software engineering, ...
  – as opposed to application software
    • applications are the target system “user”
    • used in design evaluation (pre- and post-build)
• Hardware: possibly many disciplines and levels
  – Basic circuit design and testing
  – VLSI chip design: analog and digital
• Courses exist to get you started in all of these
  areas
  – context can be either embedded or high performance
    systems
CS/ECE 3710: Computer Design Lab

- Taught in Fall semester, 3 credits
- Prereqs: CS/EE 3700, CS/EE 3810
  - Student groups design, build, and test their own computer system on an FPGA
  - Typically a 16bit processor designed using schematics, Verilog, and Xilinx-based prototyping boards
    - i.e. completely student-designed from the gates up to the software
  - Bread and butter for a Computer Engineer!

3710: Xilinx Spartan3-based Boards

- 500k-gate Spartan FPGA
  - 360Kbits RAM
  - 20 18x18 multipliers
  - 16-char, 2-line LCD
- 256Mbit SDRAM
- Connectors for VGA, PS/2, RS232,
Right Now in 3710...

- Processors are processing...
- Groups are extending things to use the VGA, serial, PS/2, Nintendo, dance pad, etc. ports
  - designing their own VGA controller
  - writing interactive video games in assembly using keyboard for input (or other things) and VGA display for output
  - using 3-d graphics using their own “graphics accelerator”
  - all sorts of other interesting things

- Watch for a CS/EE 3710 demo day towards the end of fall semester

Examples from Years Past
CE Senior Projects at Utah

- **Logistics**
  - Senior project is capstone project course
    - team based
    - student teams choose their own project
      - for once you get to pick your own homework assignment
    - best mechanism to demonstrate your abilities to future employers
  - CE Senior Project is a year long activity
    - Spring term of junior year: plan and propose
    - Summer: get parts and start building (optional)
    - Fall term of senior year: build and demonstrate
  - Exit interview feedback
    - rave reviews for being hard, fun, and instructive

04 Projects

- **Satellite Tracking station**
- **Weaver** – a 802.11 remote control vehicle interface
  - camera on car: image and commands to base station via wireless
  - car has autonomous anti-collision capability (infrared)
- **GPS Hummer**
  - autonomous navigation and anti-collision
  - some AI in route finding since Hummer remembers obstacles that it saw previously
- **PCI Coprocessor**
  - efficient acceleration via PCI add-on
- **Jiggawax**
  - build your own iPod
- **RVI** – remote vehicle interface
  - control via web or cell phone
  - control windows, engine, and door locks from RF base station
05 Projects

- **Carputer**
  - OBDII car data and 802.11g auto-sync to base station
  - monitor your car or your kids
- **IR tag**
  - paintball without the mess
- **Athlete monitor system**
  - real time tracking of position and heart rate to central coaching station
  - GPS, RF, and HRM on-athlete
- **Multi-carrier reflectometry**
  - finding faults in aircraft wires without tearing the plane apart
- **Glider avionics package**
  - using accelerometers, GPS, and strain sensors

06 projects

- **PEN**
  - electronic paper – the only paper you’ll ever buy!
- **Recipedia**
  - a cook book that talks and listens to you
- **GPS tracker**
  - use campus ubiquitous wireless to keep track of where things are via your cell phone or computer
- **OmegaCore**
  - a DVR that knows how to remove commercials for you
- **NoCPR**
  - bathtub drowning prevention
- **Tracking Visor**
  - virtual reality on your head

Come & watch this year’s projects!
Senior Project Synopsis

- This was just a peek
- Just remember
  - if you can imagine it you can usually build it
    - there are some things you just can't do in a year
  - all it takes is dedication and time
    - same is true in industry - time and resource constraints change however
- Huge diversity of both opportunities and problems
- You might have noticed the world isn’t perfect
  - so help fix it!

CE and Sustainability

- Power is a major issue in computer design
  - High performance chips need a lot of power
  - High performance computing takes a lot of chips
  - The amount of electricity used for the world’s computers is pretty amazing...
  - Think before you Google?
**Intel Core2 Duo**

- 65nm process, 75W, 144 mm² die
- 291,000,000 total transistors

**That’s a LOT of transistors**

- **Where are they used?**
  - Mostly for memory!
  - Around 6 transistors per bit of memory
  - Intel Core2 Duo: 4MB shared L2 cache, 32K Icache 32K Dcache on each core
  - \(4 \times 1024^2 \times 8 + 2 \times (64 \times 1024 \times 8) = 34,603,008 \text{ bits} \)
  - \(35,000,000 \text{ bits} \times 6 = 210,000,000 \text{ transistors} \)
  - Core2 Duo has around 291,000,000 total transistors...
  - Quad Core has around 820,000,000
Issues

- That's a LOT of transistors!
  - Need CAD tools and hierarchy to help

- That's also a LOT of power
  - $V=IR$, $P = I^2R$
  - $75W @ 1.5v = 50A$ going into your chip...

Power Dissipation

- Lead microprocessor power continues to increase

- Power delivery and dissipation will be prohibitive

Source: Borkar, De Inte10
Heat Dissipation

- 100 W light bulb has surface area of 120 cm²
- Pentium4 die dissipates 110 W over ~1.5 cm²
- Nvidia GTX280 – 236 W over ~1.5cm² (105°C)
  - Chips have enormous power densities
  - Cooling is a serious challenge
- Package spreads heat to larger surface area
  - Heat sinks may increase surface area further
  - Fans increase airflow rate over surface area
  - Liquid cooling used in extreme cases ($$$)

GPUs and Power

Highly customized processing for graphics
- Lots of matrix/vector floating point pipelines
- Lots of on-chip memory bandwidth
  - NVIDIA GeForce FX5900 (2004): 53 GFLOPS
    - 128 FP units in parallel at 450MHz
    - 192 FP units at 550 MHz, 80 watts
  - NVIDIA GeForce GTX 280 (2008): 933GFLOPS
    - 240 cores, 1.3GHz, 3 flops/sec/core, 236 watts... 105°C
    - 1GB GDDR3, 512bit interface, 141.7 GB/sec
**Chip Power Density**

![Graph showing power density over years from 1970 to 2010]

- **Heat sink** – Mounted on processor package
- **Passive cooling** – Remote system fan
- **Active cooling** – Fan mounted on sink
- **Heat spreaders** – Increase surface area
  - Example: Metal plate under laptop keyboard

\[ P=VI: \quad 75W \times 1.5V = 50\ A! \]

Source: Borkar, Intel Technology Journal, Q3 2000

**Thermal Solutions**

- **Heat sink**
- **Passive cooling**
- **Active cooling**
- **Heat spreaders**

"Thermal Challenges during Microprocessor Testing", Intel Technology Journal, Q3 2000
Environmental burden of CPUs!

- Total power consumption of CPUs in world’s PCs:
  - 1992: 160 MWatts (87M CPUs)
  - 2001: 9,000 MWatts (500M CPUs)
- That’s 4 Hoover Dams!

Andy’s vision: 1 Billion Connected PCs!

Old News!
Consider...

- **June 2009**
  - Random sample showed 66,000 online players on Call of Duty Xbox live
  - Equivalent to the entire city of Muncie Indiana...
  
  *Source: NYT Magazine, June 2009*

- **What do big data centers look like?**
  - Microsoft, Google, Yahoo, Facebook, etc...
  - Thousands and Thousands of servers!
  - 365/24
  - Total cost in US alone in 2006 just for electricity (not equipment) was around $4.5 Billion
  - ~2% of total electricity usage in the US
  - AND, that's old news! (2006)

  *Source: EnergyStar Report to Congress, 2007*

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**Old Data Centers**

- **Racks of machines on raised flooring**

- **Cool air flowing up through the floor and out the ceiling**
Google: First Production Server

There were 30 of these in their first data center in 1999
More recent data centers

An overhead view of a Quality Technology Services data center in the Atlanta area.

New Data Centers: Wow

- Servers are crammed into standard 35ft cargo containers
- Each container has power (up to 250 KWatts), networking, cooling, and over 1000 servers
- Self-contained and stackable...
One Google data center might have 45 containers
That's over 60,000 servers, and power in megawatts!
Lots of Data Centers!

• Data centers are multiplying!
• Starting to consume a noticeable fraction of the world’s electricity output!

  – Are Facebook and Twitter worth the energy?
  – Is this growth in power and resources used for computing sustainable?
  – Does YouTube give back value to offset the carbon costs of downloading all those videos?
On the other hand...
- Each Google search “costs” roughly 0.2g of CO2
- In the time it takes you to do one Google search, your own computer uses more energy than Google does answering your query.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Google searches</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 emissions of an average daily newspaper (100% recycled paper)</td>
<td>850</td>
</tr>
<tr>
<td>A glass of orange juice</td>
<td>1,000</td>
</tr>
<tr>
<td>One load of dishes in an EnergyStar dishwasher</td>
<td>6,100</td>
</tr>
<tr>
<td>A five mile trip in the average U.S. automobile</td>
<td>10,000</td>
</tr>
<tr>
<td>A cheeseburger</td>
<td>15,000</td>
</tr>
<tr>
<td>Electrically consumed by the average US household in one month</td>
<td>3,100,000</td>
</tr>
</tbody>
</table>

Source: http://www.google.com/corporate/green/datacenters/

No easy answers!
Not exactly related to the Computer Engineering program at the U either...

But, Interesting stuff to think about!

Lots of research by Computer Engineering faculty that addresses issues of power use in computers
- Architecture, circuits, software, etc.
- Not necessarily directly related to reducing data center energy costs, but it’s all related at some level
• **Exciting Opportunities in Computer Engineering**
  - Challenging Curriculum
  - Science, Engineering and Math plus Creativity
  - Financial Rewards
  - Job Satisfaction

• **Help Solve the World’s Grand Challenges**
  - Energy
  - Environment
  - Safety
  - Productivity
  - Communications