Course Outline

• Instructor
• Prerequisites
• Topics of Study
• Course Expectations
• Grading
• Class Scheduling Conflicts
Instructor

- Instructor: David Brooks (dbrooks@eecs.harvard.edu)
  - Office Hours: TBD, MD141, stop by/email whenever
Prerequisites

- **CS141 (or equivalent)**
  - Digital Logic/Pipelined Processors
  - i.e. Hennessey & Patterson Jr. (HW/SW Interface)
- **CS146 is good, but not necessary**
  - Hennessey & Patterson Sr. (Quantitative) Computer Architecture
- **If not much architecture background, but interested in low-power design**
  - Background in one of compilers, OS, or Circuits/VLSI should be good enough
  - You will become the discussion leader in the power-aware OS/compiler/Ckts papers
- **C Programming, UNIX for Project (or similar skills)**
Topics of CS246

- Introduction to Power-Aware Computing
- Architectural Level Power Modeling
- OS Level Power Modeling/Measurement
- Chip and System Level Temperature Modeling
- Newer Trends in Power-Aware Computing (di/dt, reliability, leakage power, etc)
- Architectural, Compiler, and O/S Techniques to reduce power/temperature/etc
  - Chip/HW level techniques
  - OS/Compiler/Software techniques
  - Data center energy management
Details from Previous Years

- High-level Power modeling (power abstractions)
- Power Measurement for OS control
- Temperature Aware Computing
- Di/Dt Modeling
- Leakage Power Modeling and Control
- Frequency and Voltage Scheduling Algorithms
- Power in Data Centers, Google Cluster Architecture
- Dynamic Power Reduction in Memory
- Disk Power Modeling/Management
- Application and Compiler Power Management
- Dynamic adaptation for Multimedia applications
- Architectures for wireless sensor devices
- Low-power routing algorithms for wireless networked devices
- Intel XScale Microprocessor, IBM Watchpad
- Human Powered Computing
Course Expectations

• Seminar style course:
  • Expectation: you will read the assigned papers before class so we can have a lively discussion about them
  • Will setup online-web page to post comments/questions/discussion before class
  • Paper reviews –short “paper review” highlighting interesting points, strengths/weaknesses of the paper
  • Bring one discussion point to class
  • Discussion leadership – somewhere in the middle of the semester students will be assigned to present the paper/lead the discussions
Course Expectations

- Course project
  - Several possible ideas will be given
  - Also you may come up with your own
  - Depending on enrollment, I will schedule weekly/bi-weekly meetings with each individual/group (1/2hr per project) to discuss results/progress
  - There will be two presentations
    - First, a short “progress update” (before Winter break)
    - Second, a final presentation scheduled at the end of reading week
    - Finally, a project writeup written in research paper style
Grading

• Grade Formula
  • Class Participation – 50%
  • Project (including final project presentation) – 50%
Class Scheduling

• Have some students who’d like to take the class, but conflict.
  • Any time besides MW 1-2:30
  • Maybe MW 10:30-12?
Power vs. SPECint2K

SPECINT2000 vs. Power Dissipation (W)

- AMD Athlon
- AMD Opteron
- Pentium 3
- Pentium 4
- Apple PowerPC
- Itanium
- IBM PowerPC
- UltraSPARC III
Power Issues in Microprocessors

Capacitive (Dynamic) Power

Static (Leakage) Power

Di/Dt (Vdd/Gnd Bounce)

Temperature

Voltage (V)

Current (A)

Minimum Voltage
Power-Aware Computing Applications

Temperature/di\text{-}dt\text{-}Constrained

Energy-Constrained Computing
The Battery Gap

Diverging Gap Between Actual Battery Capacities and Energy Needs

- **Interactive**
  - Mobile video-Conferencing
  - Collaboration
  - Video email
  - Voice recognition
  - Mobile commerce

- **Downlink dominated**
  - PIM, SMS, Voice
  - Web browser
  - MMS, Video clips

- **Energy (mAh)**
  - Lithium Ion
  - Lithium Polymer
  - Fuel Cells

Source: Anand Raghunathan, NEC Labs
Where does the juice go in laptops?

- Others have measured ~55% processor increase under max load in laptops [Hsu+Kremer, 2002]
Packaging cost

From Cray (local power generator and refrigeration)...

Source: Gordon Bell, “A Seymour Cray perspective”
http://www.research.microsoft.com/users/gbell/craytalk/
Packaging cost

To today…

- IBM S/390: refrigeration:
  - Provides performance (2% perf for 10°C) and reliability

350-V bulk power subassembly (under cover)

Intel Itanium packaging

Complex and expensive (note heatpipe)

Source: H. Xie et al. “Packaging the Itanium Microprocessor” Electronic Components and Technology Conference 2002
P4 packaging

- Simpler, but still…

From Tiwari, et al., DAC98

Source: Intel web site
What happens when the CPU cooler is removed?

www.tomshardware.de
www.tomshardware.com
Cooking Aware Computing
Server Farms

- Internet data centers are like heavy-duty factories
  - e.g. small Datacenter 25,000 sq.feet, 8000 servers, 2MegaWatts
  - Intergate Datacenter, Tukwila, WA: 1.5 Mill. Sq.Ft, ~500 MW
  - Wants lowest net cost per server per sq foot of data center space

- Cost driven by:
  - Racking height
  - Cooling air flow
  - Power delivery
  - Maintenance ease (access, weight)
  - 25% of total cost due to power
Environment

- Environment Protection Agency (EPA): computers consume 10% of commercial electricity consumption
  - This incl. peripherals, possibly also manufacturing
  - A DOE report suggested this percentage is much lower (3.0-3.5%)
  - No consensus, but it’s still a lot
  - Interesting to look at the numbers:
- Data center growth was cited as a contribution to the 2000/2001 California Energy Crisis
- Equivalent power (with only 30% efficiency) for AC
- CFCs used for refrigeration
- Lap burn
- Fan noise
Now we know why power is important

• What can we do about it?

• Two components to the problem:
  • #1: Understand where and why power is dissipated
  • #2: Think about ways to reduce it at all levels of computing hierarchy
  • In the past, #1 is difficult to accomplish except at the circuit level
  • Consequently most low-power efforts were all circuit related
Modeling + Design

• **First Component (Modeling/Measurement):**
  • Come up with a way to:
    – Diagnose where power is going in your system
    – Quantify potential savings

• **Second Component (Design)**
  • Try out lots of ideas
  • Or characterize tradeoffs of ideas…

• **This class will focus on both of these at many levels of the computing hierarchy**
Next Time

• Bit more overview, feel out background of class
• Course website: http://www.eecs.harvard.edu/~dbrooks/cs246
• Paper readings for this week:
  • “Power-Aware Microarchitecture: Design and Modeling Challenges for Next-Generation Microprocessors,” IEEE MICRO.
  • “Power: A First-Class Architectural Design Constraint,” IEEE Computer
• Web Page Browsing:
  • Information Technology and Resource Use: http://enduse.lbl.gov/projects/infotech.html
• Questions?