Introduction

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What About?

• What is this course about?
  – Power-aware computer systems and networks
  – Four sections
  • Power-aware real-time embedded systems
  • Power management for virtualized servers
  • Power efficiency in computer architecture
  • Power-efficient protocols in wireless sensor networks

• What to do?
  – Learn the basic principles from the textbook
  – Study state-of-the-art research papers
  • Papers are newest results in this field.
  – Do a semester-long team project
    • Collaborate to make a difference
  – Get some sense on how to do research

Outline

• Power-aware real-time embedded systems
• Power management for virtualized servers
• Power efficiency in computer architecture
• Power-efficient protocols in wireless sensor networks
• Course organization and policies

Examples of Embedded Systems

• Personal Digital Assistant (PDA), Cell phone.
• Printer.
• GPS.
• Automobile: engine, brakes, dash, etc.
• Digital camera.
• Household appliances: microwave, air conditioning
• Wrist watch.
• iPod.
• and a lot more …

• Fact: > 95% of all microprocessors are used for real-time embedded systems.

Definition

• Embedded system: any device that includes a computer but is not itself a general-purpose computer.

• Application specific
  – The design is specialized and optimized for specific application
  – Don’t need all the general-purpose bells and whistles.

Embedded Systems Development

• Three alternative technologies
  – Application-Specific Integrated Circuits (ASICs)
  – Field-Programmable Gate Arrays (FPGAs)
  – Microprocessors

• Why do we use a microprocessor?
  – Microprocessor is the dominant player
    • Flexibility and low development cost >> performance/watt consideration
    • Power management techniques are crucial
    – To be covered in this class.
  – Microprocessor + ASIC is common
    • Ex: cell phone
Embedding a computer

- Microcontroller (or MCU): a computer-on-a-chip
  - a type of microprocessor emphasizing self-sufficiency and cost-effectiveness
  - has CPU, input/output, RAM, ROM, clock and etc on a single chip

Why are those systems special?

- Application specific
  - Specialize and optimize the design for specific application
  - Not a general-purpose computer.
  - Don’t need all the bells and whistles, e.g., hard drive, monitor, keyboard...
- Have to worry about both hardware and software
- Have to worry about non-functional constraints
  - Real-time
  - Memory footprint
  - Power
  - Cost

Just functionally working is NOT enough!

Real-Time

- System works properly only if it meets its timing constraints
- Timing constraints
  - Deadline: complete a task within $D$ millisec
    - E.g., ABS, GPS
  - Throughput / rate: complete $N$ tasks per sec
    - E.g., portable DVD player

Real-Time (cont.)

- Hard real time: violating timing constraints causes failure
  - Anti-lock Brake System (ABS)
  - CD burner
  - Software modem
- Soft real time: missing deadline results in degraded performance
  - Video
  - GPS map
  - Audio (MP3 player)?

Low Power

- Battery-powered devices
  - Cell phone, iPod, wireless sensors...
- Wall-powered devices: excessive power consumption increases system cost.
  - Cooling.
  - Energy bills.

Power Management

- Microprocessors improve performance at the cost of power!
  - Performance/watt remains low.
- Solutions
  - Microprocessors offer features (hardware support) for controlling power consumption.
  - Software performs power management.
- Have high power and performance when running workloads and low power when idling
Power Control for Servers

- Power is a serious concern for data centers
  - Operating costs
  - System failures due to overheating
- High-density servers make it worse
  - Greater probability of thermal failures
- Power control
  - Most components have adjustable performance/power states
    - CPU, hard disk, memory, etc
  - Lower performance state \(\rightarrow\) lower power consumption
  - Control power of a server cluster \(\leq\) a power budget
  - Achieve best possible application performance

Power Efficiency in Computer Architecture

- Power control for chip multiprocessors (CMPs)
- Thread critical for power efficiency in CMPs
- Power-aware caches,
- Power management for memory systems
- Power issues in on-chip interconnect networks

Power Control for CMPs

- Power and temperature are serious concerns for processors
  - Processors consume a major part of power in computer systems
  - System failure due to overheating
  - Cost of thermal packaging
  - Increased level of core integration makes it worse
- Power control for chip multiprocessors
  - Peak power needs to be controlled
  - Temperature must be kept lower than a threshold
  - The performance delivered per watt needs to be maximized

Wireless Sensor Networks

- Wireless networks of numerous inexpensive miniature devices
  - Each is capable of computation, communication and sensing
- Provide a bridge between physical and virtual worlds
  - Sense/observe the natural world and process the info in digital devices
- Have a wide range of potential applications
  - Industry, science, transportation, civil infrastructure, security, etc.

Wireless Sensor Motes

- sensors + microcontroller + radio
  - All feasible at very small scale
  - e.g., Berkeley Smart Dust

Typical Applications

1. Smart sensors massively distributed and embedded in environments
2. Self-organized wireless network by communicating with each other
3. Real-time environment monitoring and control

Structural Health Monitoring
Fire Monitoring
Health Care
Habitat Monitoring
**What are you going to learn?**

- Basic principles
  - Process scheduling in OS
  - Real-time scheduling on single processors
  - Scheduling in distributed real-time systems
- Power-aware real-time embedded systems
  - Feedback control tutorial
  - End-to-end CPU utilization control
  - Energy-efficient real-time scheduling
- Power-aware computing systems and architecture
  - Power control for embedded systems, enterprise servers and server clusters
  - Data center power control
  - Multi-core systems, cache systems, thread criticality, memory systems.
- Wireless sensor networks
  - Real-time communications
  - Multi-channel communications

**What do you need to do?**

- Paper reading and critique (homework)
- Class presentation
- Group project
- Final exam

**Paper Critiques (Homework)**

- Pretend that you are a reviewer of this paper
- Critique the paper instead of just summarizing it. For example:
  - Any assumptions not reasonable or unrealistic?
  - Not work in a certain situation?
  - Missed any important factors in design?
  - Any problems in implementation and experimentation?
  - Do their results support their claims?
  - Can you think of any ways to improve this paper?
- Think big! Compare it with other papers.
- If you have critiqued the required paper before
  - Critique the optional paper

**Paper Critique Submission**

- Due midnight before the lecture of each topic
  - First critique is due on 09/07 for the topic: CPU utilization control
- How many papers to critique?
  - Presenter: both papers in this section
  - Other students: one paper (the first one)
- Submission
  - Email me in plain text with a specific title
  - Follow the format on the web page

**Class Presentation**

- Every student needs to give one presentation on a selected topic
  - Help you practice giving technical presentations
- What to do?
  - Read all papers in that section
  - Prepare slides and go through it with me three days before your presentation date.
  - Become the expert and teach us!

**Course Project**

1. Have a teammate (2 students/team)
2. Discuss with your teammate for a project idea
   - We will provide some suggestions
3. Talk to me to finalize your idea
4. Do a proposal to the class
5. Report your findings/problems at a midterm presentation
6. Report your final results at a final presentation
7. Write a final report (conference paper quality)
Grading

- Homework (Critique) 20%
- Class presentation: 15%
- Final exam: 10%
- Group project 50%
  - Proposal presentation 5%
  - Midterm presentation/demo 10%
  - Final presentation/demo 15%
  - Final report 20%
- Participation: 5%
  - Attend the classes
  - Contribute to class discussion
  - Feel free to ask questions (during project/class presentations)

Help

- Office: Ferris Hall 421
- Office hour: half an hour after each class
- Slides, schedule, announcement posted at http://www.ece.utk.edu/~xwang/ece692
- Email
  - xwang@eecs.utk.edu