I/O Systems (4): Power Management

CSE 2431: Introduction to Operating Systems
Outline

• Overview
• Hardware Issues
• OS Issues
• Application Issues
Why Power Management?

- Desktop PCs
- Battery-powered Computers
Desktop PCs

• 200-watt power supply
  – 85% efficient
  – 15% energy lost to heat

• 100 million PCs
  – Needs 20,000 megawatts
  – Total output of 20 average-sized nuclear power plants

• If power requirement is cut in half, we could get rid of 10 nuclear power plants ⇒ big win!
Battery-Powered Computers

• Examples?
  – Laptops
  – Smartphones
  – Tablets (iPad, Nexus 10, etc.)

• The key issue
  – Batteries cannot last very long
  – Battery industry is working hard on this

• For CS guys
  – Making computers more energy efficient
Reducing Power Consumption

• Hardware vendors make their electronics more energy efficient, e.g.
  – Reducing transistor size
  – Dynamic voltage scaling
  – ...

• OS turns off parts of computers (mostly I/O devices) when idle

• Application reduce energy consumption
  – Possibly degrade the quality of user experiences
Hardware Approaches

• Design CPU, memory, and I/O devices to have multiple states
  – On: Use the device
  – Sleeping: Not needed for a short time
  – Hibernating: Not needed for a long time, vs. sleeping: taking longer time to wake up and saving more energy
  – Off: Consume no power

• It is up to OS to manage the state transition at the right moment
Questions for OS

- Which devices can be controlled?
- Are they on/off, or do they have intermediate states?
- How much power is saved in the low-power states?
- Must some context be saved when going to a low-power state?
- How long does it take to go back to full power?
- ……
OS Issues

• OS must decide what to shut down and when
• The trick is to find algorithms and heuristics to make good decisions
• “Good” is highly subjective
  – One user may find it acceptable after 30 seconds of not using the computer it takes 2 seconds for it to respond to a keystroke, while another does not.
# Power Consumption of A Laptop

<table>
<thead>
<tr>
<th>Device</th>
<th>Li et al. (1994)</th>
<th>Lorch and Smith (1998)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display</td>
<td>68%</td>
<td>39%</td>
</tr>
<tr>
<td>CPU</td>
<td>12%</td>
<td>18%</td>
</tr>
<tr>
<td>Hard disk</td>
<td>20%</td>
<td>12%</td>
</tr>
<tr>
<td>Modem</td>
<td></td>
<td>6%</td>
</tr>
<tr>
<td>Sound</td>
<td></td>
<td>2%</td>
</tr>
<tr>
<td>Memory</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>22%</td>
</tr>
</tbody>
</table>
The Display

• Big spender of the energy budget
• To get a bright sharp image, the screen must be backlit, which takes substantial energy
• Shut down the display (sleep state) when there has been no activity for a threshold
• More aggressive method: Divide the screen into zones and power up/down zones independently

Zone-based Method

Using zones for backlighting the display
The Disk

- Spinning at high speed needs substantial energy.
- One method is to spin it down after being idle for a threshold.
- But it is in hibernating state so it requires quite a few seconds to spin it up again, which consumes considerable energy.
Two Ways for Disk Issues

• Have a substantial disk cache in RAM
  – If a needed block is in cache, an idle disk does not have to spin up
  – If a write to the disk can be buffered in the cache, a stopped disk does not have to restart

• Keep running programs informed about disk states
  – Discretionary writes can be skipped or delayed
The CPU

• Reducing CPU voltage ⇒
  – Saving energy
  – Reducing the clock cycle (running slower)

• Power consumption is proportional to the square of the voltage ⇒
  – Halving the voltage makes the CPU about $\frac{1}{2}$ as fast, but $\frac{1}{4}$ the power
CPU Voltage Scaling

- Running at full clock speed
- Cutting voltage by two
  - cuts clock speed by two,
  - cuts power by four
The Memory

• Cache can be flushed and then switched off
  – Sleep mode since cache can be quickly reloaded from main memory

• Write the contents of main memory to disk, then switch off the main memory
  – Hibernation mode due to a substantial reload time, especially when disk is off too
Wireless Communication

• The radio transmitter and receiver are often first-class power hogs
  – Radio receiver always on $\Rightarrow$ battery may drain quickly
  – Radio switched off $\Rightarrow$ incoming messages may be missed

• One solution: Notify base station before switching off radio so that messages can be buffered [KK98]

Thermal Management

• Modern CPUs get extremely hot due to high speed
  – Desktop is OK due to internal electric fans
  – Laptop is different

• OS has to monitor the temperature continuously, when temperature is high
  – Switch on the fan
  – Reduce power consumption by various components
Battery Management

• Smart batteries communicate with OS
• Upon request, they can report
  – Maximum voltage
  – Current voltage
  – Maximum charge
  – Current charge
  – ……
• With multi-batteries, OS needs to arrange a graceful migration from a drained battery to a fresh one.
Driver Interface

• Advanced Configuration and Power Interface (ACPI)
• OS can send conformant driver commands
  – Inquire about devices’ capabilities and states
  – Instruct the drivers to cut their power levels
• Another direction of the traffic
  – A device detects activity ⟹ send signal to wake up the system
Application Issues

• Telling the programs to use less energy
  – May mean poorer user experience
  – It happens when the battery charge is below some threshold
  – It is then up to the programs to decide between degrading performance or risk running out of energy
Examples

- Change from color output to black and white
- Speech recognition reduces vocabulary
- Less resolution or detail in an image
Summary

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• OS Issues
• Application Issues