Operating Systems Design
25. Power Management

Paul Krzyzanowski
pxk@cs.rutgers.edu

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Power Management

Goal: Improve the battery life of mobile devices

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CPU Voltage & Frequency Scaling

- Dynamic CPU Frequency Scaling
  - Adjust the frequency of a CPU on the fly
    - Conserve power & reduce heat (reduce need for a fan)
  - Reduce # of instructions per time
    - Goal: use this when processes are not CPU bound
- Examples of CPU support:
  - Intel *SpeedStep*
  - AMD *PowerNow!*, AMD *Cool 'n' Quiet*
  - ARM *Intelligent Energy Manager* (*IEM*)
- OS management of voltage/frequency control
  - Linux: *cpuspeed* (RedHat) or *cpufrequtils* (Ubuntu)

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Managing CPU performance

- Governors
  - Pre-configured power schemes
  - Loaded as kernel modules. Governors include:
    - cpufreq_performance: run at maximum speed (default)
    - cpufreq_ondemand: dynamically increase/decrease based on load
      - Programmable threshold based on % CPU utilization
    - cpufreq_conservative: similar to *ondemand* but slower changes
    - cpufreq_powersave: run CPU at minimum speed
    - cpufreq_userspace: allow user to configure speeds

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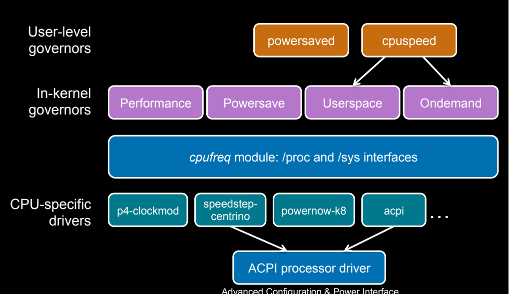
CPUfreq system in Linux



From http://software.intel.com/en-us/articles/enhanced-intel-speedstepr-technology-and-demand-based-switching-on-linux/

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ACPI Power Management

- Global states (G)
  - G0/S0: Working
  - G1: Sleeping
    - G1/S1: all CPU caches flushed, CPU stopped; power to CPU & RAM is ON
    - G1/S2: CPU is powered off
    - G1/S3: Standby/Sleep: RAM is powered on
    - G1/S4: Hibernation: Copy all of RAM to a swap partition or file
  - G2/S5: Soft OFF: most systems off but the machine can wake from LAN, USB, keyboard, or real-time clock inputs
  - G3: OFF (only the real-time clock running)

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ACPI Power Management

- Device Control (D)
  - D0: Fully on
  - D1, D2: intermediate
  - D3: OFF and not responsive to the bus
- CPU states (C)
  - C0: normal operating state
  - C1: Halt: not executing but can start instantly
  - C2: Stop-clock: CPU keeps state but takes longer to start
  - C3: Sleep: cache may not be updated
- Power: Voltage/Frequency scaling (P)
  - P0: maximum voltage & frequency
  - P*n*: voltage and/or frequency scaled

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Sleep & Hibernation

- Sleep (standby) mode
  - *Stop processor execution, keep RAM powered*
- Hibernate mode
  - *Save memory state onto non-volatile storage* (disk/flash)
  - Most systems are shut off
    - except USB/LAN/alarm/switch wake detection
  - Suspend-to-disk
  - Suspend-to-file
  - Suspend-to-ram
- Hybrid
  - *Store contents to disk and then sleep*
  - If power to memory is lost then wake via disk restore
  - Examples:
    - Windows Vista Fast Sleep & Resume
    - OS X Safe Sleep

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Power Management: BIOS Support

- Old interface: APM
  - BIOS call; actions fully handled by hardware
- Most PCs support ACPI
  - Advanced Configuration and Power Interface
  - Fan control, dock/undock detection, temperature sensing, device control, …
  - Intel provides a fixed function interface for control
  - Other systems are hardware-specific

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Example

- Hit a sleep key, close lid, …
  1. Hardware interrupt – interrupts CPU: general purpose event
  2. OS interrupt handler
  3. User-level power management daemon listens to events via /proc/acpi/events
  4. User process decides that the action requires a *suspend to RAM*
  5. Suspend to RAM initiated

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Example

- Hit a sleep key, close lid, …
  4. …
  5. Suspend to RAM initiated
     a. Script/program does initial work: unloads various drivers that are not power-management-aware
     b. Initiate suspend by echoing the right state into /sys/power/state
        - E.g., echo "mem" >/sys/power/state
     c. Kernel stops user-level actions (process execution)
     d. Goes through each device: calls suspend methods on each active driver
     e. Call ACPI methods: PTS (Prepare To Sleep), GTS (Go To Sleep)
     f. Address of kernel wakeup code written to an address in the FADT – *Fixed Address Descriptor Table* in the ACPI
     g. Write values to ACPI to sequence the machine to *suspend*
        - S3 state: shut the machine down but keep RAM on.

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Example: Waking up

6. User presses the power button
   - BIOS start code invoked
     - BIOS checks the ACPI status register: system was suspended to RAM
       - Jumps to the programmed wakeup address
     - Executes kernel-provided real-mode x86 code
       - Restores register state, switches the CPU to protected mode
     - Now the kernel is running
   - Kernel
     - calls the ACPI WAK method
     - Resumes all drivers
     - Restarts userspace (scheduling)
     - The shell script that was running when we suspended resmes and reloads drivers.

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Tickless Kernel

- Traditional kernel:
  - Periodic tick
  - Always ticking … whether the processor is busy or not
  - Used for
    - Timer management
    - Time slice management
    - SMP load balancing
  - Wakeup during idle is bad
    - Does not let CPU go to deep sleep states
    - Hurts battery life

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Tickless Kernel

- Tickless kernel:
  - On-demand timer interrupts
  - Turn off periodic tick when the CPU is idle
  - Clock event wakeup programmed based on next event
- Keep the kernel quiet
  - Group timers to avoid multiple interrupts
  - Round timeout values
  - Defer the expiration of non-critical timers during idle

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The End

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