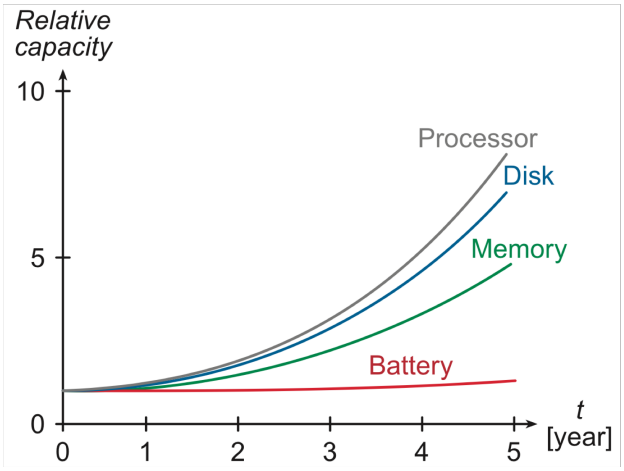
System example: laptop



System level energy management

- Energy management can be done at
  - User level
  - Application level
  - Operating system level
  - Component level
- Issues
  - How much is power reduced? Relative to system power?
  - How is a feature changing power of other components?
  - How is the battery capacity affected?
- *"Maximum battery lifetime is not necessarily what users want, they want to maximize the amount of work they can accomplish before the battery runs out"*

Power budget

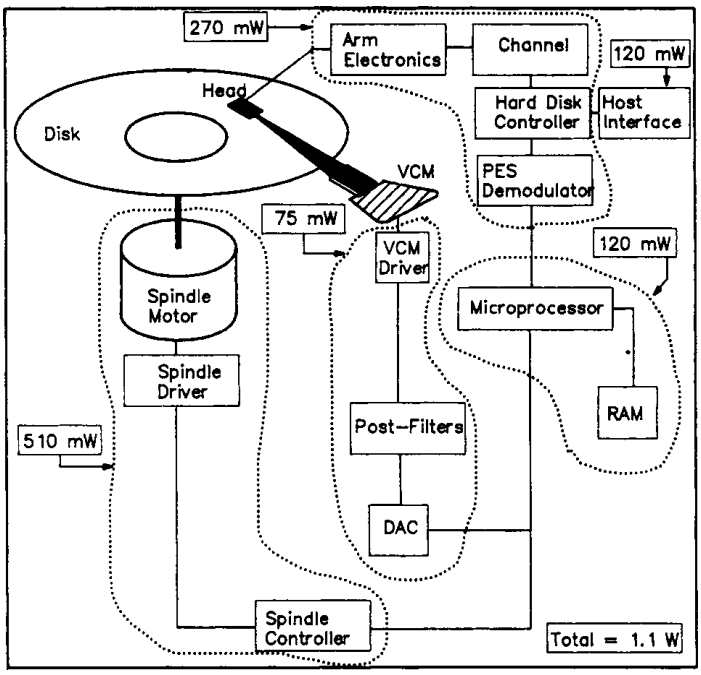
- Battery technology
  - The highest capacity battery technology is lithium-ion, today providing ~500 Wh/L and ~150 Wh/kg
- Main consumers of power (with active power management)
  - Backlight
  - Processor
  - Video system
  - Hard disk
  - Memory
  - Wireless communication

Energy optimizations in software

- Needed component information
  - Knowledge about its power mode characteristics
  - Information about its future functionality requirements
- Optimization strategies
  - Transition: When should a component switch between modes?
  - Load-change: How modify a component's functionality needs so it can be put in LP modes more often?
  - Adaptation: How can software permit novel, power-saving uses of components?

Hard disk

- Typical power modes
  - Active—disk operates
  - Idle—motor on
  - Standby—controller on
  - Sleep—reset logic on
  - Off



Hard disk

- Power considerations
  - Cache improves the overall performance of secondary storage and reduces its power consumption
  - Turning the motor off may increase energy consumption
  - Loosing cache may also increase energy consumption

Hard disk load-change strategies

- Examples on load change
  - Increasing cache size
  - Increasing dirty block timeout
  - File name and attribute caching
  - Prefetching data
  - Improving memory access locality

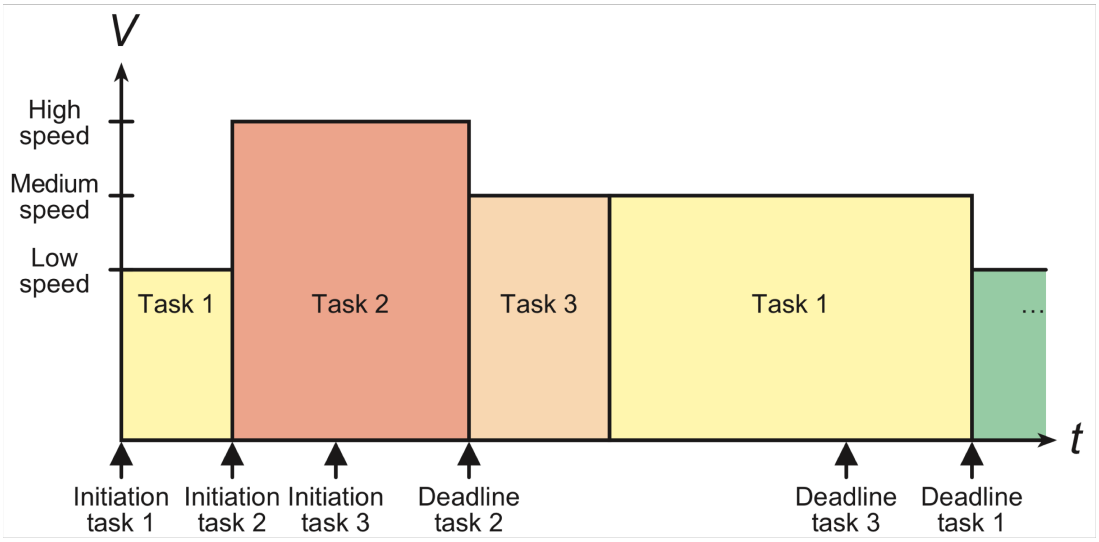
Disk adaptation strategies

- Examples on adaptation
  - Use of flash memory as low-power disk
  - Use of flash memory as disk cache
  - Wireless connection to a file server
  - Use disk merely as a large cache for the server file system
  - Make computer into a pure terminal
  - Low rotation speed modes

Processor

- Power-saving processor features
  - Slow down the clock (and decrease *V* to reduce *E* consumption)
  - Selectively shut off functional units
  - Shut down processor operation
- Software
  - Use energy-aware compilers (decrease # of executed instructions)
- Hardware innovations
  - Design other system components with low power states
  - Use multiple power domains

Scheduling processor speed



Wireless transition strategies

- Wireless device power consumption depends strongly on distance
- Wireless communication devices typically have five operating modes
  - Transmit
  - Receive
  - Idle
  - Sleep
  - Off
- Transition strategies
  - Entering sleep mode quickly
  - Changing transmission power depending on quality of service

Wireless load-change strategies

- Load-change strategies
  - Compressing TCP/IP headers can reduce their size by an order of magnitude
  - Reduce the data transmission rate or stop data transmission altogether when the channel is bad
  - Provide mobile clients with versions of data with reduced fidelity and smaller size
  - Use a medium access protocol dictating when wireless devices may receive data
  - Simultaneous change of error correction and link bandwidth

Display and backlight

- Power considerations
  - The display unit including backlight typically consumes more power than any other component
  - Low-power backlight and display states ⇒ 32-67% reduction
- Transition strategies
  - Turning display off
  - Reducing brightness level
  - Reducing update frequency
  - Switching from color to monochrome

Display and backlight

- Hardware innovations
  - Switch to a lower update frequency when the items displayed do not require a high update frequency
  - Switch to a lower-power display mode when the visually important parts do not require high quality
  - If a device detects when the user is not looking at the screen, the system can turn off the display and backlight
  - If a device senses the ambient light level, the system can dim the backlight accordingly
  - Using a light virtual desktop pattern rather than a dark one can reduce the load on the backlight
  - Software could decrease the resolution of a screen image by only illuminating a certain fraction of its pixels

Memory

- Memory is implemented using DRAM with three modes
  - Active
  - Standby
  - Off
- Saving memory power
  - Main memory is saved to disk and the memory system is turned off
  - Use of energy-aware compilers
  - Use of compact and efficient operating system code
  - Convince the user to purchase a machine with less main memory
  - Divide memory into independent banks
  - Compress the contents of memory, and turn off unused banks

Energy management conclusions

- General considerations
  - Software modification is generally needed to make the best use of a hardware feature
  - Energy consumption can be reduced by introducing lower-power, lower-functionality modes for those components
  - There is a trade-off between energy savings and performance
  - Seemingly independent energy management strategies can interact

Reference

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