Software Engagement with Sleeping CPUs

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Energy Proportionality and CPU Sleeps

- Energy proportionality [Barroso and Hölzle 2007]
  - Energy is consumed only when performing work.
- CPU hardware sleeps, idle states, or C states
  - An idle CPU can save power by halting cycles, shutting off clocks, flushing and powering down caches, and even removing core voltage.
  - On a dual-socket (24-cpu) Intel Haswell machine, active idle of all CPUs consume 91W (processor+DRAM) while C6 sleeps consume just 14W.
- The energy benefit is recognized [Le Sueur and Heiser 2011] and CPU sleeps are routinely utilized in existing systems
  - But profound system implications in today's context (emerging devices and workloads) require strong, principled software management.

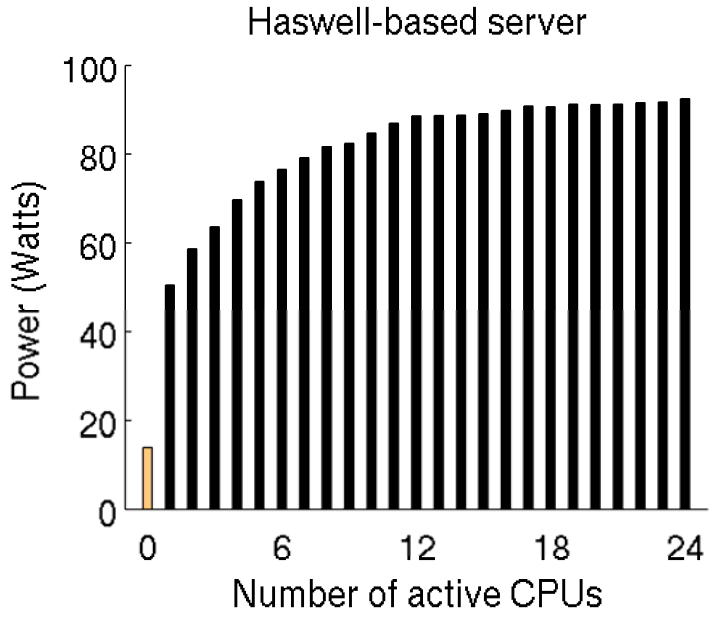
Sleep Exits Are Not Instantaneous

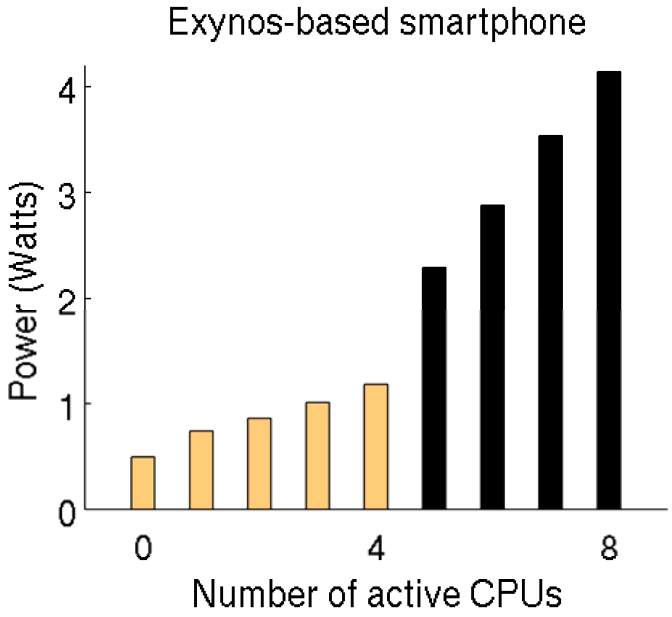
- Deep CPU sleeps incur delays to reactivate
  - Activating voltage/clocks, resuming cycles, loading flushed cachelines, …
  - 100usecs or more on modern multicore processors
- May add substantial (possibly multi-fold) delays to
  - operations on emerging fast devices like SSDs and integrated GPUs
  - fine-grained network services (e.g., in-memory hashtable) in a data center

⇨ On-demand (interrupt-driven) resource activation is inadequate for high responsiveness.

Energy Disproportionality on Multicores

- Due to multicore resource sharing, power is not proportional to the number of active (non-sleeping) CPUs.





⇨ Energy efficiency motivates new resource scheduling to shape desirable sleep patterns.

Anticipatory CPU Wakeups

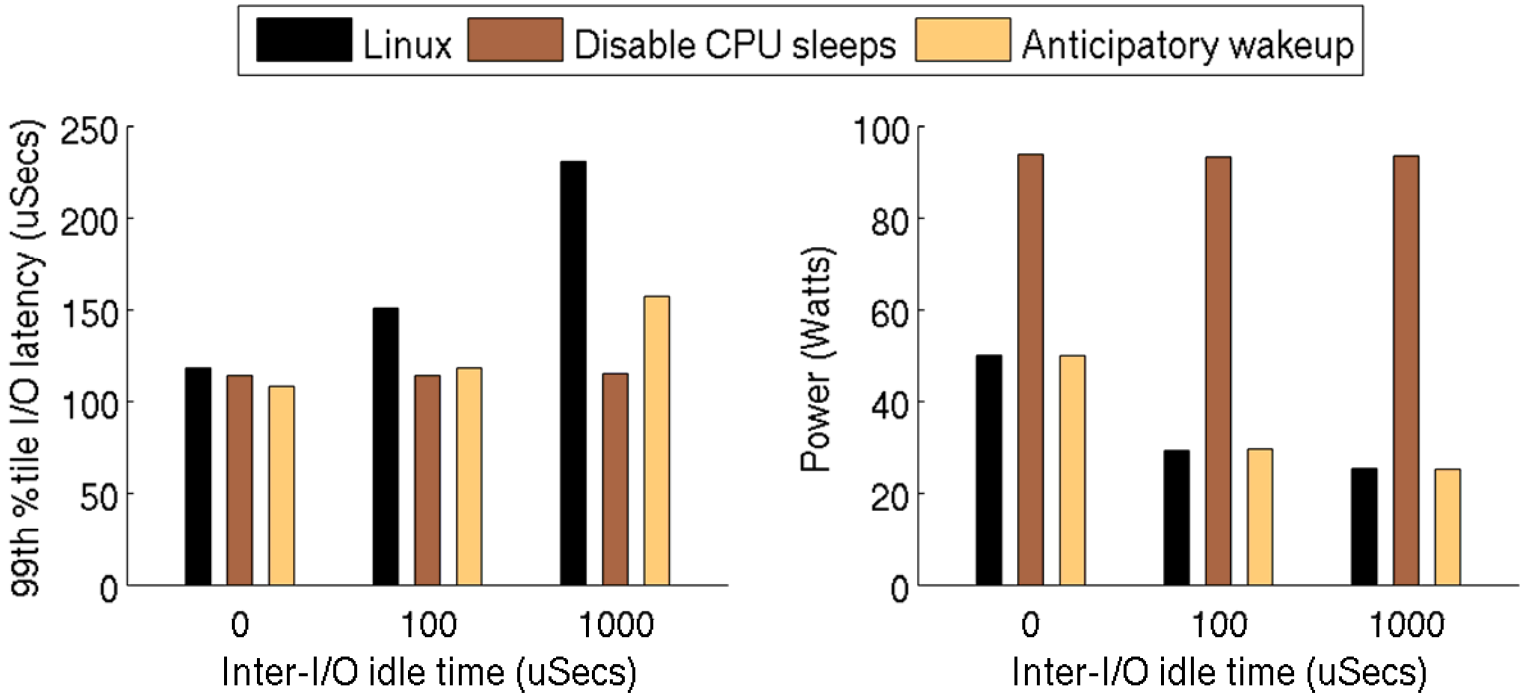
- For high responsiveness, a sleeping CPU should wake up in advance so that it is immediately ready for work when needed.
- Main challenge: anticipate the timing of future work.
  - When blocked on SSD I/O, future work is anticipated at the I/O completion time (modeled linearly on the I/O size) ⇨ Anticipation in system
  - Computation time on Turing-complete GPUs is hard to model, but many apps (iterative solvers, ML refinements) iterate over similar kernels many times and allow history-based prediction ⇨ Anticipation by application
  - On a network server, anticipation of future client requests may require client notification in advance ⇨ Anticipation over network
- Related to anticipatory I/O [Iyer and Druschel 2001]
  - Aiming for a binary decision, rather than anticipating the future event timing

A Simple Prototype

- We augment the block layer
  - predict SSD I/O time using a linear model (on I/O size)
  - request anticipatory CPU wakeup for synchronous I/O operation
  - fully transparent to applications
- Activate all CPUs necessary for work
  - CPU that'll run the blocked application process
  - CPU that'll handle the I/O interrupt

Preliminary Evaluation

- 24-CPU Intel Haswell machine, Samsung 850 PRO SSD



Energy-Conserving Sleep Shaping

- Saving most power on multicore by simultaneous CPU sleeps of
  - an entire multicore socket
  - the high-power cluster on a heterogamous smartphone SOC
- Motivate energy-conserving sleep shaping
  - Non-work-conserving CPU scheduling
- Exploit quality-of-service slacks for opportunities to delay work
  - Not all work in a smartphone system critically affects user interaction.
  - A server system may only be concerned about responses beyond a certain threshold.

Server Staged Bursts

- A server machine alternates between two phases–
  - a staging phase that buffers requests without running them, and
  - a burst phase that runs buffered requests in high parallelism.
- The staging proxy best runs on a low-power companion processor, or on a few designated proxies in a data center.
- A simple case evaluation:
  - Apache Solr search engine, searching Wikipedia pages, 100 reqs/sec workload
  - reduce power from 68 Watts to 53 Watts, while keeping peak responses below 500 msecs

Energy-Conserving Sleep Shaping

- Main challenge:
  - When can work be delayed or slowed without hurting quality-of-service?
- In a smartphone system
  - Quality-of-service is defined by responsiveness to a user interaction (from touch screen input to screen rendering of results).
  - Identify causal dependencies and critical path in a user interaction through sync/communication events (pipes, sockets, signals, Android binders, …).
  - During an I/O operation on the critical path, concurrent CPU work may be delayed or slowed without hurting user response.

Summary

- Energy proportionality has brought us aggressive CPU sleeps, but
  - sleep exit time is causing significant latency increase on emerging fast devices (SSDs, integrated accelerators) and fine-grained network services
  - on multicores, power is disproportionate to the number of active (non-sleeping) CPUs
- Advocate new CPU resource management approaches
  - anticipatory wakeups to minimize latency impact
  - non-work-conserving sleep shaping to maximize energy efficiency
- Concept (particularly anticipatory wakeups) is applicable to other dynamic-power resources (memory, storage, …)