Energy Discounted Computing On Multicore Smartphones

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Overview

- Energy constraints in a smartphone
    - Li-Ion Battery
- Arm big.LITTLE
    - Hardware Sharing

What is Energy Discounted Computing?

- ➔ Activation of first core consumes incurs much higher power
- ➔ Typical smartphone application have limited parallelism.
- ➔ So we can get rest of the core at deep energy discount.

Multicore Processors

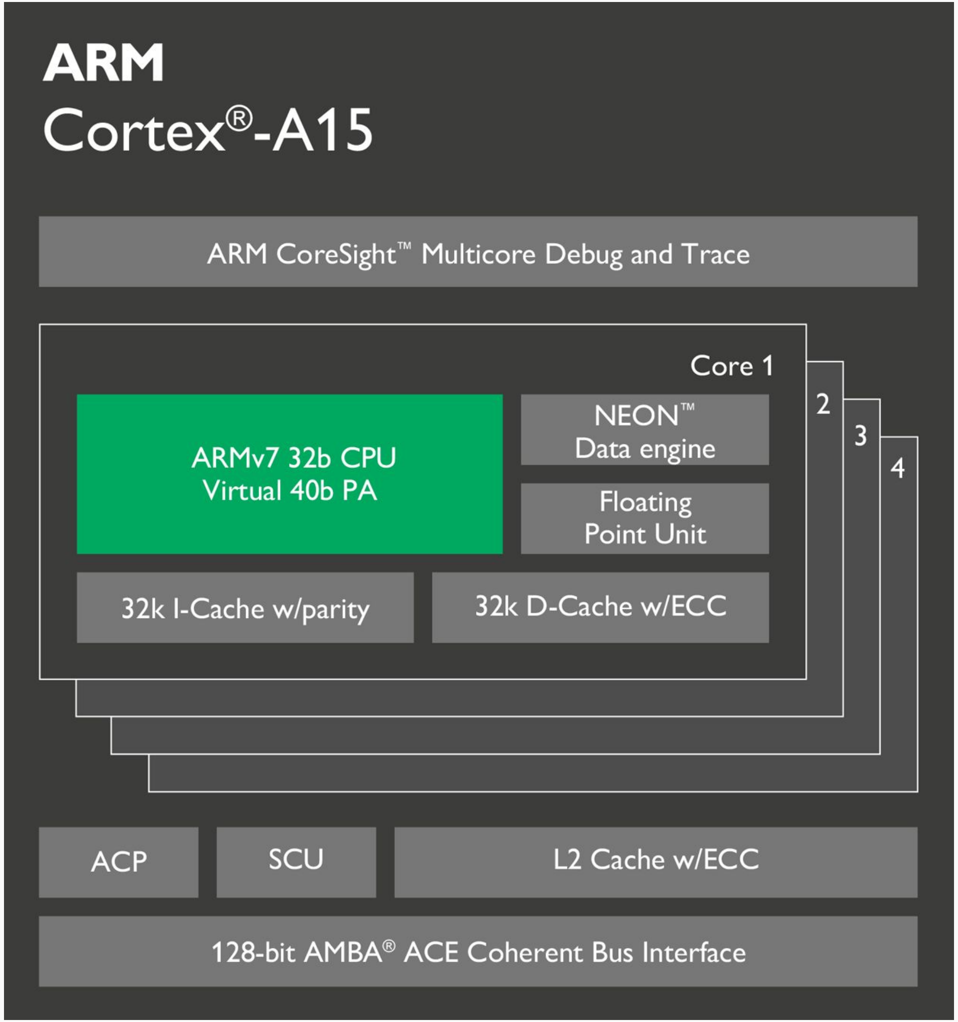
- Latest smartphones are shipping with 4-8 cores
- They have different power saving states.
- Ex: C0, C1, C2.
- They enter different power saving states to adapt to different workloads.
- They use DVFS to achieve different power/performance setting.

Multicores are Energy Disproportional

- Modern processors are good at power gating
  - When the system is idle, most parts of the CPU can be shut down
- Aggressive hardware sharing
  - drive down cost
  - reduce footprint
  - save power
- Example: CPU on one socket usually share power rail and oscillator

ARM Cortex 15

Source: http://www.arm.com/assets/images/Cortex-A15-chip-diagram-16-LG.png



Multicores are Energy Disproportional...

➔ hardware sharing also affects the CPU idle states

State	Name	Power	Target residency	Description
C0	Wait for interrupt (WFI)	403 mW	1 nSec	Processor is clock gated but can respond to cache / TLB maintenance (e.g., L2 snoop) requests without exiting the WFI state.
C1	Individual powerdown	365 mW	1 mSec	Processor is power gated. All state including L1 cache content is lost and the processor is removed from the coherency protocol.
C2	Cluster powerdown	214 mW	4 mSecs	Can only be entered when all processors are in individual powerdown mode. All state including the L2 cache content is lost.

Energy Constraints in a Smartphone

- Slow progress on battery technology, size restrictions
- Quadcore and Octacore processors popularity

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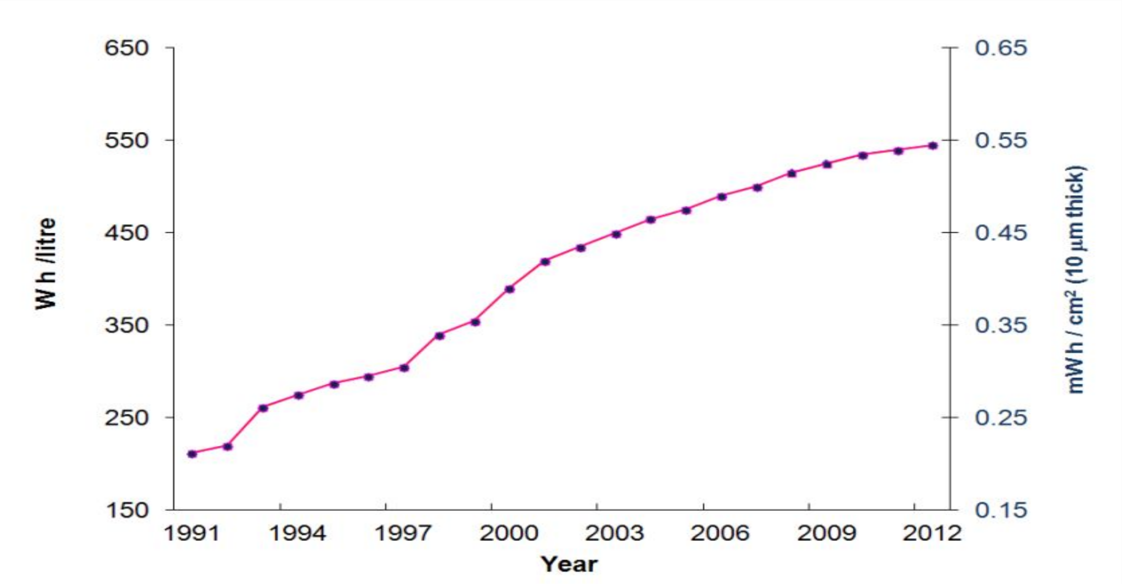
Li-Ion Battery



http://www.intechopen.com/books/energy-storage-battery-materials-and-architectures-at-the-nanoscale

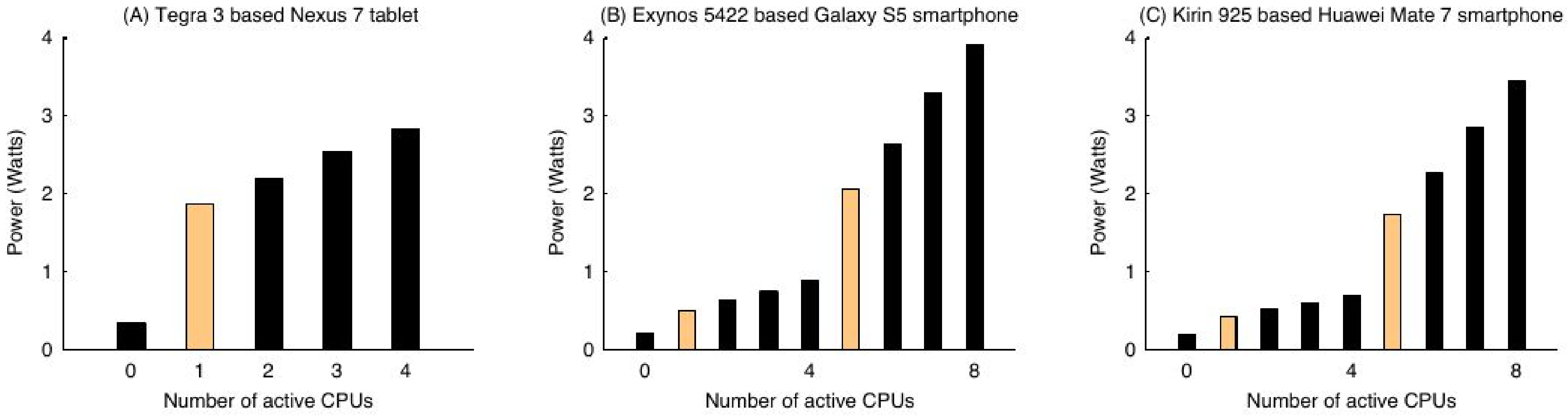
Energy Constraints in a Smartphone

- Slow progress on battery technology, size restrictions
    - Li Ion battery already at 80% energy density
- Quadcore and Octacore processors popularity

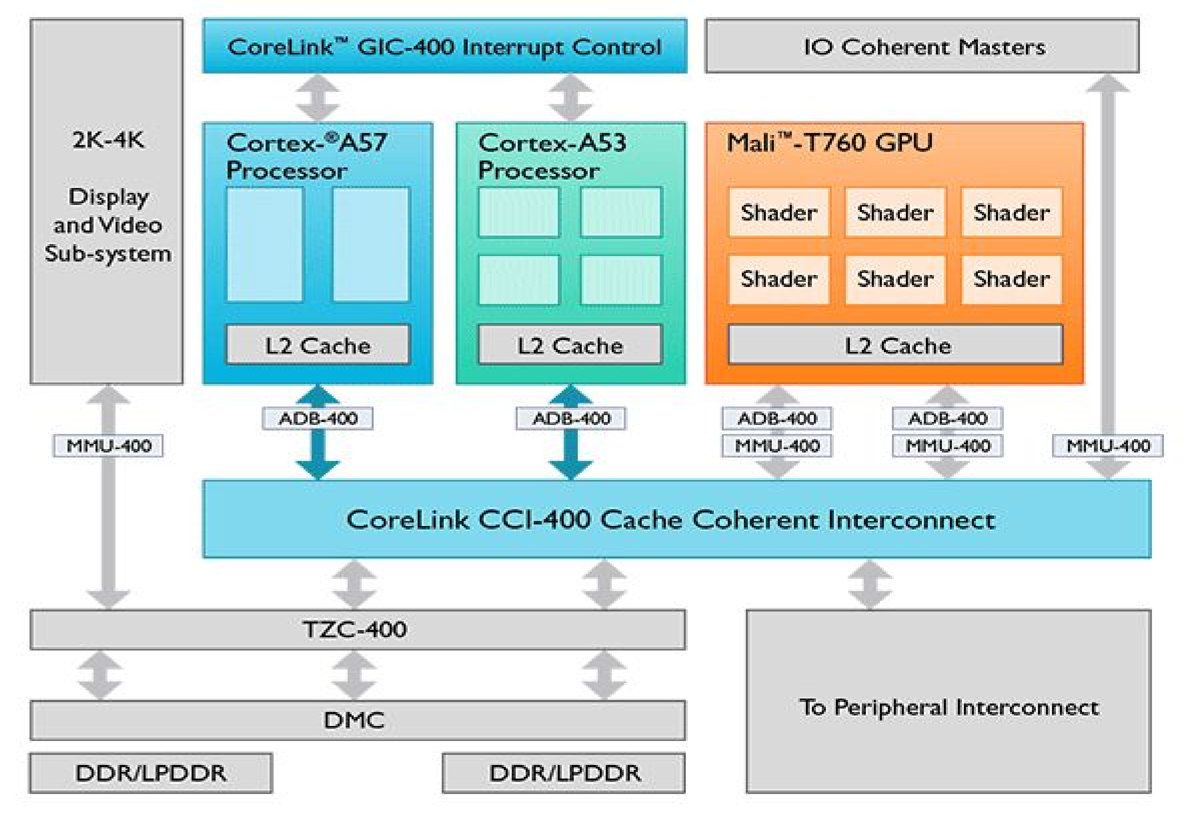
Energy Constraints in a Smartphone

- Slow progress on battery technology, size restrictions
  - Li Ion battery already at 80% energy density
- Quadcore and Octacore processors popularity
  - Heavily energy disproportional on smartphones

Disproportionate Power Consumption



SOC with ARM big.LITTLE



Idle States (‘C’ States)

State	Name	Power	Target residency	Description
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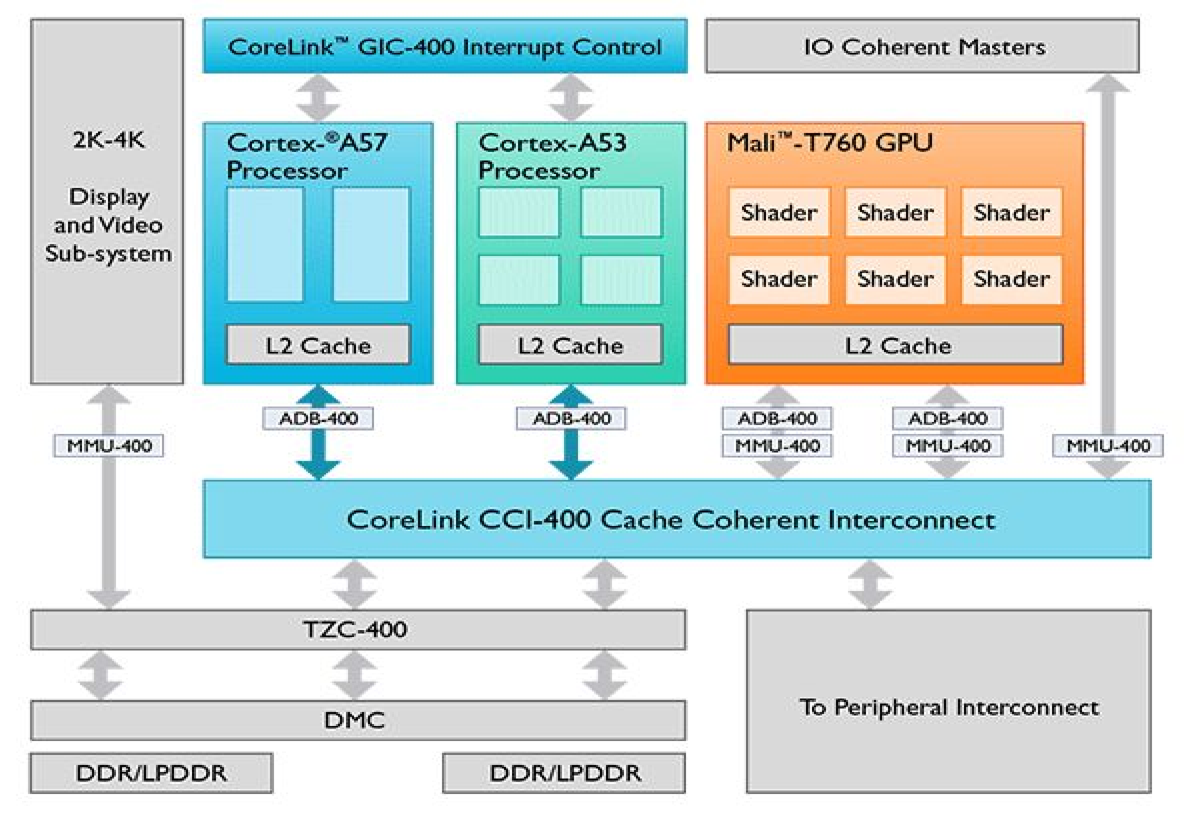
SOC with ARM big.LITTLE



Advantages of BigLittle

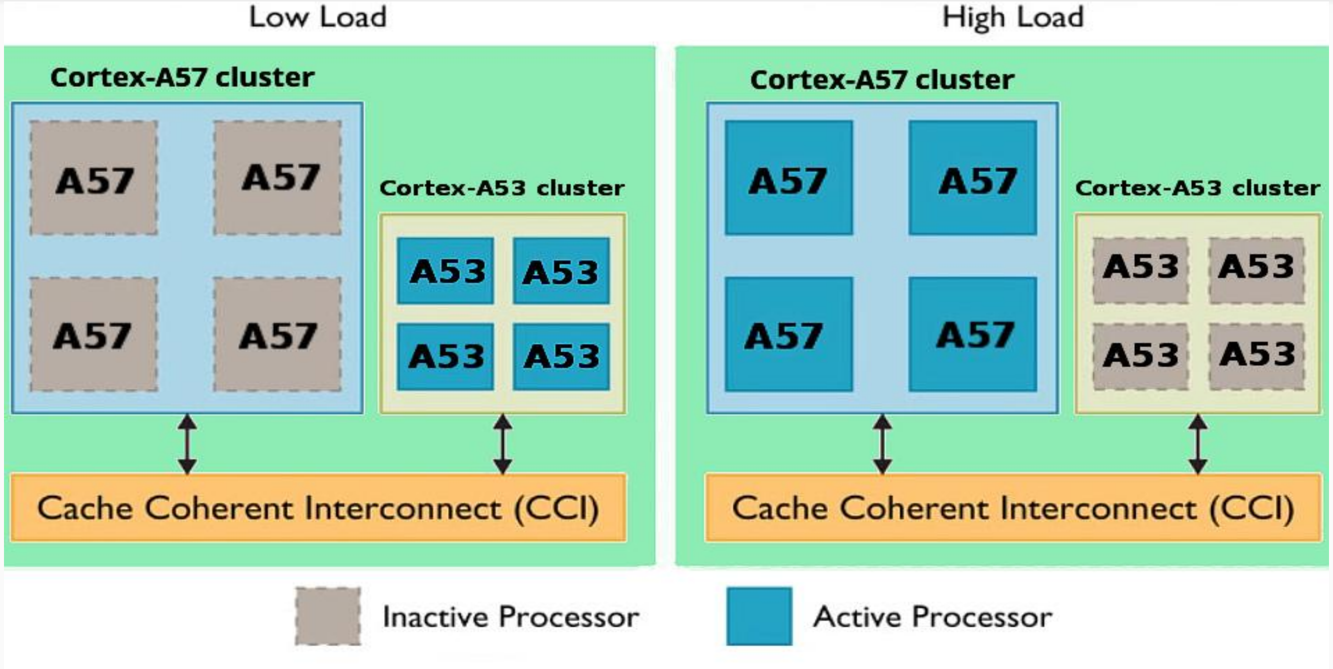
Heterogenous Architecture (Uses all the cores)

- Automatic Task Allocation among the cores
    - Dependent on the work load

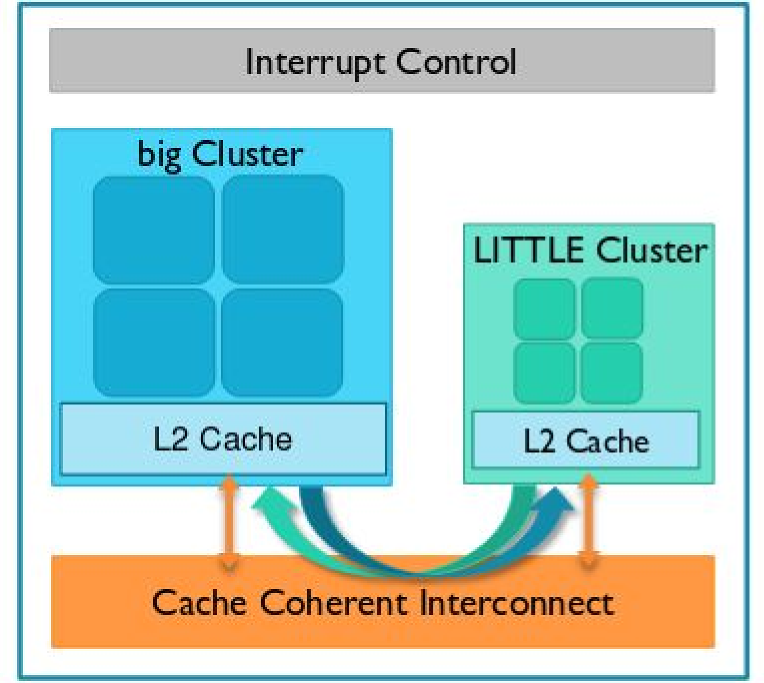
2x higher performance vs. LITTLE only

Up to 75% CPU powersavings vs. big only

ARM Big Little Architecture



ARM Big Little Architecture



Hardware Coherency

- Cache Coherent Interconnect (CCI)
- L1 and L2 snooping between clusters

Use of Multicores on Smartphones?

- ➔ Typical phone apps are built on event-driven, UI-centric framework
- ➔ Don’t have sufficient parallelism to utilize multiple cores simultaneously.
- ➔ Limited multi-processing

Hence,

- ➔ Co-run best effort task.

Best Effort Task(BET)

- ➔ Workloads that are meaningful to the user but do not involve direct interaction.
- ➔ Loose quality-of-service requirements.

Upload & download

- Examples:
  - Syncing data with cloud
  - Posting on social websites
  - Software/Update installation
- Significant energy consumption comes from the transmission module
- CPUs also consume substantial energy
  - Compression/Decompression
  - Encryption/Decryption

System Maintenance Work

- *kswapd* daemon scan for memory pages that can swapped out to free up space
- *dhd_dpc* which analyzes network packets and scans for Wi-Fi hotspots
- Re-compiling the bytecode for better native performance
- May have timing constraints

Background Sensing & Proactive Tasks

➔ Using camera sensors to analyze facial expression or eye movement

➔ Siri can provide recommendations, news and applications even before one asks for it.

While co-execution of applications on multicore processors may improve the energy efficiency, it also risks significant interference on shared hardware resources, memory bandwidth and last-level-cache space in particular, and thereby leads to poor interactive application performance and degraded user experience.

Energy Discounted Computing

POWER STATE PRESERVATION

- CPU idle state, or ACPI “C” state
  - Often long idle gaps between user interactions and CPUs entering deep sleep state.
  - It is crucial to keep best-effort tasks from disrupting these idle periods.
  - During active application executions, due to lack of parallelism, idle CPUs will often enter per-core idle states.
  - These shallow sleep states, do not save much energy.
  - CPU scheduler needs to schedule best-effort tasks opportunistically in accordance with interactive applications.
  - So schedule Best Effort Task only if at-least one core is active

Energy Discounted Computing...

- Core frequency state, or ACPI “P” state
  - CPUs use DVFS to quickly adjust power levels to conserve energy and meet performance needs of different workloads.
  - In our co-run scheme, the system should avoid raising the CPU frequency / voltage levels for best-effort tasks.
  - Otherwise, the extra energy consumption will negate the energy discount.
  - At the same time, such caution should not affect the performance of interactive applications.
  - CPU frequency adjustment should only focus on the needs of interactive applications and ignore the presence of best-effort tasks.

Energy Discounted Computing...

- Smartphone suspension state, or ACPI “S” state
  - Systems in the suspension state consume very little energy by shutting down most parts of the hardware, including the CPU and memory.
  - On some platforms (notably Android), applications can prevent system suspension by making explicit requests to the operating system.
  - Best-effort tasks are not permitted to make such requests. The system should be able to enter the suspension state regardless of best-effort tasks.

Resource Contention Mitigation

- ➔ Co-running tasks on a multicore may slow down each other.
- ➔ One easy mitigation is: adjust CPU scheduling priority(nice value, cpu limit)

But,

- ➔ Due to the hardware resource sharing on multi-core processors, contention could also result from shared hardware resources.
- ➔ Monitor the last-level-cache miss rate using PMU. Contention is identified if the miss rate reaches a threshold

Implementation

- **BUSY** indicates the CPU is running normal tasks(e.g., interactive applications),
- **IDLE** indicates the CPU is in idle state (regardless of the level of idle state),
- **BEST-EFFORT** indicates the CPU is running best-effort tasks,
- **UNDEF** is a transient state (e.g., during context switches).

Implementation

- → **Linux Control Groups**

Implementation

- **Linux Control Groups**
  - Linux Kernel Facility allowing grouping of tasks into tree

Implementation

- **Linux Control Groups**
  - Linux Kernel Facility allowing grouping of tasks into tree
  - Allows the groups for
    - Priority allocation
    - CPU resources
    - Memory B/W
    - Disk
    - Network

Implementation

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Implementation

- → **Non Work Conserving CPU scheduling**

Linux Complete Fair Scheduler

Implementation

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Non Work Conserving Scheduler

Implementation

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Linux Complete Fair Scheduler

Non Work Conserving Scheduler

Three options : nice , cpulimit **,cgroups**

Implementation

- ➔ Non Work Conserving CPU scheduling
- ➔ **Frequency Preservation**

Implementation

- Non Work Conserving CPU scheduling
- Frequency Preservation
- **Suspension Management**

Implementation

- → Non Work Conserving CPU scheduling
- → Frequency Preservation
- → **Suspension Management**

/sys/power/wake_unlock

Implementation

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- ➔ Frequency Preservation
- ➔ **Suspension Management**

/sys/power/wake_lock

/sys/power/wake_unlock.

Implementation

- ➔ Non Work Conserving CPU scheduling
- ➔ Frequency Preservation
- ➔ **Suspension Management**

/sys/power/wake_lock

Reject requests from best effort tasks for wake-lock

Implementation

- Non Work Conserving CPU scheduling
- Frequency Preservation
- Suspension Management
- **Contention Triggered Throttling**

Implementation

➔ **Contention Triggered Throttling**

performance monitoring unit:

ARMV7 A15 PERFCTR L2 CACHE REFILL READ

ARMV7 A15 PERFCTR L2 CACHE REFILL WRITE as L2

Implementation

- ➔ **Contention Triggered Throttling**

performance monitoring unit:

ARMV7 A15 PERFCTR L2 CACHE REFILL READ

ARMV7 A15 PERFCTR L2 CACHE REFILL WRITE as L2

Update at 20 ms granularity

Implementation

- Non Work Conserving CPU scheduling -> C State Preservation
- Frequency Preservation -> P State Preservation
- Suspension Management -> S state Preservation
- Contention Triggered Throttling -> Contention Mitigation

Experimental Setup

Device: Huawei Mate7 (late 2014)

– 1.8 GHz ARM Cortex-A15 Quad Core

– 32KB/32KB L1 instruction and data cache

– 2MB L2 cache, 2GB RAM with 12.8 GBps

– Power measurement using Monsoon power meter with smartphone battery detached

Benchmarks

Interactive application:

- Bbench: load locally cached websites
- Angry bird: casual game

Best-effort tasks: Spin, Compression, Encryption,

- AppOpt, FaceAnalysis

Test Flow

- Use automate UI testing tools (RERAN[1]) to minimize variations
- Launch two applications roughly at the same time
- Configure the workload such that application executions mostly overlap

$$\text{Discount } \sigma = 1 - \frac{E_{\text{co-run}} - E_{\text{interactive\_alone}}}{E_{\text{best-effort\_alone}}}$$

Related Work

- CARROLL , A., AND HEISER, G. An analysis of power consumption in a smartphone. In Proc. of the USENIX 2010.
- C ARROLL , A., AND H EISER , G. Mobile multicores: use them or waste them. In Proc. of the Workshop on Power-Aware Computing and System (HotPower) (Nov. 2013).
- SONG , W., S UNG , N., C HUN , B.-G., AND KIM , J. Reducing energy consumption of smartphones using user-perceived response time analysis. Santa Bar-bara, CA, Feb. 2014

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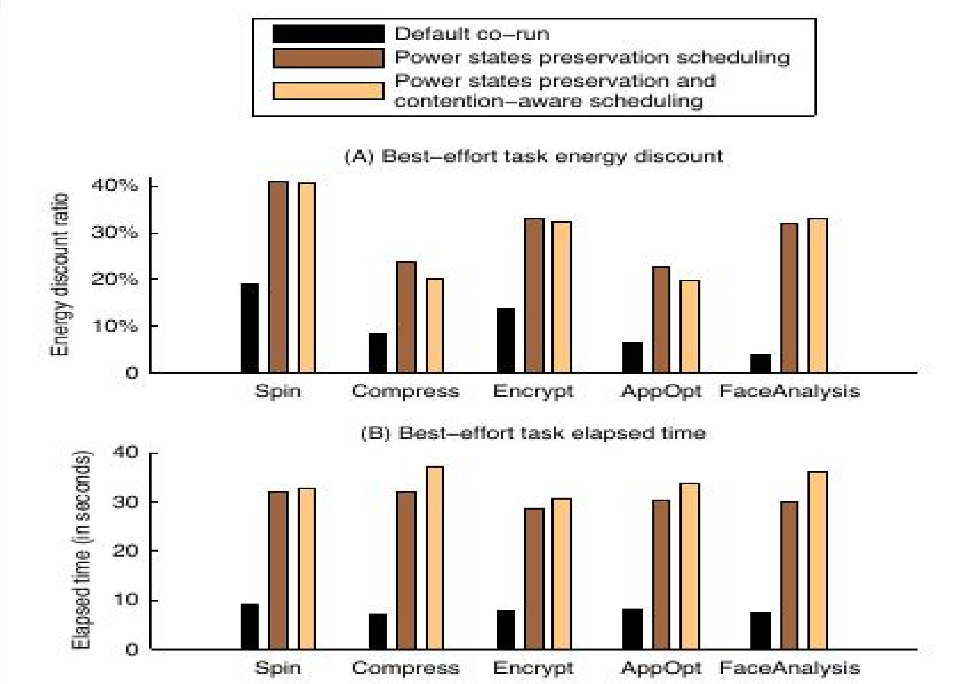
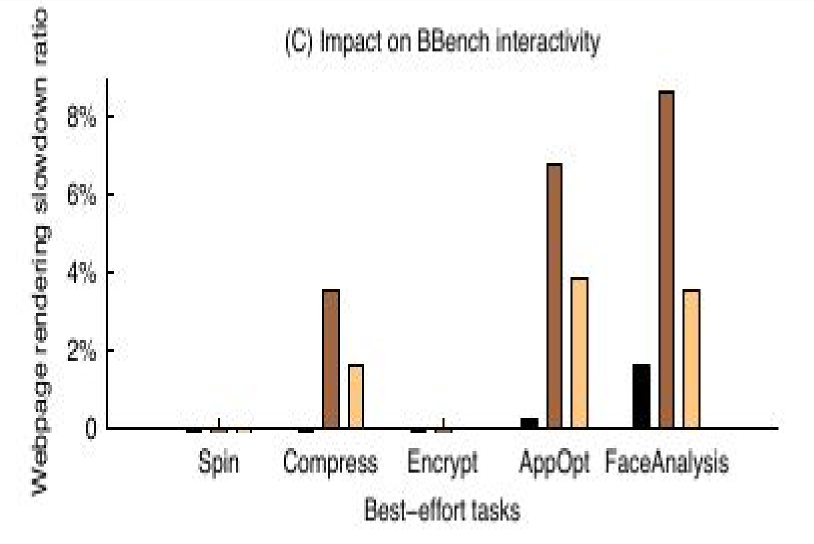
BBench

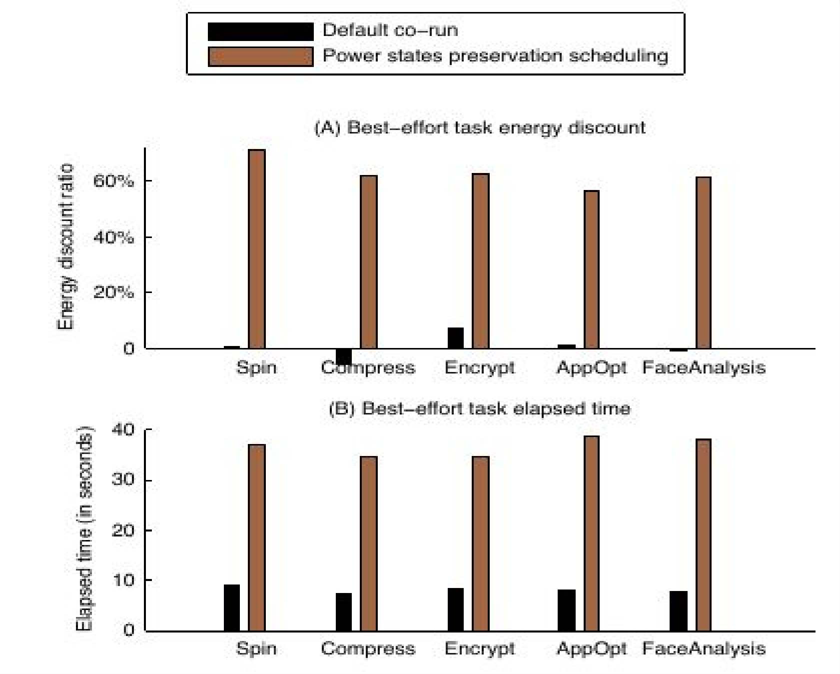


Default co–run
Power states preservation scheduling
Power states preservation and contention–aware scheduling
(A) Best–effort task energy discount
Energy discount ratio
40%
30%
20%
10%
0
Spin
Compress
Encrypt
AppOpt
FaceAnalysis
(B) Best–effort task elapsed time
Elapsed time (in seconds)
40
30
20
10
0
Spin
Compress
Encrypt
AppOpt
FaceAnalysis

BBench

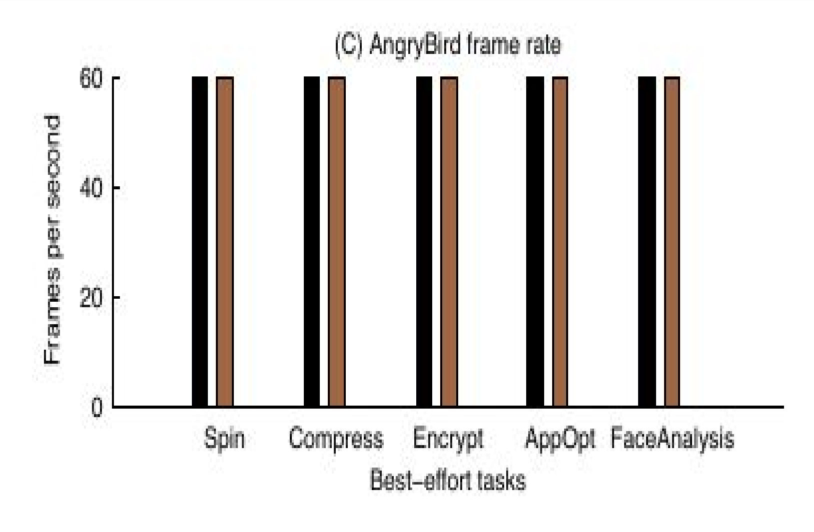

(C) Impact on BBench interactivity
Webpage rendering slowdown ratio
8%
6%
4%
2%
0
Spin
Compress
Encrypt
AppOpt
FaceAnalysis
Best-effort tasks

AngryBird



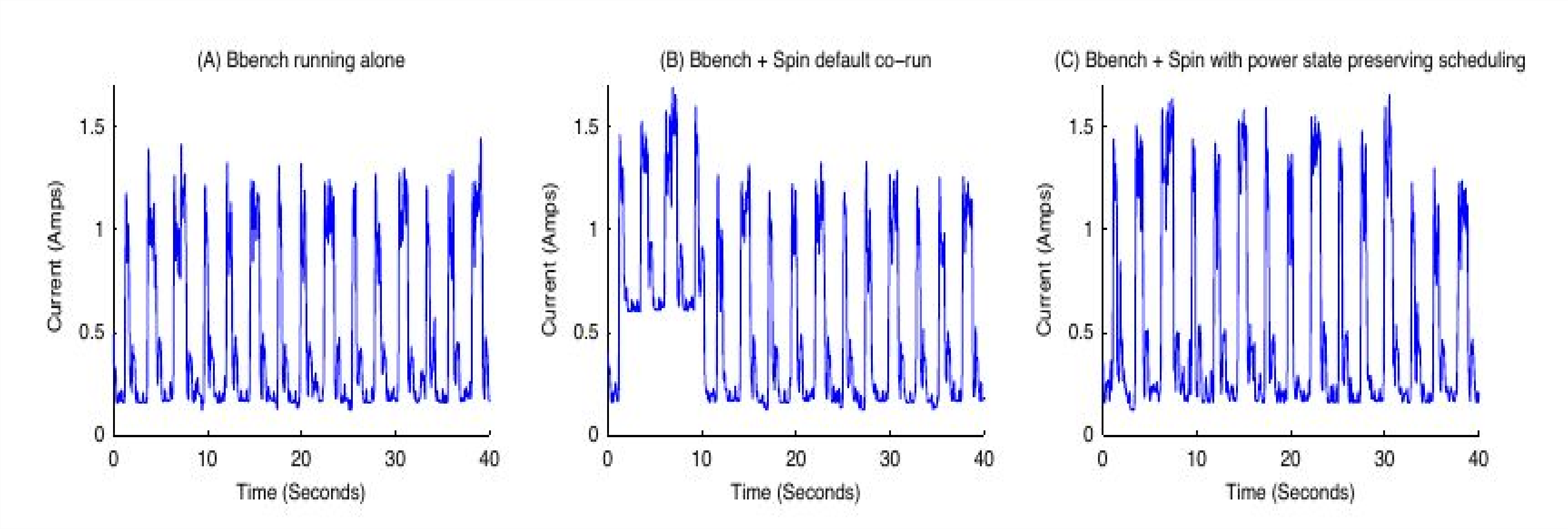
Default co–run
Power states preservation scheduling
(A) Best–effort task energy discount
Energy discount ratio
60%
40%
20%
0
Spin
Compress
Encrypt
AppOpt
FaceAnalysis
(B) Best–effort task elapsed time
Elapsed time (in seconds)
40
30
20
10
0
Spin
Compress
Encrypt
AppOpt
FaceAnalysis

AngryBird



(C) AngryBird frame rate
Frames per second
0
20
40
60
Spin
Compress
Encrypt
AppOpt
FaceAnalysis
Best–effort tasks

BBench



(A) Bbench running alone
(B) Bbench + Spin default co−run
(C) Bbench + Spin with power state preserving scheduling
Current (Amps)
Time (Seconds)
0
0.5
1
1.5
0
10
20
30
40

Bbench

(A) Bbench + FaceAnalysis

Throttling threshold (misses/μSecs)	Best-effort task elapsed time	Bbench slowdown ratio
7.5	42.65 Secs	3.94 %
10.0	36.25 Secs	3.57 %
12.5	32.42 Secs	6.58 %
15.0	30.20 Secs	8.73 %

(B) Bbench + AppOpt

Throttling threshold (misses/μSecs)	Best-effort task elapsed time	BBench slowdown ratio
6.0	43.10 Secs	4.20 %
7.5	36.85 Secs	3.72 %
10.0	33.87 Secs	3.88 %
12.5	29.62 Secs	5.80 %
15.0	29.77 Secs	6.81 %

Category	Abundance of discounted CPU cycles (multicore)	Abundance of discounted CPU cycles (single-core)	Equivalent work of FaceAnalysis (frames of faces can be analyzed)	Equivalent work of Encryption (minutes of video can be encrypted)
Web Browsing	1.63	0.66	30	21
Video Streaming	2.41	0.85	4	3
Gaming	1.61	0.65	21	15
Navigation	2.42	0.85	13	9
Messaging	2.88	0.97	3	2
Social Network	1.88	0.72	12	9
Camera	2.10	0.77	5	4
Music Streaming	1.63	0.66	7	5

Table 4: Results for the trace-based application study. Each usage scenario lasts for one minute. Abundance of

Related Work

- CARROLL , A., AND HEISER, G. An analysis of power consumption in a smartphone. In Proc. of the USENIX 2010.
    - The same paper as Prasanth and Aaskash discussed.
- CARROLL , A., AND HEISER , G. Mobile multicores: use them or waste them. In Proc. of the Workshop on Power-Aware Computing and System (HotPower) (Nov. 2013).
    - That a core should be kept online as long as there is work

Related Work

- SONG , W., SUNG , N., CHUN , B.-G., AND KIM , J. Reducing energy consumption of smartphones using user-perceived response time analysis. Santa Bar-bara, CA, Feb. 2014
    - Decreases the frequency when user facing(display on) tasks are completed.
- M ARTINS , M., C APPOS , J., AND F ONSECA, R.Selectively taming background android apps to improve battery lifetime. In USENIX ATC 15
    - monitor and intercept smartphone background activities while the system is in suspension state to extend the battery life.