Low power Design Techniques in Mobile Processors
Continued smartphone momentum
World’s largest technology platform

~8B
Cumulative smartphone unit shipments forecast between 2014-2018

Source: Gartner, Sept '13

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Mobile scale
Cumulative global unit shipments, 2013–2017

Smartphones & Tablets

PCs
Vehicles
Digital media adapters
Digital video recorders
Portable game consoles
Portable media players

Audio systems
Blu-ray disc players
Digital cameras
Game consoles
Flat-panel TVs
Set-top-boxes

Sources: Smartphones, tablets and PCs: Gartner, Sep. ’13; Vehicles: ABI, Apr. 2013; All others: Strategy Analytics, Mar. ’13

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Always On, Always Aware

- Fuses data from all sources & sensors
- Discovers patterns from data

Driving need for new ultra low power design solution and architectures
Wearable and IoT drive new low power design requirements

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Wearable and IoT drive new low power design requirements
Cloud and Mobile Computing

Big Data and abundant computing power are pushing computing to the Cloud.

Instant Data generated by sensors and users are pushing computing to the Edge.

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Phone: Convergence of Disparate Technologies

- Camera
- Audio
- Multimedia
- Display
- Video
- Power Management
- Security
- RF
- Software/HLOS
- Memory
- Connectivity

- Sensors (Motion & Environmental)
- Position Location
- CPU
- GPU
- Modem
- DSP

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Stay connected and stream large files fast with industry leading connectivity, including the world’s most advanced 4G LTE and Qualcomm® VIVE™ 2-stream 802.11ac Wi-Fi.

Capture sharper photos, even in low light, with the mobile industry’s first dual ISP.

Enjoy Ultra HD resolution content on Ultra HD-capable mobile devices and Ultra HD TVs with the Snapdragon Display Processor.

Find your way outdoors and indoors with Qualcomm® IZat™ GNSS with support for GPS, Glonass and BeiDou constellations.

Faster performance and more multitasking with Krait 450 CPU at up to 2.7 GHz.

Console quality gaming with new generation Adreno 420 GPU.

More power-efficient apps and system processing with the Hexagon DSP.

Capture and play back Ultra HD video and enjoy 7.1 surround sound on the go or at home with advanced video and audio engines.

Get more use and greater accuracy from sensor-intensive apps with the dedicated Snapdragon Sensor Engine.

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Mobile has historically lagged the PC market
- Now at par or exceeding

Mobile requirements are quickly accelerating
- DDR bandwidth exceeding **50 GB/s** in next generation devices
James Joule
Energy
Capacity for doing work
\[ J = \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = \text{N} \cdot \text{m} \]

James Watt
Power
Time rate of doing work or delivering energy
\[ W = \frac{J}{\text{s}} \]
What has more energy?

**Smartphone battery**

\[ E = 11.4 \text{ Wh} \times 3,600 \text{ s/h} \]

**E = 41,040 J**

**AR-15 bullet**

\[ m = 0.0039 \text{ kg} \]
\[ v = 975 \text{ m/s} \]

\[ E = \frac{1}{2} m v^2 = \frac{1}{2} \times 0.0039 \text{ kg} \times (975 \text{ m/s})^2 \]

**E = 1,854 J**
What takes more power?

**Smartphone battery**

\[ V = 5 \text{ V} \]
\[ I = 1.8 \text{ A} \]
\[ P = V \times I = 5 \text{ V} \times 1.8 \text{ A} \]
\[ P = 9 \text{ W} \]

**AR-15 bullet**

\( E = 1,854 \text{ J} \)
\( t = 0.0008 \text{ s} \)
\[ P = \frac{E}{t} = \frac{1,854 \text{ J}}{0.0008 \text{ s}} \]
\[ P = 2,317,500 \text{ W} \]

(*) Assumes 16” barrel (~0.4m) and constant acceleration from 0 to 975 m/s at the muzzle
The Human Brain

- is a massively parallel machine with ~86B neurons
- has no system clock, it is event driven
- has no hardware/software distinction
- performs processing and memory by the same components
- is a self-organizing, self healing system
The brain is a massively parallel machine

Modern computer
Dense, real-valued data

Human brain
Sparse ‘Events” or “Spikes”

>10^6 processing steps
<10^1 parallelism

<10^1 processing steps
>10^6 parallelism
Brain Functions

- **Frontal lobe**: Executive functions, thinking, planning, organizing and problem solving, emotions and behavioral control, personality
- **Motor cortex**: Movement
- **Sensory cortex**: Sensations
- **Parietal lobe**: Perception, making sense of the world, arithmetic, spelling
- **Occipital lobe**: Vision
- **Temporal lobe**: Memory, understanding, language
- **Cerebellum**: Controls balance and co-ordination
- **Brain Stem**: Breathing, body temperature, heart activity, …

**Left Brain**
- Detail
- Logic
- Math
- Science

**Right Brain**
- Big picture
- Feeling
- Art
- Philosophy

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Neural Processing Units (NPUs)

A new class of processors mimicking human perception and cognition

Massively parallel, reprogrammable

Comprehensive tools

Human-like functions

CONNECTIVITY
4G LTE, Wi-Fi
USB, BT and FM

Computer Vision
Low Power

Sensors
Accelerometer, Pressure, and Gyro,

Autonomous Mode
GPS

CPUs

GPU

DSP

SENSORS

ISPs

DISPLAY / LCD

NAVIGATION

MULTIMEDIA
Audio, Video and Gestures

4G LTE, Wi-Fi
USB, BT and FM

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Mobile Heterogeneous Compute Units to Lower Power

Custom Accelerators

Neural Processing Unit (NPU)

GPU & DSP

Power Efficiency

High Flexibility

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Mobile heterogeneous computing approach is needed

Run the appropriate 4K task on the most suitable processing engine

Power reduction by running HEVC decode on specialized video engine versus the CPU

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Right task on the right processing engine

The performance & power benefits of heterogeneity

Source: Internal Qualcomm technologies measurements on existing Snapdragon™ devices
Snapdragon is a product of Qualcomm Technologies, Inc.

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Hierarchical Computing

mW-MHz Pyramid

Micro

Nano

Pico

MHz

mW

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System and circuit low power techniques

**System Techniques**
- Structured & Tunable Clock Trees
- AVS with PVT & Aging Sensors
- On-Die Voltage Regulation
- Hierarchical Computing
- Brain Inspired Computing
- Error Tolerant Design
- Asynchronous Logic
- Clock Stretching
- RBB and FBB
- DVFS

**Circuit Techniques**
- NTC
- 3DVLSI
- MRAM
- Power Gating
- Multi-Vt Design
- Glitch Reduction
- Retention Registers
- Optimized Gate Sizing
- Multiple Voltage Domains
- Register/Latch Trays & Arrays
- Clock Gating & Multiple Clock Domains

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**More Moore Techniques**

\[ I_{D,Sat} = \mu W C_{inv} v_s (V_G - V_{th}) \]

\(v_s\) is the saturation velocity for short channel lengths

**Strained Silicon**

*or high mobility channel materials

**Hi-K Metal Gate**

** Appropriately tuned transistors**

**FinFet Technology**

**ACKNOWLEDGEMENTS:** Perlmutter, D. 2012 Sustainability in Silicon and Systems Development. ISSCC Dig. Tech Papers, 30-34.
Device Roadmap: Mobility vs. Bandgap
Mobile Computing – The Vdd Scaling Issue

Vdd scaling most difficult:
$V_t$ associated with leakage – SCEs, RDF

Compute Key FOM:

Past: Flops/Sec

Now: Flops/W

ALL ABOUT POWER!
### MRAM and SpinLogic

**MRAM power advantage**
- Zero retention/standby power from non-volatility, operating voltage much lower than SRAM
- Reduction in write current also results in higher MRAM density (approaching 5x of SRAM density)

<table>
<thead>
<tr>
<th>Memory Element</th>
<th>CMOS SRAM</th>
<th>In-plane MRAM</th>
<th>Perpendicular MRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic Anisotropy</td>
<td>N/A</td>
<td>In-plane</td>
<td>Perpendicular</td>
</tr>
<tr>
<td>Switching Mechanism</td>
<td>Charge Racing</td>
<td>Spin-Transfer Torque (STT)</td>
<td>Spin-Transfer Torque (STT)</td>
</tr>
</tbody>
</table>
| Energy per Cell per Write | 0.52 pJ (40nm UMC) | W0: ~2x SRAM  
W1: ~1x SRAM | W0: ~24% SRAM  
W1: ~12% SRAM |

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From voltage islands to embedded voltage regulators

- **Voltage Islands**
  - Independent power shutdown
  - Independent voltage control of each island
  - Needs level-shifters between island
  - 25-50% power reduction

- **Embedded Voltage Regulators (EVR)**
  - Enables more granular voltage islands
  - Enables faster supply current transitions
  - Reduces margin to account for voltage drops from PMIC to gates
  - Considerable additional power saving
  - Performance improvement

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Envelop tracking

- Maximizes the PA efficiency by operating the PA in compression for most envelope amplitudes.
- Time alignment between Envelope and RF signal is critical (1-2 nsec for LTE 10 MHz).
- DPD required to correct for dynamic supply voltage induced AM-AM and AM-PM.

\[ \eta_{total} = \eta_{VddAmp} \times \eta_{RFstage} \]

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Software on Heterogeneous Hardware

Developers and library writers have to agree on what functions will be available in the library ahead of time.

Whether app install time, startup time, just-in-time, or fully dynamic compilation.

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Qualcomm MARE
Parallel computing for high performance mobile applications

Parallel Algorithms With Multicore Processors
Developer Friendly Programming Library
SW to Manage Parallelism & Energy Efficiency
Designed for Heterogeneous Compute

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Qualcomm IZat Always-on Geofencing 3.0 Using Aware/ QCT Sensors Motion Classifier

User Context: 24 hour Day of Use

~12x latency reduction
~4x power reduction

GF2.1 (120 sec latency)
GF3.0 (10 sec latency)

1 Power reduction with context gating using CMC (coarse motion classifier) algorithm on QTI chips. CMC is a significant context gating source which enables low latency use cases (~10 sec) to be realized at low power (<1mA) by IZat Geofencing.
Conclusion

• Mobile computing, Wearable and IoT will continue driving requirement for low power design
• Heterogeneous computing will continue to be the architecture of choice for mobile computing
• Hierarchical computing is emerging as a complementary solution to heterogeneous computing
• Brain inspired computing will emerge to enrich heterogeneous architectures
• Industry will continue perfecting circuit and system level low power design solutions
• Embedded voltage regulators will become more streamlined

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