Reliability in the Dark Silicon Era

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IT is ever more indispensable

Our life w/o digital data is unimaginable as

• Enterprises
• Scientists
• Governments
• Societies
• Individuals

“He saw your laptop and wants to know if he can check his Hotmail.”
IT: An Exponential Growth

Four decades of digital platform proliferation
Exponential increase in density & decrease in cost
A Brief History of IT

Communication Era

Consumer Era

1970s- 1980s  1990s  Today+

Mainframes

PC Era

• From scientific instrument to commodity
• From product to service
IT: The Consumer Era

Phenomenal change from decades ago:

• Instant connectivity
• Shopping now online
• Daily interaction > 300 people
• Augmented reality
• Streaming movies
• .....

IT is at core of everyone’s life!
Change in IT’s Landscape

➡ Emergence of Data-Centric Universe
  – IT focus on massive data

• End of Dennard Scaling
  – Higher density ➔ higher energy

• Data-Centric Universe meets Energy Wall

What are design implications?
Our Data-Centric Universe:
Data Growing faster than Technology

- Commerce entirely data-driven
- Science handling massive data
- Companies spending $$$ to collect/analyze data
- Personalized computing

[Graph showing Technology Growth (Moore’s law) and Top Ten Data Warehouse size from 1998 to 2012]

WinterCorp Survey, www.wintercorp.com
Data Deluge: 1200 Exabytes in 2010
(Economist, Feb. 25th 2010)

- Only 150 Exabytes in 2005
- Supply-chain management, 10x increase in data in a year
- US aerial surveillance models 30x more data in 2011
• Era of “knowledge economy”
• 50% of economic value in developed countries
• Dominant supply-chain component of products/services
Data-Centric Science: “The Fourth Paradigm”

Mining data from:
• Archives
• Humans
• Sensors/instruments
• Simulations

Unifying theory, experimentation, simulation, analytics on massive data
Data Comes in Various Flavors

Satellite

Entertainment

Life

Health

Search

Simulation

Commerce
It’s all about Accessing Data!

Data Centers

Cloud Computing
A computing paradigm shift to enable ubiquitous connectivity
How to design for massive data?
Change in IT’s Landscape

• Emergence of Digital Universe
  – IT focus on massive data

➔ End of “Free Energy”
  – Higher density ➔ higher energy

• Data-centric Universe meets Energy Wall

What are design implications?
IT Energy is Shooting Up!

IT riding on technology that was energy-friendly

• Exponentially better performance, density
• Constant power envelope

But, energy is shooting up!
Household Energy in the UK (UK BERR, 2008)

Cell phones, Laptops
### Comparing Energy Use

Comparison of a typical television set-top box configuration with Energy Star-rated appliances and devices.

<table>
<thead>
<tr>
<th>Average Kilowatt-Hours a Year</th>
<th>HD Set-Top Box</th>
<th>HD DVR</th>
<th>Time in Use Each Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical HD television set-top box configuration</td>
<td>446</td>
<td>171</td>
<td>275</td>
</tr>
<tr>
<td>Refrigerator (21-cubic-foot)</td>
<td>415</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCD television (42-inch)</td>
<td>181</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desktop computer</td>
<td>175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compact fluorescent light bulb (15-watt)</td>
<td>17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Natural Resources Defense Council
Data center Energy in the US (extrapolated from Energy Star, 2007)

- Exponential costs if not mitigated
- Today, carbon footprint of airline industry
• Servers are getting relatively cheaper
• Power is beginning to dominate cost

James Hamilton’s Blog, mvdirona.com, 2008
Technology Inflection Point in 2004!

- Num Transistors (in Thousands)
- Relative Performance
- Clock Speed (MHz)
- Power Typ (W)
- NumCores/Chip

Year of Introduction

National Research Council (NRC) – Computer Science and Telecommunications Board (CSTB.org)
Four decades of Dennard Scaling

$P = C V^2 f$

- Increase in device count
- Lower supply voltages

$\Rightarrow$ Constant power/chip

Dennard et. al., 1974

Robert H. Dennard, picture from Wikipedia
Leakage Killed Dennard Scaling

Leakage:
• Exponential in inverse of $V_{th}$
• Exponential in temperature
• Linear in device count

To switch well
• must keep $V_{dd}/V_{th} > 3$

$\Rightarrow V_{dd}$ can’t go down
Supply voltages going down at much lower rate!
Dark Silicon: End of Manycore Scaling

Can not power up chip

Parallelism has limits even in Servers!

Must:
- specialize
- selectively power up

Number of Cores

Year of Technology Introduction

Max EMB Cores
EMB
GPP
Ideal

Hardavellas et. al., “Towards Dark Silicon in Servers”, 2011
Specialization can buy $1000x$ in Energy
(from a sample of 20 chips)

Performance ≠ Energy

Energy proportionality
• Avoid idle energy (today 70% of peak in DC’s)

Energy minimization
• Perform same task with less energy
  – E.g., specialized hardware
• Exploit slack in energy ➔ Batch tasks/ops

Less energy, same performance
Massive Data meets Energy Wall
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What are design implications?
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Less energy for reliability:
• Trade off HW for less work/energy
• Let it die, detect it, deal with it in SW

Less energy for computation:
• Exploit approximation
• Exploit inherent resilience in data
Temperatures in Datacenters up 30F!

Google, HP, Microsoft

- Pushing temps up
- No perceived change in failure
- High cost reduction

Energy > capital cost:

- Detect failure
- SW fault tolerance takes center stage

Christian Belady, 2009
Cheaper Reliability

Processors:
- Lightweight detectors
- Fingerprinting, Argus, SWAT revisited for energy
- Sampling DMR

Memory:
- 2D ECC
- Count-based ECC
- Virtualized ECC
Dark Silicon & Reliability

Match made in heaven:
- Provide only necessary coverage
- Specialize reliability (with computation)

Dark silicon:
- Trade off real estate functionality for spare
- Trade off capacity for lower voltages
Exact vs. Probabilistic

Much computation is error-resilient:
• Machine learning/analytics
• Image processing/visual computation
• Audio/speech
• Search

Similarly, two flavors of data
• Exact: affects functionality (pointer address)
• Probabilistic: affects quality (pixels in image)
Perforated (Skipped) Computation

**bodytrack** benchmark (PARSEC)
- Compiler-driven perforation
- Skip 40% of computation
- Maintains track on head, chest and legs

Computation does not have to be exact!

Hoffman et. al., “Using Loop Perforation to Dynamically Adapt Application Behavior to Meet Real-Time Deadlines”, 2010
DeSyRe: Hybrid Reliability

Exploit resilience in computation & data

• Reliable + unreliable substrate
• Partition tasks according to resilience
• Maximize throughput with less energy
Scaling in Third Dimension

Many technological challenges to overcome

Worse thermal behavior

Great for massive data

• TB/sec bandwidth
• Reduces I/O energy
Scale-Out vs. Scale-Up Workloads

Emerging workloads scale out!
Emerging Workloads are Scale-Out

Examples:

• Data serving (YCSB)
• Streaming
• Search
• Analytics
• Web
Scale-Out vs. Scale-Up Chips

- Scaling out divides chip among disconnected servers
- Hardware isolation → improved reliability
The EuroCloud Server: A Scale-Out Chip for Massive Data
(www.eurocloudserver.com)

3D SoC/DRAM:
• 1000x more connectivity
• 10x less system energy
• To run off-the-shelf cloud stack

Your Future 1-Watt Datacenter Chip
Bringing it All Together

- IT is changing everything & itself changing
- Future: Plow massive data with minimal energy
- Our way of computing is inefficient
- Are our systems too exact, too robust?

Oh, I can be reliable and for an extra 300 hundred a week can be efficient too.
Thank You!

For more information please visit us at

dclocld.ch