THE ENERGY IMPACT OF NETWORKED SERVICES

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ATTRIBUTION

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• These slides incorporate material from:
  • The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines, 2nd ed., by Barroso, Clidaras, and Hölzle.
Today’s material available in canvas

The Datacenter as a Computer
Designing Warehouse-Scale Machines
Third Edition

Luiz André Barroso
Urs Hölzle
Parthasarathy Ranganathan

SYNTHESIS LECTURES ON COMPUTER ARCHITECTURE
Margaret Martonosi, Series Editor
FIGURE 5.7: Human energy usage vs. activity levels (adult male) [52].
Figure 2.4: Example of daily traffic fluctuation for a search service in one data center over a 24-hr period.
Figure 1.1: Example hardware building blocks for WSCs. Left to right: (a) a server board, (b) an accelerator board (Google’s Tensor Processing Unit [TPU]), and (c) a disk tray.
Figure 5.7: Subsystem power usage in an x86 server as the compute load varies from idle to full usage.
FIGURE 5.5: Activity profile of a sample of 5,000 Google servers over a period of 6 months.
WHAT ABOUT “POWER SAVING” FEATURES ON MODERN COMPUTERS?

Figure 5.4: Example benchmark result for SPECpower_ssj2008; bars indicate energy efficiency and the line indicates power consumption. Both are plotted for a range of utilization levels, with the average energy efficiency metric corresponding to the vertical dark line. The system has two 2.1 GHz 28-core Intel Xeon processors, 192 GB of DRAM, and one M.2 SATA SSD.
Figure 5.8: Normalized system power vs. utilization in Intel servers from 2007–2018 (courtesy of David Lo, Google). The chart indicates that Intel servers have become more energy proportional in the 12-year period.
```java
for (iterations = 1 to 100) {
    work = new Task[10000];
    for (i = 1 to 10000) {
        rpc.asyncCall(server[i], work[i]);
    }
    waitForAllAsyncCallsToComplete();
}
```

Assume latency drawn from $N(\mu, \sigma)$ with 1 in 100 requests $\geq$ 1 second

What happens to the ~9,900 servers that finished “quickly”?
Figure 4.4: The main components of a typical data center.
Figure 4.5: Comparison of AC and DC distribution architectures commonly employed in the data center industry.
Figure 4.8: Airflow schematic of an air-economized data center.
Figure 4.9: Raised floor data center with hot-cold aisle setup (image courtesy of DLB Associates [Dye06]).
Figure 4.16: Copper cold plates and hose connections provide liquid cooling for Google’s third-generation TPU.
NUMBERS FROM JAMES HAMILTON (EARLY 2010S) (MSFT, AMAZON)

- CPUs: 42.0%
- DRAM: 15.4%
- Disks: 14.3%
- Networking: 11.7%
- Misc.: 7.7%
- Power Overhead: 4.9%
- Cooling Overhead: 4.0%
FIGURE 5.2: Breakdown of datacenter energy overheads (ASHRAE).
Figure 1.8: Approximate distribution of peak power usage by hardware subsystem in a modern data center using late 2017 generation servers. The figure assumes two-socket x86 servers and 12 DIMMs per server, and an average utilization of 80%.
QUANTIFYING ENERGY-EFFICIENCY: PUE

- PUE = Power Usage Effectiveness
- Simply compares
  - Power used for computing vs Total power used
- Historically cooling was a huge source of power
  - E.g., 1 watt of computing meant 1 Watt of cooling!

\[
\text{PUE} = \frac{\text{Facility Power}}{\text{Computing Equipment power}}
\]
FIGURE 5.1: LBNL survey of the power usage efficiency of 24 datacenters, 2007 (Greenberg et al.) [41].
# LBNL PUE Survey (2013)

## Table 1: Summary of power/energy data

<table>
<thead>
<tr>
<th>Data center IT devices (W/device)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume server</td>
<td>235</td>
</tr>
<tr>
<td>Midrange server</td>
<td>450</td>
</tr>
<tr>
<td>External HDD spindle</td>
<td>26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data center PUE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Server closet</td>
<td>2.5</td>
</tr>
<tr>
<td>Server room</td>
<td>2.1</td>
</tr>
<tr>
<td>Localized</td>
<td>2</td>
</tr>
<tr>
<td>Mid-tier</td>
<td>2</td>
</tr>
<tr>
<td>Enterprise-class</td>
<td>1.5</td>
</tr>
<tr>
<td>Cloud</td>
<td>1.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Network data transmission (μJ/bit)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wired</td>
<td>100</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>100</td>
</tr>
<tr>
<td>Cellular (3G/4G)</td>
<td>450</td>
</tr>
</tbody>
</table>
Figure 5.1: Uptime Institute survey of PUE for 1100+ data centers. This detailed data is based on a 2012 study [UpI12] but the trends are qualitatively similar to more recent studies (e.g., 2016 LBNL study [She+16]).
Figure 5.3: A representative end-to-end breakdown of energy losses in a typical datacenter. Note that this breakdown does not include losses of up to a few percent due to server fans or electrical resistance on server boards.