CS 744: DATACENTER AS A COMPUTER

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Fall 2021
ANNOUNCEMENTS

- Assignments
  - Assignment zero is due!
  - Form groups for Assignment 1 on Piazza

- Class format
  - Review
  - Lecture
  - Discussion
OUTLINE

- Hardware Trends
- Datacenter design
- WSC workloads
- Discussion
WHY IS ONE MACHINE NOT ENOUGH?

The Digital Universe: 50-fold Growth from the Beginning of 2010 to the End of 2020

WHAT’S IN A MACHINE?

Interconnected compute and storage

Newer Hardware
  - GPUs, FPGAs
  - RDMA, NVlink
Moore’s law

- Stated by Intel founder Gordon Moore
- Number of transistors on microchip double every 2 years
- Today “closer to 2.5 years” Intel CEO Brian Krzanich
Dennard Scaling is the Problem

Suggested that power requirements are proportional to the area for transistors

- Both voltage and current being proportional to length
- Stated in 1974 by Robert H. Dennard (DRAM inventor)

Broken since 2005

“Adapting to Thrive in a New Economy of Memory Abundance,” Bresniker et al
DENNARD SCALING IS THE PROBLEM

Performance per-core is stalled

Number of cores is increasing

“Adapting to Thrive in a New Economy of Memory Abundance,” Bresniker et al
MEMORY TAKEAWAY

Data access from memory is getting more expensive!

- Capacity: Growing +15% per year
- Bandwidth: 128x
- Latency: 20x
- DRAM Improvements (log): 1.3x
HDD BANDWIDTH

Disk bandwidth is not growing

*Figure 4: Maximum sustained bandwidth trend*
SSDS

Performance:
- Reads: 25us latency
- Write: 200us latency
- Erase: 1.5 ms

Steady state, when SSD full
- One erase every 64 or 128 reads (depending on page size)

Lifetime: 100,000-1 million writes per page
ETHERNET BANDWIDTH

Growing 33-40% per year!
New – EC2 P3dn GPU Instances with 100 Gbps Networking & Local NVMe Storage
TRENDS SUMMARY

CPU speed per core is flat
Memory bandwidth growing slower than capacity
SSD, NVMe replacing HDDs
Ethernet bandwidth growing
STORAGE HIERARCHY (DC AS A COMPUTER V2)

One Server
- DRAM: 16 GB, 100 ns, 20 GB/s
- Disk: 2TB, 10 ms, 200 MB/s
- Flash: 128 GB, 100 us, 1 GB/s

Local Rack (80 servers)
- DRAM: 1 TB, 300 us, 100 MB/s
- Disk: 160 TB, 11 ms, 100 MB/s
- Flash: 20 TB, 400 us, 100 MB/s

Cluster (30 racks)
- DRAM: 30 TB, 500 us, 10 MB/s
- Disk: 4.80 PB, 12 ms, 10 MB/s
- Flash: 600 TB, 600 us, 10 MB/s
WAREHOUSE-SCALE COMPUTERS

Single organization
Homogeneity (to some extent)
Cost efficiency at scale
  – Multiplexing across applications and services
  – Rent it out!

Many concerns
  – Infrastructure
  – Networking
  – Storage
  – Software
  – Power/Energy
  – Failure/Recovery
  – …
SOFTWARE IMPLICATIONS

- Reliability
- Storage Hierarchy
- Workload Diversity
- Single organization
WORKLOAD: PARTITION-AGGREGATE
WORKLOAD: SCHOLAR SIMILARITY

Map Stage  Reduce Stage
VIDEO ENCODING

ORIGINAL → TRANSCODE VOD → UNIVERSAL FORMAT → TRANSCODE VOD

PLAY

1080P

144P

MEASURED POPULAR

TRANSCODE VOD

1080P

144P

PLAY
Table 2.1: Six production applications plus ResNet benchmark. The fourth column is the total number of operations (not execution rate) that training takes to converge.

<table>
<thead>
<tr>
<th>Type of Neural Network</th>
<th>Parameters (MiB)</th>
<th>Examples to Convergence</th>
<th>Training ExaOps to Conv</th>
<th>Ops per Example</th>
<th>Inference Ops per Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLP0</td>
<td>225</td>
<td>1 trillion</td>
<td>353</td>
<td>353 Mops</td>
<td>118 Mops</td>
</tr>
<tr>
<td>MLP1</td>
<td>40</td>
<td>650 billion</td>
<td>86</td>
<td>133 Mops</td>
<td>44 Mops</td>
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<tr>
<td>LSTM0</td>
<td>498</td>
<td>1.4 billion</td>
<td>42</td>
<td>29 Gops</td>
<td>9.8 Gops</td>
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<tr>
<td>LSTM1</td>
<td>800</td>
<td>656 million</td>
<td>82</td>
<td>126 Gops</td>
<td>42 Gops</td>
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<tr>
<td>CNN0</td>
<td>87</td>
<td>1.64 billion</td>
<td>70</td>
<td>44 Gops</td>
<td>15 Gops</td>
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<tr>
<td>CNN1</td>
<td>104</td>
<td>204 million</td>
<td>7</td>
<td>34 Gops</td>
<td>11 Gops</td>
</tr>
<tr>
<td>ResNet</td>
<td>98</td>
<td>114 million</td>
<td>&lt;3</td>
<td>23 Gops</td>
<td>8 Gops</td>
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</tbody>
</table>
DISCUSSION

https://forms.gle/nFrMPkSAWTjMcgUp6

Scale-up vs Scale-out
DISCUSSION

Scale-up vs Scale-out
DISCUSSION

The graph illustrates the relationship between the number of servers and the probability of service latency exceeding 1 s for different rates: 1-in-100, 1-in-1000, and 1-in-10,000. As the number of servers increases, the probability of latency exceeding 1 s decreases, approaching a constant value. The data points for each rate are marked on the graph, showing how the probability changes with the number of servers.
NEXT STEPS

Next class: Storage Systems

Assignment 1 out Thursday.
Submit groups before that!