Warehouse-Scale Computers

Hot Interconnects
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Cloud computing = really small + really big

UI-centric devices

Large consolidated computing farms

Not really just a data center

<table>
<thead>
<tr>
<th><strong>Data center</strong></th>
<th><strong>Warehouse-scale computer</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-located machines that share security, environmental requirements</td>
<td>Computing system designed to run massive Internet services</td>
</tr>
<tr>
<td>Applications → a few binaries, running on a small number of machines</td>
<td>Applications → tens of binaries running on hundreds-thousands of machines</td>
</tr>
<tr>
<td>Heterogeneous hardware and system software</td>
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</tr>
<tr>
<td>Partitioned resources, managed and scheduled separately</td>
<td>Common pool of resources managed centrally</td>
</tr>
<tr>
<td>Facility and computing equipment designed separately</td>
<td>Integrated design of facility and computing machinery</td>
</tr>
</tbody>
</table>

Another way to tell them apart

- If your storage system has a few Petabytes of data
- If it’s 1am and your storage system pages you because there are only a few Petabytes of free space left

| Data center | Warehouse-scale computer |

Plan for today

Warehouse-scale computers (WSCs)
FLASH, performance variability, reliability
Energy efficiency
WSC Networks
**The Machinery**

![Diagram of Warehouse-scale Computer (WSC)](image)

- **Servers**: CPUs, DRAM, Disk
- **Racks**: 40-80 servers, Ethernet switch

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**Example warehouse-scale system**

- **Servers**: Dual-socket x86 platform, 16GB of DRAM, 5x 1TB disk drives, 1x 160GB SSD (FLASH)
- **Racks**: 40 servers, 1x 48-port GigE switch (8 ports up, 40 down – 5x1 oversubscription)
- **Warehouse-scale computer**: 10,000 machines (250 racks), 2K x1GigE non-oversubscribed switch fabric (made from ~500 port switches)

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**FLASH (SSDs) in Warehouse-scale machines**

- Promising technology yet somewhat slow adoption
  - Endurance and retention not yet proven in the field
  - Not a DRAM replacement (too slow)

- Intriguing proposition as a hard drive replacement:
  - SSDs are 17-32x more expensive per GB
  - SSDs are 50-150x less expensive per random read op/sec

- More useful metric is what you get for the same cost:
  - 1/16 of the capacity for 40x the RdOPS

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**FLASH (cont)**

- **Bottom line**: Too good to ignore
  - Too expensive to replace hard drives

- Will indeed become an additional storage layer
  - Software engineers will be harmed
    - 90% of the data is on disk
    - 99% of your accesses come from FLASH

- Cluster-level architecture may need to be re-visited
  - Replacing one HD in a 6 disk storage node with an SSD increases RdOPS per server by 10x
  - Will require better networking at the warehouse scale

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**Storage availability**

- Data blocks of each stripe are placed in different fault domains
  - Different disks, servers, racks
  - Data blocks are distributed across the whole cluster
    - Read operations are easily load-balanced
    - Recovery is highly efficient

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**Large scale → exposure to performance variability**

- Rare slowdown events can hurt
  - Average server response time is 100ms, but every 10,000 queries it takes 1 second (random performance hiccup)
  - A service that uses one machine
    - 0.01% slow queries
  - A service that uses 5x such machines
    - 35.4% slow queries

- Minimizing performance idiosyncrasies is key
  - Software systems need to tolerate these slowdowns
Large scale ➔ exposure to faults

Some fault/availability stats to keep in mind

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>99 - 99.9%</td>
<td>Consumer Internet availability</td>
</tr>
<tr>
<td>&gt; 1%</td>
<td>Rate of uncorrectable DRAM errors/server/year</td>
</tr>
<tr>
<td>2 - 10%</td>
<td>Disk drive annualized failure rate</td>
</tr>
<tr>
<td>-2</td>
<td>Server crashes/year</td>
</tr>
<tr>
<td>-1</td>
<td>Utility power events per year</td>
</tr>
</tbody>
</table>

Internet service running on 2000 servers will see over 10 machines crash per day!

Service level outages

Top three causes
1. Networking issues
2. Power issues
3. Oops issues

Rare but actual causes of long-haul networking problems
- Wild dogs
- Sharks
- Dead horses
- Thieves
- Blasphemy
- Drunken hunters
- ...

Energy efficiency challenges

Costs breakdown of a large datacenter

- Electricity costs themselves not yet dominant
- Energy related costs are approaching server costs
- One reason: inefficient traditional datacenters

Efficiency of Warehouse-Scale Computers

Carbon usage
- 0.2g Answering one Google query
- 20g Using a Laptop for one hour
- 75g Using a PC & monitor for one hour
- 173g One weekday newspaper (physical copy)
- 209g Producing a single glass of orange juice
- 280g Washing one load of laundry in an efficient machine
- 532g One beer

Dramatic efficiency improvements

Typical* PUE = 2.0
- 4% Power and distribution
- 11% Lighting
- 35% IT
- 50% Facility

Google PUE = 1.16
- 3% Power and distribution
- 7% Lighting
- 9% IT
- 80% Facility

Google data center efficiencies

Google’s container-based data center video

Remember: Watts drive Dollars

- Electricity costs themselves not yet dominant
- Energy related costs are approaching server costs

Handheld vs. WSC (or Landheld)

- Lots of idle time
- Never idle. Rarely at peak

Idle-mode energy efficiency suffices
Need to be efficient across the usage spectrum

Idleness doesn’t occur in the wild

Idleness is fragile
- takes everyone to build and anyone to destroy

Well designed distributed systems software will:
- parallelize over lots of machines
- load balance effectively
- distribute data widely
- exploit locality
- avoid bursts
- ... work against idleness

Energy proportional computing

The idea:
- No work, no power consumed
- Some work, some power consumed
- Lots of work, lots of power consumed
Impact of energy proportionality on data centers

- Energy used could be halved!
- Peak data center power is lowered too

Source: Fan, Weber, Barroso, ISCA’07

Energy Proportional Network Challenges

- Similar constraint: the network won’t be idle
- Today’s networks aren’t a large power component at peak (~10%)
- But with energy proportional servers, 25% is in the cards...
- Don’t forget that capex is just as important (or more)
- And please don’t introduce variable latency

Networks for Warehouse-Scale Computers

- Peak data center power is lowered too

Energy Proportional Network Challenges

- Cost pressure requires low capex and low power usage
- Clusters are getting larger and nodes are getting faster
- Not enough bandwidth at a reasonable price
  - 48-port (rack) 10GigE switch: $16/port
  - 10,000-port (data center) switch: priceless
- User messaging latency is embarrassingly high
  - Real-life RPC performance (Linux + Ethernet): XX - XXXx, highly variable
- Number of cores per Gb/s of network bandwidth is rising faster than pin density
  - Switch bandwidth does not grow at Moore’s Law
  - Wires don’t scale
Need increased bandwidth and uniform latency and bandwidth to network.

**What the industry really needs**

- **High-performance, low latency chip sets**
  - A BIOS (OpenFlow)
  - An OS

**Existing Solution: HPC Interconnect**

- Great bandwidth and latency
  - maybe too great?
- Expensive (typical $/WSC node < typical $/HPC node)
- Often not flexible (can’t easily grow a cluster)
- Not a commodity
- Often coupled to CPU interconnect
- Not Ethernet
  - The WSC needs to connect to standard Ethernet/IP/TCP fabrics

**Possible solution: Ethernet Clos Fabric**

- Al-Fares (SIGCOMM 2008) and others: build Clos fabric from small Ethernet switches
- Promises cheap, scalable, simple fabric
- Requires multiple hops per server-to-server roundtrip
- k*N cables…
- Distance limited with copper, expensive with fiber
- Needs custom SW for network and/or hosts
- "Interesting" failure behavior when a commodity switch fails

**Existing solution: multiple Ethernet switches**

- Rack Switch has 2, 4 or 8 uplinks to large chassis switch
- Combines cheap rack switches with expensive large switches
- Pros: affordable, reliable; cheap intra-rack bandwidth
- Cons: oversubscription causes SW complexity; doesn’t scale well

**Existing solution: commercial datacenter switches**

- Arista, Cisco, Juniper
- Larger switches (~3Tbps vs ~1Tbps) make more natural Clos elements
- Custom HW + SW, no standards
- Price points still more suited to Wall St than free cloud services

**Switch Bandwidth of HPC machines**

- Amdahl’s Law effects
  - maybe too great?
- The WSC needs to connect to standard Ethernet/IP/TCP fabrics

**Existing Solution: HPC Interconnect**

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  - The WSC needs to connect to standard Ethernet/IP/TCP fabrics
• Warehouse-scale computers aren’t just datacenters
• FLASH, distributed storage, increasing cluster size all put pressure on the traditional Ethernet interconnect
• No great solutions yet for WSC networks

Thank You!

References:
- The Datacenter as a Computer: an introduction to the design of warehouse-scale machines (Barroso & Hölzle), Morgan & Claypool Synthesis Series on Computer Architecture, 2009