Introduction

- Warehouse-scale computer (WSC)
  - Provides Internet services
    - Search, social networking, online maps, video sharing, online shopping, email, cloud computing, etc.
  - Differences with HPC “clusters”:
    - Clusters have higher performance processors and network
    - Clusters emphasize thread-level parallelism, WSCs emphasize request-level parallelism
  - Differences with datacenters:
    - Datacenters consolidate different machines and software into one location
    - Datacenters emphasize virtual machines and hardware heterogeneity in order to serve varied customers
Introduction

Important design factors for WSC:
- Cost-performance
  - Small savings add up
- Energy efficiency
  - Affects power distribution and cooling
  - Work per joule
- Dependability via redundancy
- Network I/O
- Interactive and batch processing workloads
- Ample computational parallelism is not important
  - Most jobs are totally independent
  - “Request-level parallelism”
- Operational costs count
  - Power consumption is a primary, not secondary, constraint when designing system
- Scale and its opportunities and problems
  - Can afford to build customized systems since WSC require volume purchase

Prgrm’g Models and Workloads

Batch processing framework: MapReduce

- **Map**: applies a programmer-supplied function to each logical input record
  - Runs on thousands of computers
  - Provides new set of key-value pairs as intermediate values

- **Reduce**: collapses values using another programmer-supplied function
Prgrm’g Models and Workloads

Example:

- map (String key, String value):
  - // key: document name
  - // value: document contents
  - for each word w in value
    - EmitIntermediate(w,"1");  // Produce list of all words

- reduce (String key, Iterator values):
  - // key: a word
  - // value: a list of counts
  - int result = 0;
  - for each v in values:
    - result += ParseInt(v);  // get integer from key-value pair
    - Emit(AsString(result));

MapReduce runtime environment schedules map and reduce task to WSC nodes

Availability:
- Use replicas of data across different servers
- Use relaxed consistency:
  - No need for all replicas to always agree

Workload demands
- Often vary considerably
**Computer Architecture of WSC**

- WSC often use a hierarchy of networks for interconnection
- Each 19” rack holds 48 1U servers connected to a rack switch
- Rack switches are uplinked to switch higher in hierarchy
  - Uplink has 48 / n times lower bandwidth, where n = # of uplink ports
  - “Oversubscription”
- Goal is to maximize locality of communication relative to the rack

**Storage**

- Storage options:
  - Use disks inside the servers, or
  - Network attached storage through Infiniband
  - WSCs generally rely on local disks
  - Google File System (GFS) uses local disks and maintains at least three replicas
Array Switch

- Switch that connects an array of racks
  - Array switch should have 10 X the bisection bandwidth of rack switch
  - Cost of $n$-port switch grows as $n^2$
  - Often utilize content addressable memory chips and FPGAs

WSC Memory Hierarchy

- Servers can access DRAM and disks on other servers using a NUMA-style interface

<table>
<thead>
<tr>
<th></th>
<th>Local</th>
<th>Rack</th>
<th>Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAM latency (microseconds)</td>
<td>0.1</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Disk latency (microseconds)</td>
<td>10,000</td>
<td>11,000</td>
<td>12,000</td>
</tr>
<tr>
<td>DRAM bandwidth (MB/sec)</td>
<td>20,000</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Disk bandwidth (MB/sec)</td>
<td>200</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>DRAM capacity (GB)</td>
<td>16</td>
<td>1,040</td>
<td>31,200</td>
</tr>
<tr>
<td>Disk capacity (GB)</td>
<td>2,000</td>
<td>160,000</td>
<td>4,800,000</td>
</tr>
</tbody>
</table>
Infrastructure and Costs of WSC

- Location of WSC
  - Proximity to Internet backbones, electricity cost, property tax rates, low risk from earthquakes, floods, and hurricanes
- Power distribution

Infrastructure and Costs of WSC

- Cooling
  - Air conditioning used to cool server room
  - 64 F – 71 F
    - Keep temperature higher (closer to 71 F)
  - Cooling towers can also be used
    - Minimum temperature is “wet bulb temperature”
Infrastructure and Costs of WSC

- Cooling system also uses water (evaporation and spills)
  - E.g. 70,000 to 200,000 gallons per day for an 8 MW facility

- Power cost breakdown:
  - Chillers: 30-50% of the power used by the IT equipment
  - Air conditioning: 10-20% of the IT power, mostly due to fans

- How many servers can a WSC support?
  - Each server:
    - “Nameplate power rating” gives maximum power consumption
    - To get actual, measure power under actual workloads
  - Oversubscribe cumulative server power by 40%, but monitor power closely

Measuring Efficiency of a WSC

- Power Utilization Effectiveness (PEU)
  - Power Utilization Effectiveness (PEU) = Total facility power / IT equipment power
  - Median PUE on 2006 study was 1.69

- Performance
  - Latency is important metric because it is seen by users
  - Bing study: users will use search less as response time increases
  - Service Level Objectives (SLOs)/Service Level Agreements (SLAs)
    - E.g. 99% of requests be below 100 ms
Cost of a WSC

- Capital expenditures (CAPEX)
  - Cost to build a WSC

- Operational expenditures (OPEX)
  - Cost to operate a WSC

Cloud Computing

- WSCs offer economies of scale that cannot be achieved with a datacenter:
  - 5.7 times reduction in storage costs
  - 7.1 times reduction in administrative costs
  - 7.3 times reduction in networking costs
  - This has given rise to cloud services such as Amazon Web Services
    - “Utility Computing”
    - Based on using open source virtual machine and operating system software