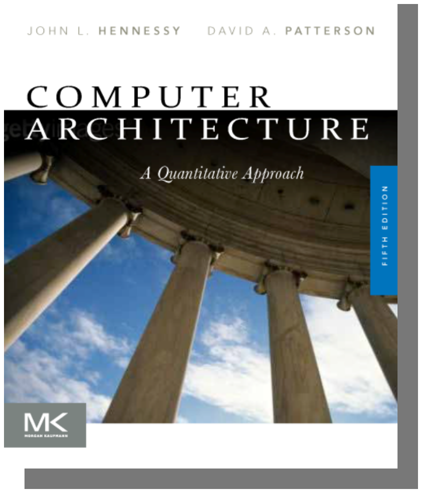


Chapter 6

Warehouse-Scale Computers to Exploit Request-Level and Data-Level Parallelism:

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));**

Prgrm’g Models and Workloads

- 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 relicas**

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 addressible memory chips and FPGAs

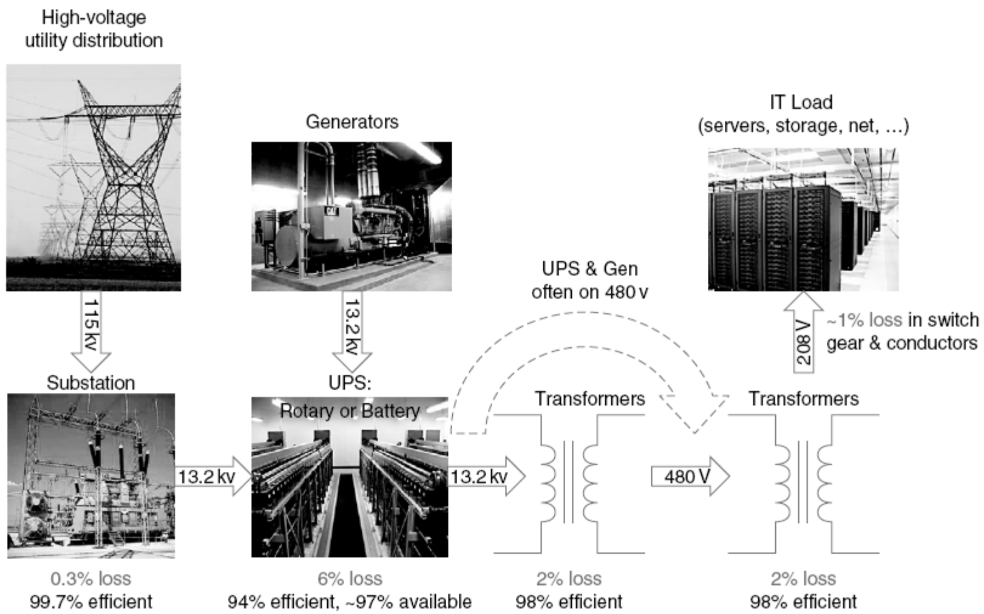
WSC Memory Hierarchy

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

	Local	Rack	Array
DRAM latency (microseconds)	0.1	100	300
Disk latency (microseconds)	10,000	11,000	12,000
DRAM bandwidth (MB/sec)	20,000	100	10
Disk bandwidth (MB/sec)	200	100	10
DRAM capacity (GB)	16	1,040	31,200
Disk capacity (GB)	2000	160,000	4,800,000

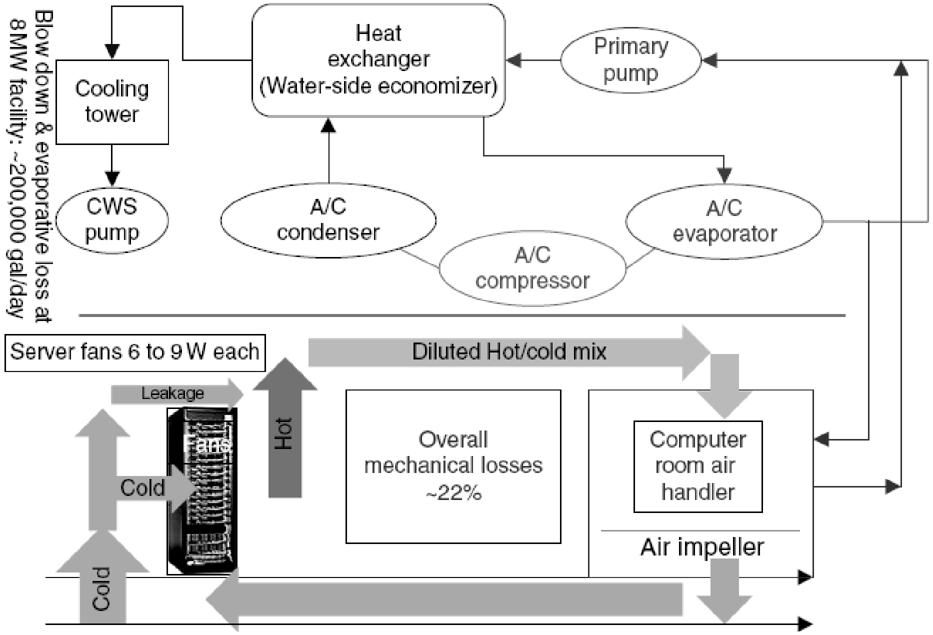
Infrastructure and Costs of WSC

- 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 man 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)
  - = 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