CS 61C: Great Ideas in Computer Architecture (Machine Structures)
Lecture 17 – Datacenters and Cloud Computing

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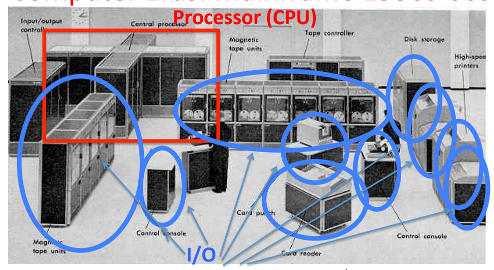
Computer Eras: Mainframe 1950s-60s



"Big Iron": IBM, UNIVAC, … build $1M computers for businesses ➔ COBOL, Fortran, timesharing OS

Minicomputer Eras: 1970s

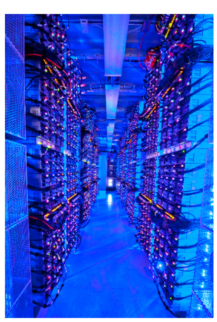
Using integrated circuits, Digital, HP… build $10k computers for labs, universities ➔ C, UNIX OS

PC Era: Mid 1980s - Mid 2000s

Using microprocessors, Apple, IBM, … build $1k computer for 1 person ➔ Basic, Java, Windows OS

PostPC Era: Late 2000s - ??

Personal Mobile Devices (PMD): Relying on wireless networking, Apple, Nokia, … build $500 smartphone and tablet computers for individuals
➔ Objective C, Java, Android OS + iOS



Cloud Computing: Using Local Area Networks, Amazon, Google, … build $200M Warehouse Scale Computers with 100,000 servers for Internet Services for PMDs
➔ MapReduce, Ruby on Rails

Why Cloud Computing Now?

- "The Web Space Race": Build-out of extremely large datacenters (10,000's of ***commodity*** PCs)
  – Build-out driven by growth in demand (more users)
  ⇒ Infrastructure software and Operational expertise
- Discovered economy of scale: 5-7x cheaper than provisioning a medium-sized (1000 servers) facility
- More pervasive broadband Internet so can access remote computers efficiently
- Commoditization of HW & SW
  – Standardized software stacks

March 2013 AWS Instances & Prices

Instance	Per Hour	Ratio to Small	Compute Units	Virtual Cores	Compute Unit/ Core	Memory (GiB)	Disk (GiB)	Address
Standard Small	$0.065	1.0	1.0	1	1.00	1.7	160	32 bit
Standard Large	$0.260	4.0	4.0	2	2.00	7.5	850	64 bit
Standard Extra Large	$0.520	8.0	8.0	4	2.00	15.0	1690	64 bit
High-Memory Extra Large	$0.460	5.9	6.5	2	3.25	17.1	420	64 bit
High-Memory Double Extra Large	$0.920	11.8	13.0	4	3.25	34.2	850	64 bit
High-Memory Quadruple Extra Large	$1.840	23.5	26.0	8	3.25	68.4	1690	64 bit
High-CPU Medium	$0.165	2.0	5.0	2	2.50	1.7	350	32 bit
High-CPU Extra Large	$0.660	8.0	20.0	8	2.50	7.0	1690	64 bit

- Closest computer in WSC example is Standard Extra Large
- @ At these low rates, Amazon EC2 can make money!
  - even if used only 50% of time

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Warehouse Scale Computers

- Massive scale datacenters: 10,000 to 100,000 servers + networks to connect them together
  - Emphasize cost-efficiency
  - Attention to power: distribution and cooling
- (relatively) homogeneous hardware/software
- Offer very large applications (Internet services): search, social networking, video sharing
- Very highly available: < 1 hour down/year
  - Must cope with failures common at scale
- "…WSCs are no less worthy of the expertise of computer systems architects than any other class of machines" Barroso and Hoelzle 2009

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Design Goals of a WSC

- Unique to Warehouse-scale
  - *Ample parallelism*:
    - Batch apps: large number independent data sets with independent processing. Also known as *Data-Level Parallelism*
  - *Scale and its Opportunities/Problems*
    - Relatively small number of these make design cost expensive and difficult to amortize
    - But price breaks are possible from purchases of very large numbers of commodity servers
    - Must also prepare for high # of component failures
  - *Operational Costs Count*:
    - Cost of equipment purchases << cost of ownership

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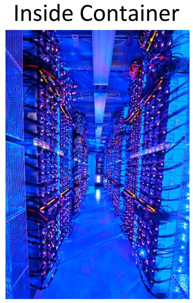
E.g., Google's Oregon WSC

Containers in WSCs

Inside WSC

Inside Container



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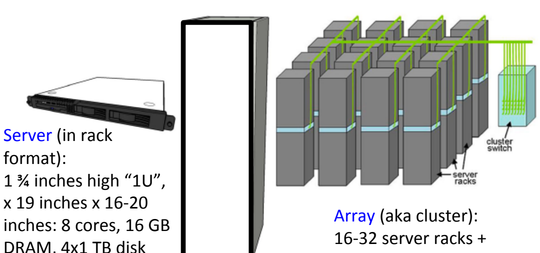
Equipment Inside a WSC



Server (in rack format):
1 ¾ inches high "1U", x 19 inches x 16-20 inches: 8 cores, 16 GB DRAM, 4x1 TB disk

7 foot Rack: 40-80 servers + Ethernet local area network (1-10 Gbps) switch in middle ("rack switch")

Array (aka cluster): 16-32 server racks + larger local area network switch ("array switch")
10X faster → cost 100X: cost f(N^2)

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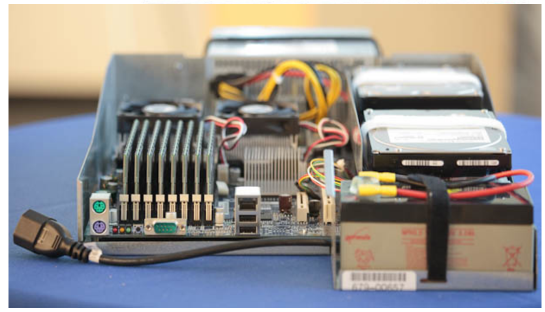
Server, Rack, Array

Google Server Internals



Defining Performance

- What does it mean to say X is faster than Y?

- 2009 Ferrari 599 GTB
  - 2 passengers, 11.1 secs for quarter mile (call it 10sec)
- 2009 Type D school bus
  - 54 passengers, quarter mile time? (let's guess 1 min)

http://www.youtube.com/watch?v=KwyCoQuhUNA

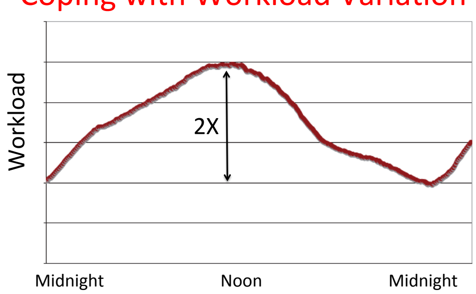
- *Response Time* or *Latency*: time between start and completion of a task (time to move vehicle ¼ mile)
- *Throughput* or *Bandwidth*: total amount of work in a given time (passenger-miles in 1 hour)

Coping with Performance in Array

Lower latency to DRAM in another server than local disk
Higher bandwidth to local disk than to DRAM in another server

	Local	Rack	Array
Racks	--	1	30
Servers	1	80	2400
Cores (Processors)	8	640	19,200
DRAM Capacity (GB)	16	1,280	38,400
Disk Capacity (TB)	4	320	9,600
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

Coping with Workload Variation

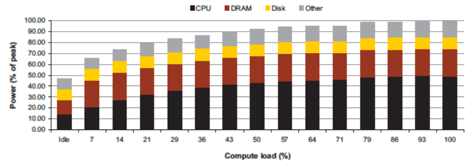


- Online service: Peak usage 2X off-peak

Impact of latency, bandwidth, failure, varying workload on WSC software?

- WSC Software must take care where it places data within an array to get good performance
- WSC Software must cope with failures gracefully
- WSC Software must scale up and down gracefully in response to varying demand
- More elaborate hierarchy of memories, failure tolerance, workload accommodation makes WSC software development more challenging than software for single computer

Power vs. Server Utilization



- Server power usage as load varies idle to 100%
- Uses ½ peak power when idle!
- Uses ⅔ peak power when 10% utilized! 90%@ 50%!
- Most servers in WSC utilized 10% to 50%
- Goal should be *Energy-Proportionality*:
  % peak load = % peak energy

Power Usage Effectiveness

- Overall WSC Energy Efficiency: amount of computational work performed divided by the total energy used in the process
- Power Usage Effectiveness (PUE):
  Total building power / IT equipment power
  - A power efficiency measure for WSC, *not* including efficiency of servers, networking gear
  - 1.0 = perfection

PUE in the Wild (2007)

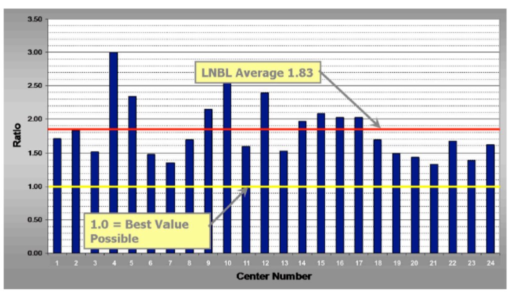


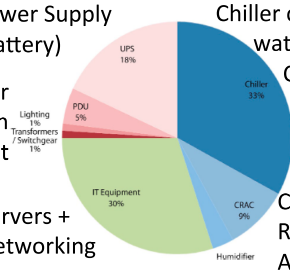
FIGURE 5.1: LBNL survey of the power usage efficiency of 24 datacenters, 2007 (Greenberg et al.)

High PUE: Where Does Power Go?

Uninterruptable Power Supply (battery)

Chiller cools warm water from Air Conditioner

Power Distribution Unit



Servers + Networking

Computer Room Air Conditioner

Google WSC A PUE: 1.24

- Careful air flow handling
  - Don't mix server hot air exhaust with cold air (separate warm aisle from cold aisle)
  - Short path to cooling so little energy spent moving cold or hot air long distances
  - Keeping servers inside containers helps control air flow
- Elevated cold aisle temperatures
  - 81°F instead of traditional 65°- 68°F
  - Found reliability OK if run servers hotter
- Use of free cooling
  - Cool warm water outside by evaporation in cooling towers
  - Locate WSC in moderate climate so not too hot or too cold
- Per-server 12-V DC UPS
  - Rather than WSC wide UPS, place single battery per server board
  - Increases WSC efficiency from 90% to 99%
- Measure vs. estimate PUE, publish PUE, and improve operation

Summary

- Parallelism is one of the Great Ideas
  - Applies at many levels of the system – from instructions to warehouse scale computers
- Post PC Era: Parallel processing, smart phone to WSC
- WSC SW must cope with failures, varying load, varying HW latency bandwidth
- WSC HW sensitive to cost, energy efficiency
- WSCs support many of the applications we have come to depend on