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

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In the news


Urs Hoelzle, Google SVP
Co-author of today's reading

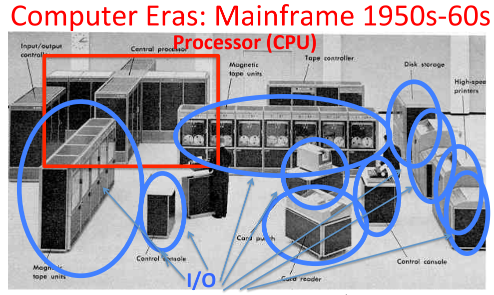
- Google disclosed Thursday that it continuously uses enough electricity to power 200,000 homes, but it says that in doing so, it also makes the planet greener.
- Search cost per day (per person) same as running a 60-watt bulb for 3 hours

http://www.nytimes.com/2011/09/09/technology/google-details-and-defends-its-use-of-electricity.html

Review

- Great Ideas in Computer Architecture
  1. ✓ Layers of Representation/Interpretation
  2. Moore's Law
  3. ✓ Principle of Locality/Memory Hierarchy
  4. Parallelism
  5. ✓ Performance Measurement and Improvement
  6. Dependability via Redundancy

Computer Eras: Mainframe 1950s-60s



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

Minicomputer Eras: 1970s

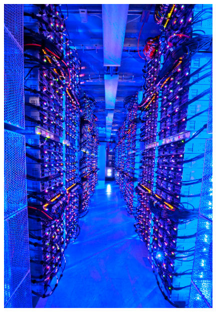
Using integrated circuits, Digital, HP… build $10k computers for labs, universities => C, UNIX OS

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, Android OS



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

January 2011 AWS Instances & Prices

Instance	Per Hour	Ratio to Small	Compute Units	Virtual Cores	Compute Unit/ Core	Memory (GB)	Disk (GB)	Address
Standard Small	$0.085	1.0	1.0	1	1.00	1.7	160	32 bit
Standard Large	$0.340	4.0	4.0	2	2.00	7.5	850	64 bit
Standard Extra Large	$0.680	8.0	8.0	4	2.00	15.0	1690	64 bit
High-Memory Extra Large	$0.500	5.9	6.5	2	3.25	17.1	420	64 bit
High-Memory Double Extra Large	$1.000	11.8	13.0	4	3.25	34.2	850	64 bit
High-Memory Quadruple Extra Large	$2.000	23.5	26.0	8	3.25	68.4	1690	64 bit
High-CPU Medium	$0.170	2.0	5.0	2	2.50	1.7	350	32 bit
High-CPU Extra Large	$0.680	8.0	20.0	8	2.50	7.0	1690	64 bit
Cluster Quadruple Extra Large	$1.600	18.8	33.5	8	4.20	23.0	1690	64 bit

- Closest computer in WSC example is Standard Extra Large
- @$0.11/hr, Amazon EC2 can make money!
  - even if used only 50% of time

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

Design Goals of a WSC

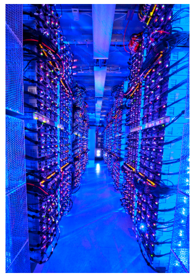
- Unique to Warehouse-scale
  - *Ample parallelism*:
    - Batch apps: large number independent data sets with independent processing. Also known as *Data-Level Parallelism*
  - *Scale and its Opportunities/Problems*
    - Relatively small number of these make design cost expensive and difficult to amortize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

E.g., Google's Oregon WSC

Containers in WSCs

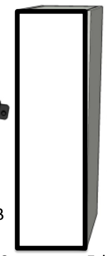
Inside WSC

Inside Container

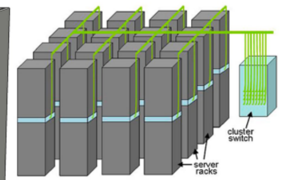


Equipment Inside a WSC

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



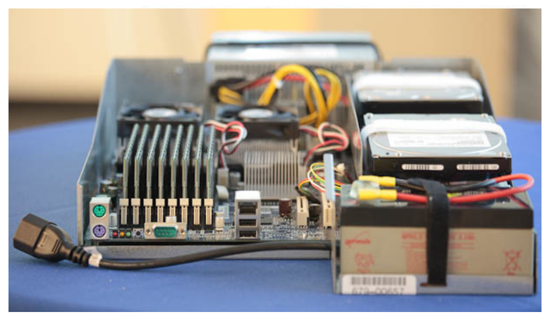
7 foot Rack: 40-80 servers + Ethernet local area network (1-10 Gbps) switch in middle ("rack switch")



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

Server, Rack, Array

Google Server Internals

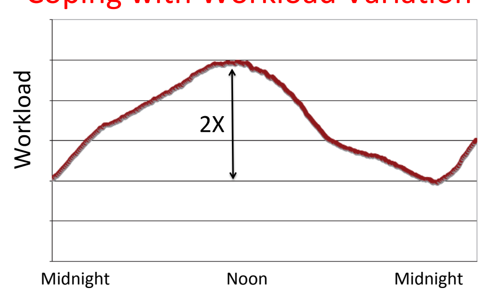


Coping with Performance in Array

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 (GB)	4,000	320,000	9,600,000
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

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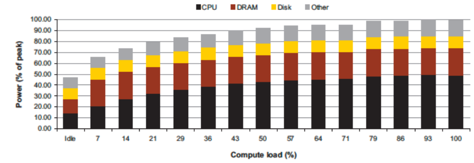
Power vs. Server Utilization



- 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

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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
  - An power efficiency measure for WSC, *not* including efficiency of servers, networking gear
  - 1.0 = perfection

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PUE in the Wild (2007)

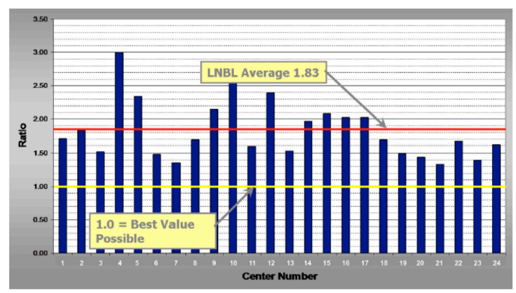

FIGURE 5.1: LBNL survey of the power usage efficiency of 24 datacenters, 2007 (Greenberg et al.)

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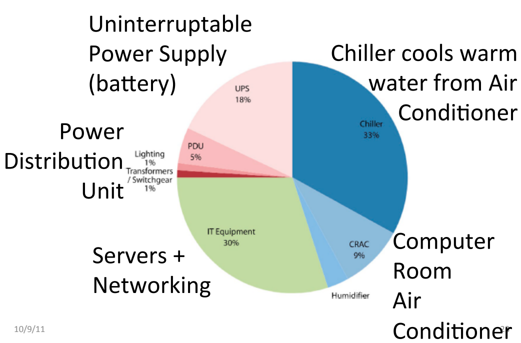
High PUE: Where Does Power Go?



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Google WSC A PUE: 1.24

1. Careful air flow handling
2. Elevated cold aisle temperatures
3. Use of free cooling
4. Per-server 12-V DC UPS
5. Measure vs. estimate PUE, publish PUE, and improve operation

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Google WSC A PUE: 1.24

1. 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

Google WSC A PUE: 1.24

2. Elevated cold aisle temperatures
- 81°F instead of traditional 65°- 68°F
- Found reliability OK if run servers hotter
3. 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

Google WSC A PUE: 1.24

4. Per-server 12-V DC UPS
- Rather than WSC wide UPS, place single battery per server board
- Increases WSC efficiency from 90% to 99%
5. 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