

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

Instructor:

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In the news

- Google disclosed 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>

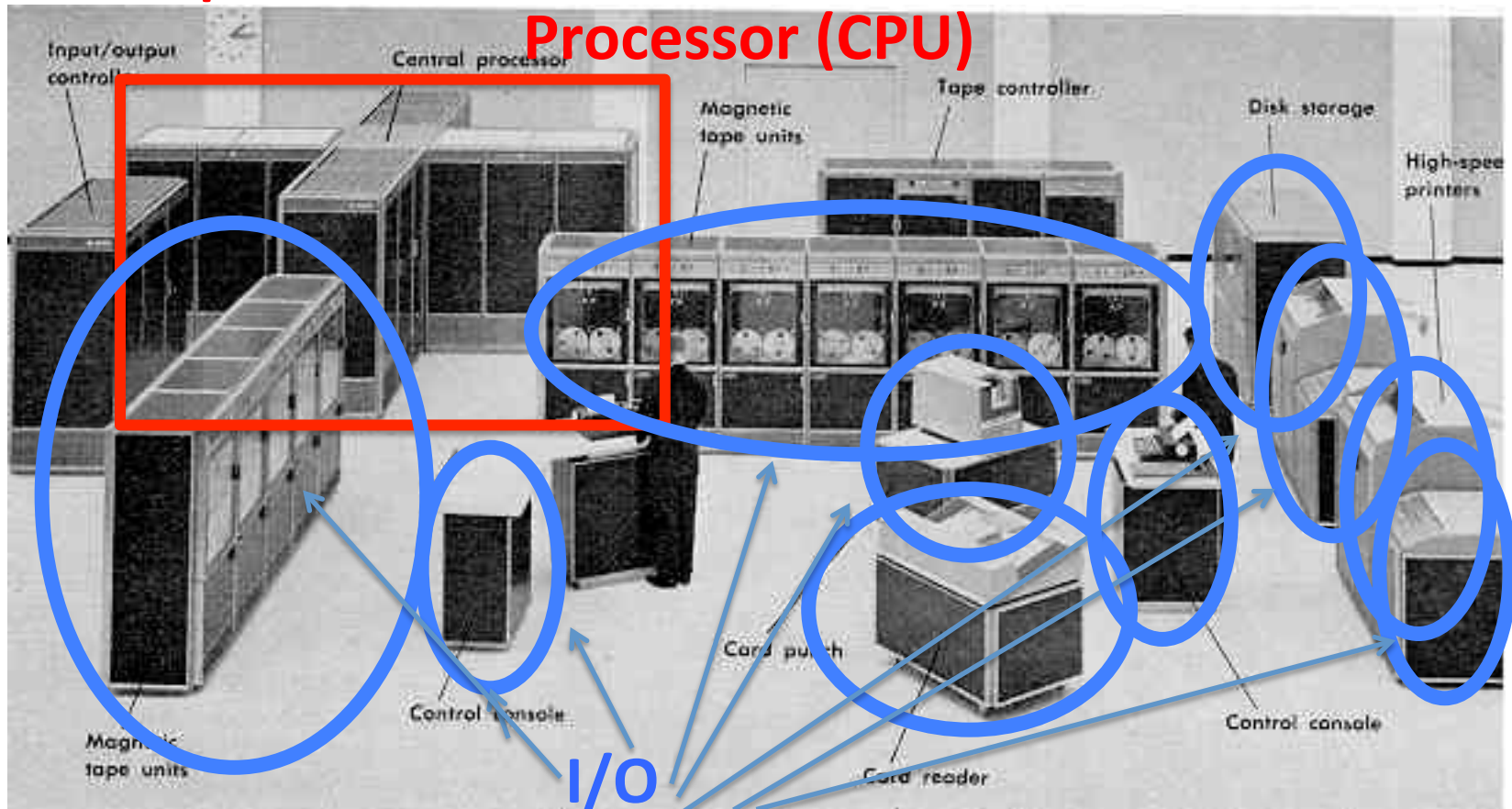


Urs Hoelzle, Google SVP
Co-author of today's reading

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



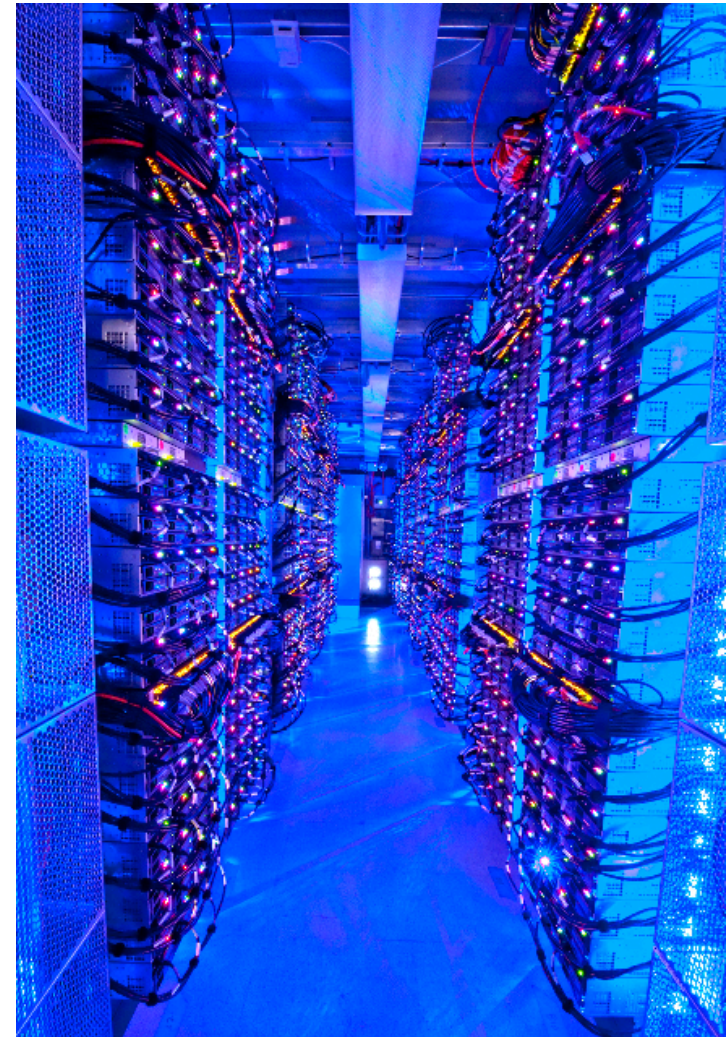
Using microprocessors, Apple, IBM, ... build \$1k computer for 1 person → Basic, Java, Windows OS

PostPC Era: Late 2000s - ??



Personal Mobile Devices (PMD):
Relying on wireless networking, Apple, Nokia, ... build \$500 smartphone and tablet computers for individuals
→ Objective C, 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 2014 AWS Instances & Prices

aws.amazon.com/ec2/pricing

Instance	Per Hour	Ratio to Small	Compute Units	Virtual Cores	Compute Unit/Core	Memory (GiB)	Disk (GiB)
Standard Small	\$0.065	1.0	1.0	1	1.00	1.7	160
Standard Large	\$0.260	4.0	4.0	2	2.00	7.5	840
Standard Extra Large	\$0.520	8.0	8.0	4	2.00	15.0	1680
High-Memory Extra Large	\$0.460	5.9	6.5	2	3.25	17.1	420
High-Memory Double Extra Large	\$0.920	11.8	13.0	4	3.25	34.2	850
High-Memory Quadruple Extra Large	\$1.840	23.5	26.0	8	3.25	68.4	1680
High-CPU Medium	\$0.165	2.0	5.0	2	2.50	1.7	350
High-CPU Extra Large	\$0.660	8.0	20.0	8	2.50	7.0	1680

- 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

Administrivia

- **Midterm will be in 9 days...**
 - Details of how to divide yourselves up into 3 rooms will follow
- **Predicted grade on Midterm?**
 - A) well above avg
 - B) slightly above avg
 - C) avg
 - D) slightly below avg
 - E) well below avg

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 # of component failures
 - *Operational Costs Count:*
 - Cost of equipment purchases \ll cost of ownership

E.g., Google's Oregon WSC



Containers in WSCs

Inside WSC



Inside Container

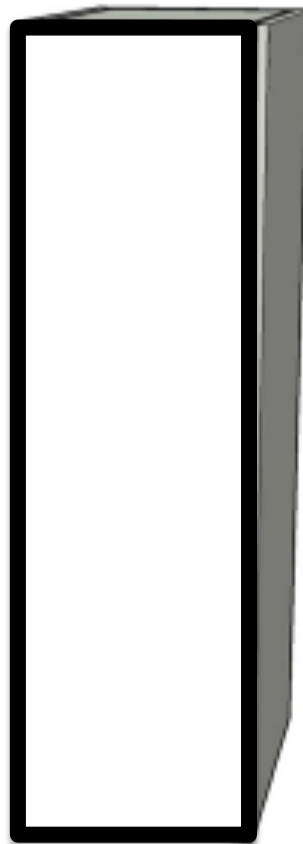


Equipment Inside a WSC

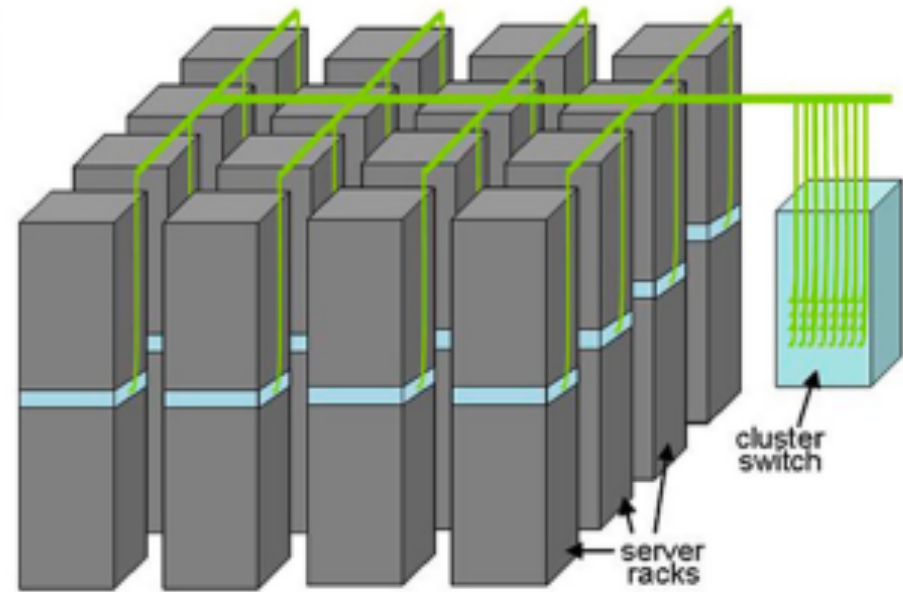


Server (in rack format):

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



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 $\frac{1}{4}$ mile)
- *Throughput* or *Bandwidth*: total amount of work in a given time (passenger-miles in 1 hour)

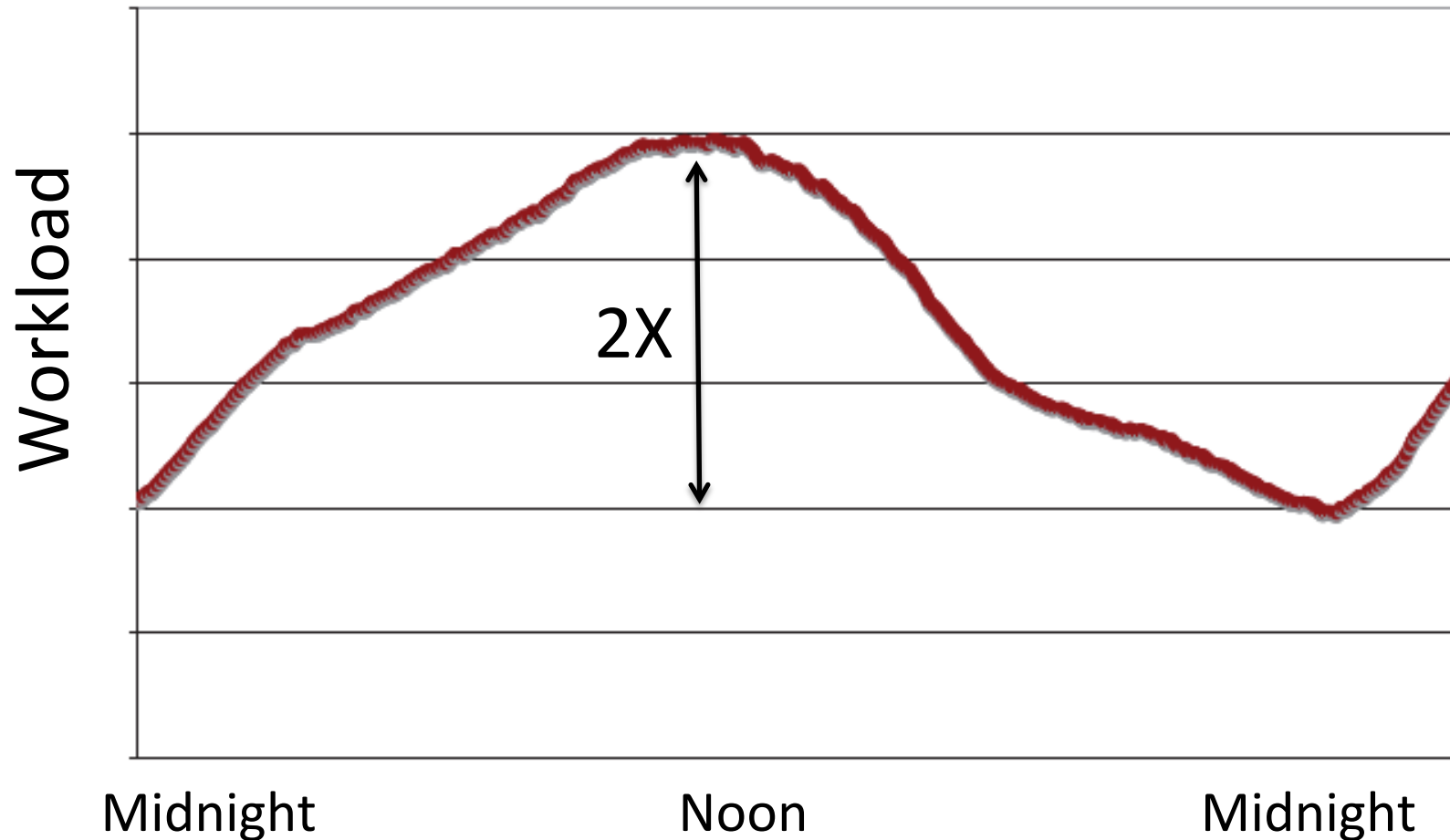
Coping with Performance in Array

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

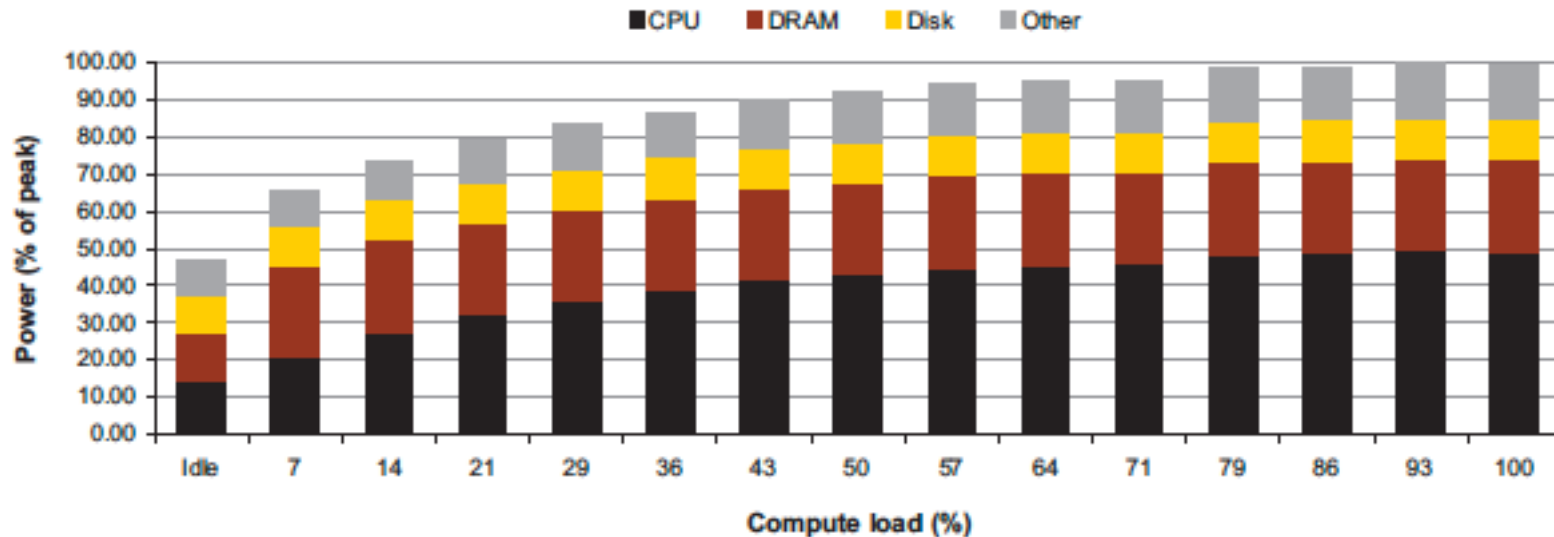


- Online service: Peak usage 2X off-peak

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 $\frac{1}{2}$ peak power when idle!
- Uses $\frac{2}{3}$ 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)

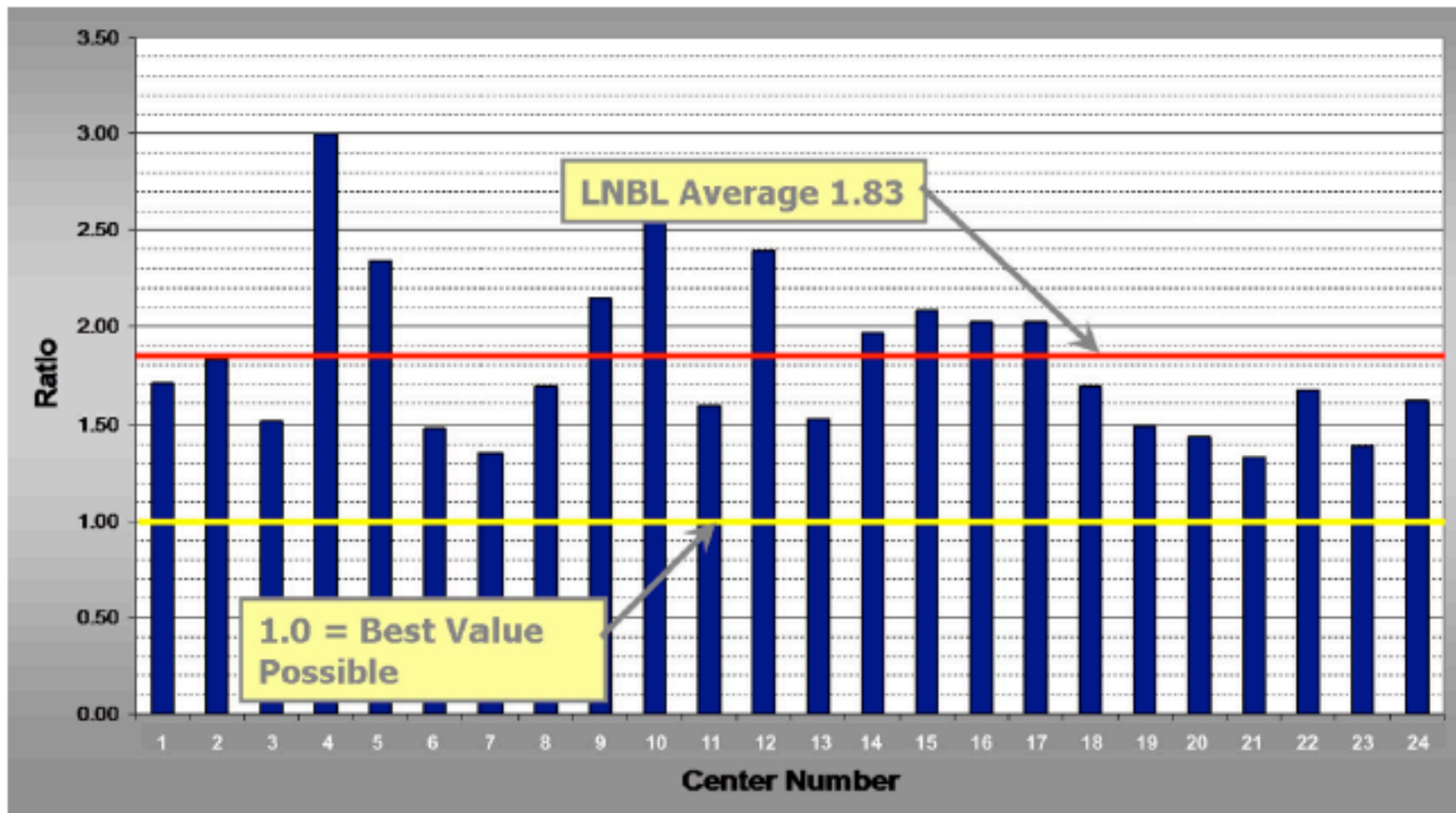
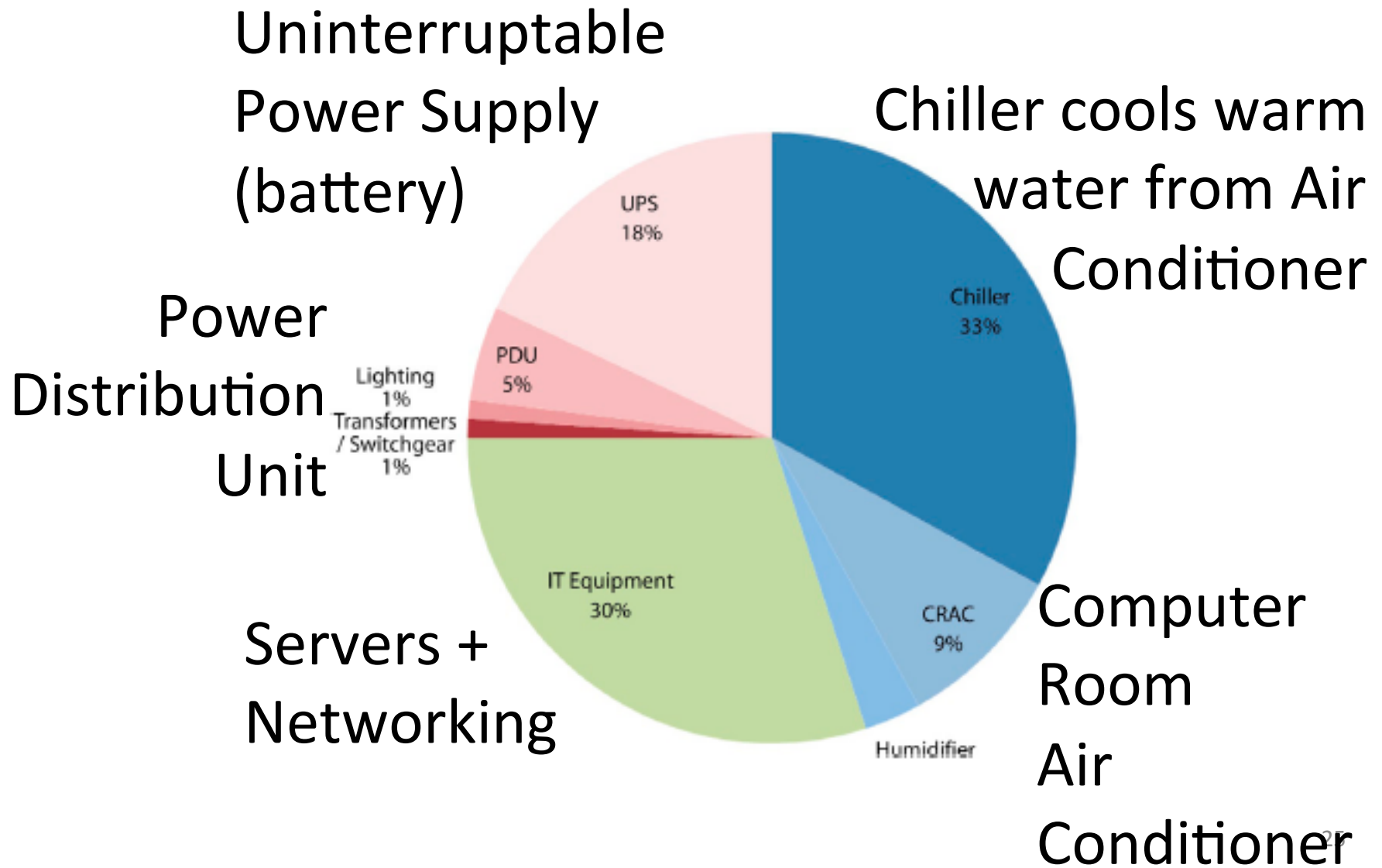


FIGURE 5.1: LBNL survey of the power usage efficiency of 24 datacenters, 2007 (Greenberg et al.)

High PUE: Where Does Power Go?



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