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YEAR ANNIVERSARY

Energy Efficiency and Cloud Computing

David Patterson, UC Berkeley
Reliable Adaptive Distributed Systems Lab

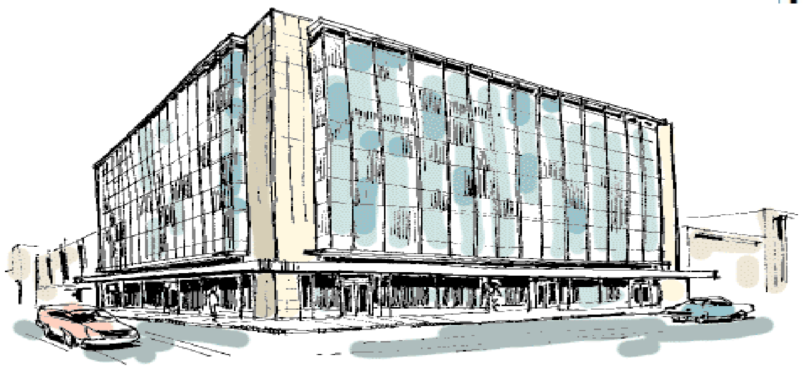
Image: John Curley http://www.flickr.com/photos/jay_que/1834540/

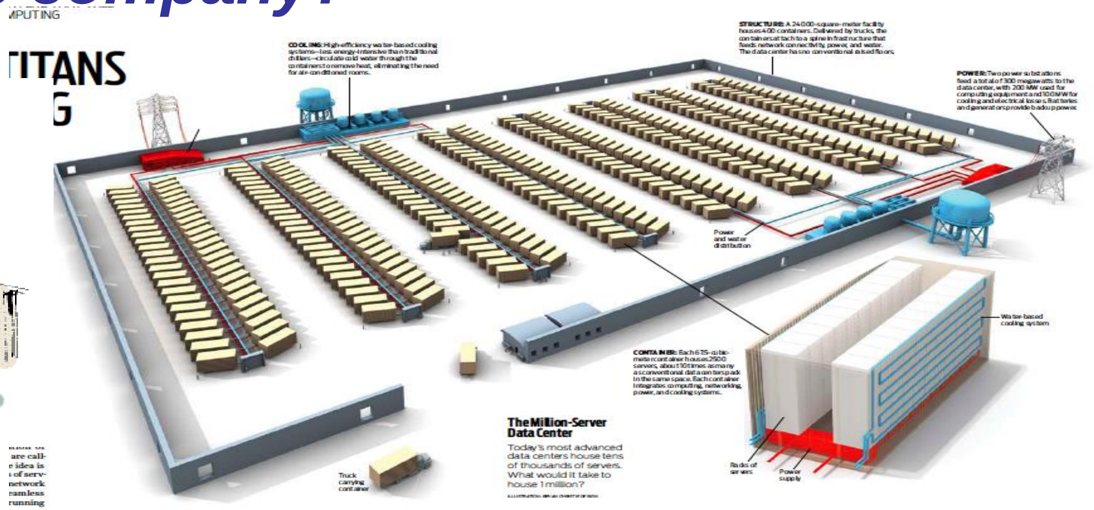
Outline

- Energy Proportionality vs. Reality
- Turing Off Servers vs. Ensuring Full ROI
- Turning Off and Reliability
- Defining Cloud Computing
- RAD Lab Vision
- Datacenter OS and Energy Efficiency
- Datacenter Store and Energy Efficiency

Datacenter Is New "Server"

- *"Program"* == Web search, email, map/GIS, …
- *"Computer"* == 1000's computers, storage, network
- Warehouse-sized facilities and workloads
- New datacenter ideas (2007-2008): truck container (Sun), floating (Google), datacenter-in-a-tent (Microsoft)
- ***How to enable innovation in new services without first building & capitalizing a large company?***





photos: Sun Microsystems and datacenterknowledge.com

Tie to Cloud Computing

- Cloud Computing saves energy?
- Don’t buy machines for local use that are often idle
- Better to ship bits as photons vs.
  ship electrons over transmission lines to spin disks locally
  - Clouds use nearby (hydroelectric) power
  - Leverage economies of scale of cooling, power distribution

Tie to Cloud Computing

- Techniques developed to stop using idle servers to save money in Cloud Computing can also be used to save power
  - Up to Cloud Computing Provider to decide what to do with idle resources

- New Requirement: Scale DOWN and up
  - Who decides when to scale down in a datacenter?
  - How can Datacenter storage systems improve energy?

Energy Proportional Computing

"The Case for Energy-Proportional Computing,"
Luiz André Barroso,
Urs Hölzle,
IEEE Computer
December 2007

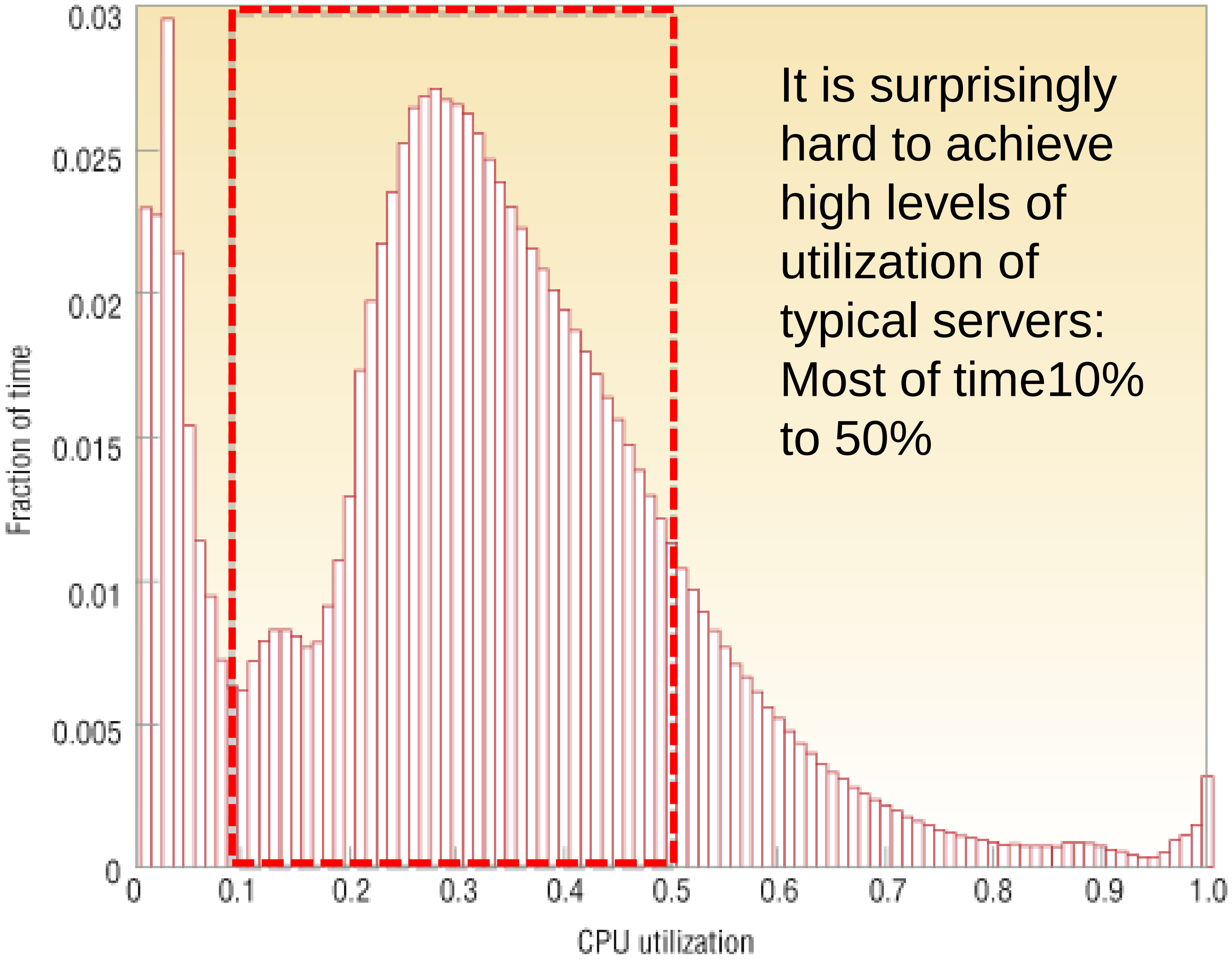


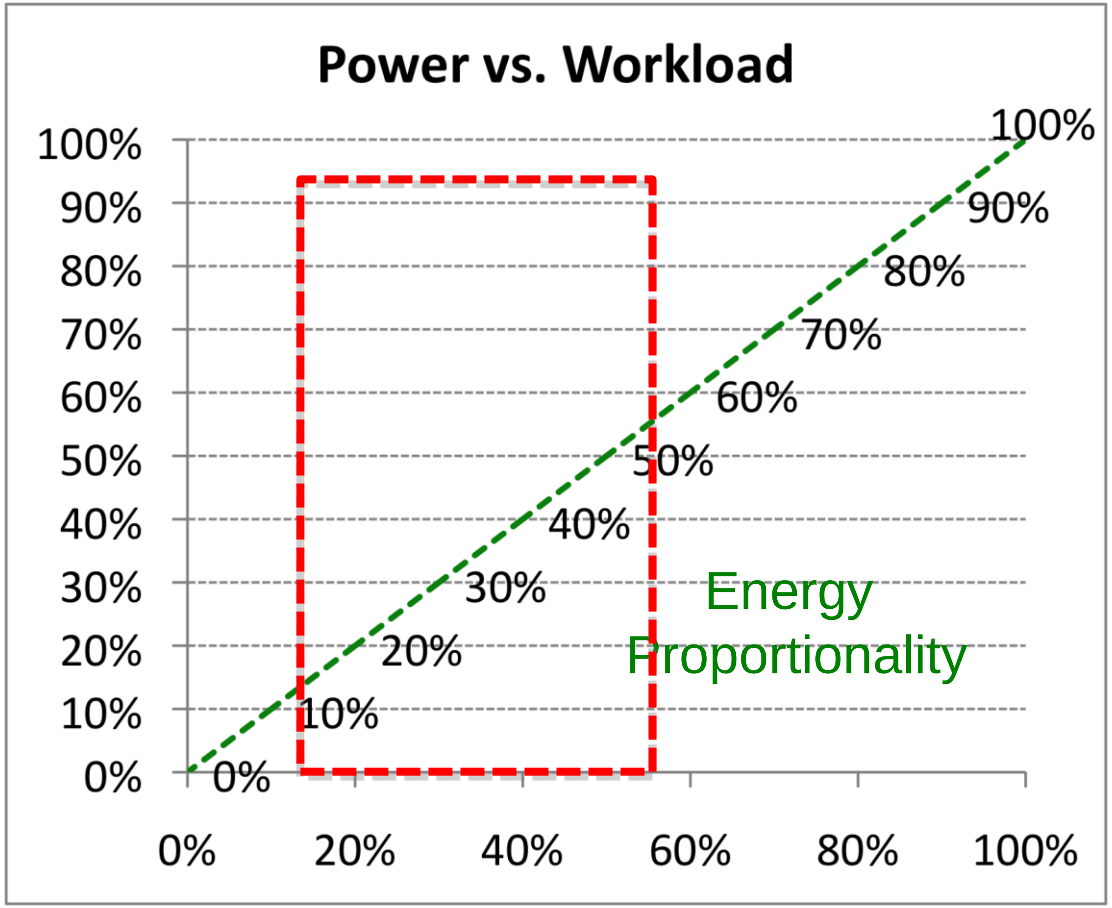
Figure 1. Average CPU utilization of more than 5,000 servers during a six-month period. Servers are rarely completely idle and seldom operate near their maximum utilization, instead operating most of the time at between 10 and 50 percent of their maximum

Energy Proportionality?

- How close to “Energy Proportionality”?

  10% of peak utilization =>
  10% of peak power?

- “The Case for Energy-Proportional Computing,” Barroso and Hölzle, *IEEE Computer*, Dec. 2007



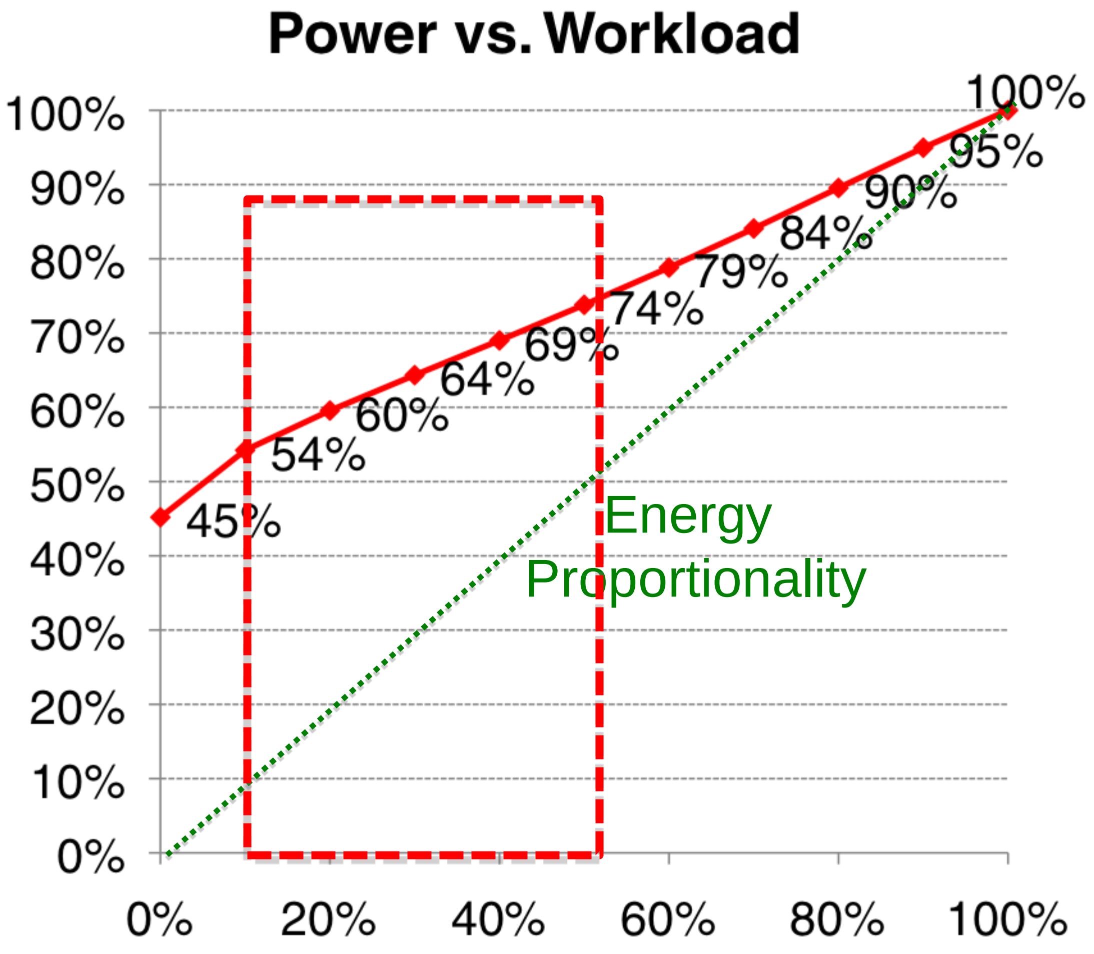
Benchmarking Power

- SPECPower benchmark December 2007
  - Run ~SPECJBB Java benchmark (requests/s)
  - Vary requests/s in 10% increments:100% to 0%
  - Single number sum of requests / sum of power
- 1.5 years for companies to compare results, innovate, and tune hardware and software
  - Publish results every quarter: > 100 results
  - Average result improved 3X in 1.5 years
  - Benchmarketing or real progress?

SPECPower Results

- SPECpower 2008:
  - Average of 23 results from 2Q 2009
- 50% utilization
  => 74% Peak Power
- 10% utilization
  => 54% Peak Power
- Save power by consolidate and turn off

  5 computers @ 10% = 270%
  1 computer @ 50% = 74%
- Save 2/3 of power (during slower periods)



But Powering off Hurts Hardware Reliability?

- Theory: if turn on and off infrequently, could IMPROVE reliability!
- Which is better: hot and idle vs. turned off and no wear but cycle temperature?
- Disks: MTTF measured in powered on hours
  - 50,000 start/stops guaranteed (~1/hour over lifetime)
  - More years if fewer powered on hours per year?
- Integrated Circuits: there is small effect of being powered on vs. temperature cycle of off and on
  - One paper says improve lifetime by 1.4X if turn off 50% with infrequent power cycles (~1/hour over lifetime)

Small Experiment

- DETER Project at ISI and Berkeley
- 64 Nodes at ISI: Turn off when idle one hour
- 64 Identical nodes at Berkeley: Always on
- Ran for 18 months (so far)
- Failures
  - ISI ≤ 3 failures
  - Berkeley 5 failures
    (but more temperature variation)
- Didn’t hurt reliability (for small experiment)

Tradeoff: Turning Off vs. Ensuring Full ROI

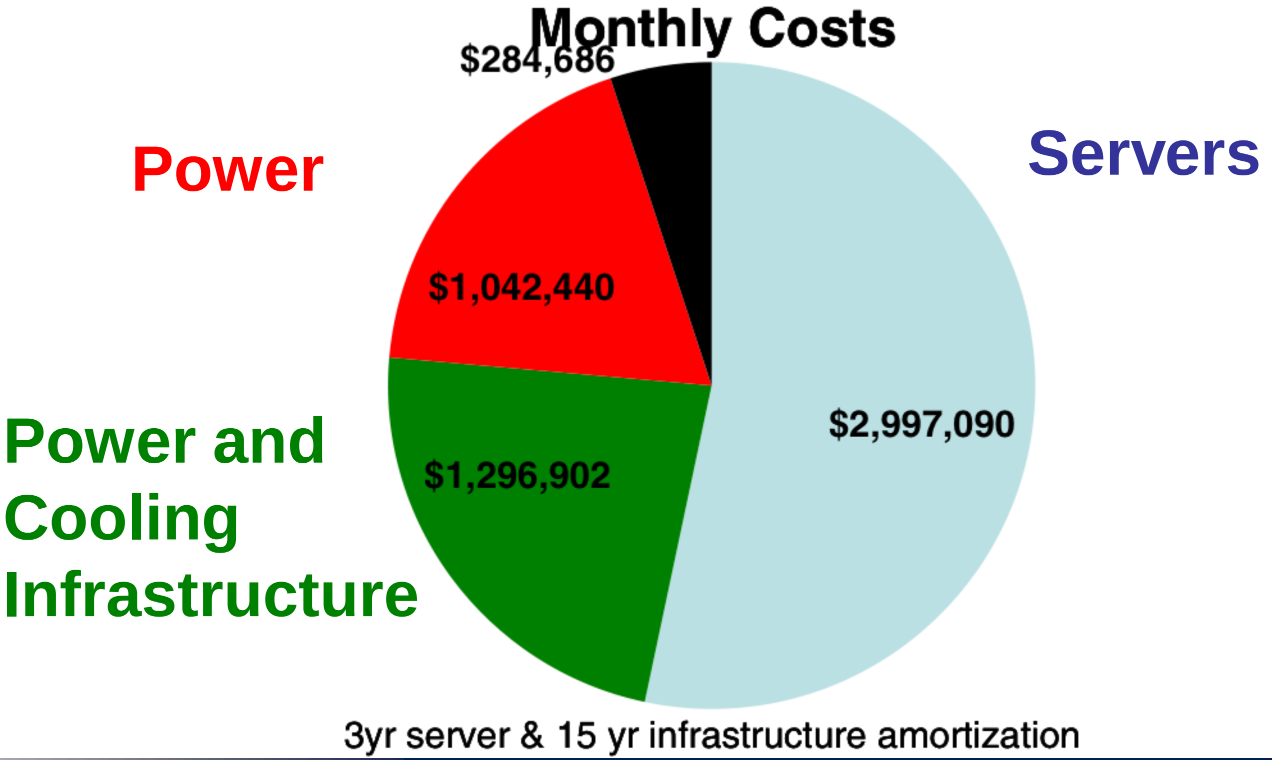
- Given diurnal patterns and high power even when idle, turn off computers and consolidate during traditional slow periods
  - Problem: Existing monitoring software assumes broken if server doesn't respond: change monitoring software or ???
- Given huge capital investment in power and cooling, to maximize ROI, increase workload of other valuable tasks during traditional slow periods

Case for Getting Value

- Cost of Internet-Scale Datacenter
  - James Hamilton, perspectives.mvdirona.com
  - Keynote, Int'l Symp. Computer Arch., 6/23/09
- Largest costs is server and storage H/W
  - Followed by cooling, power distribution, power
  - People costs <10%(>1000+:1 server:admin)
  - Services interests work-done-per-$ (or joule)
  - Networking $ varies: very low to dominant, depending upon service

Example Monthly Costs

- 50,000 servers @ $2k/server
- 15MW facility @ $200M, $0.07 per KWH
- Power$ 1/3 Servers$, <Power, cooling infra.

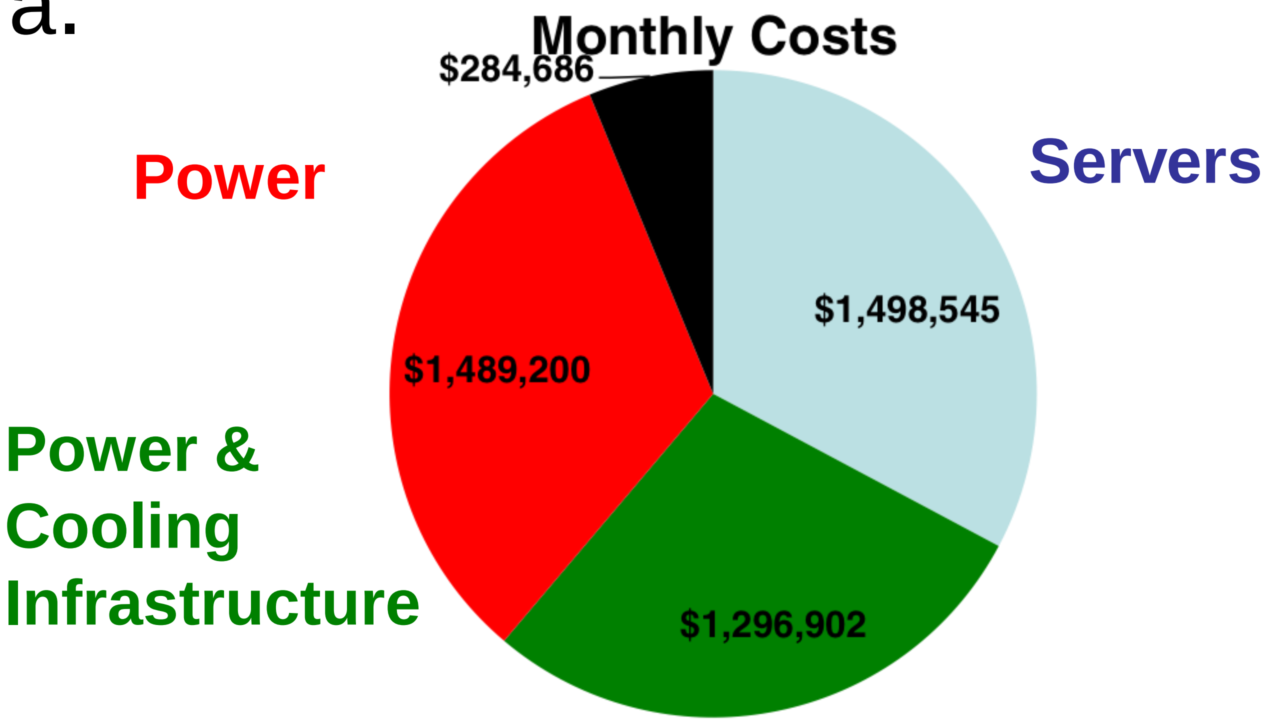


Given Costs, Why Turn Off?

- Only saving part of 20% of monthly costs
- Better to run batch jobs (MapReduce) overnight to add value to company
  - (Or rent idle machines to others)
- How much value do you really get from batch jobs?
- Electric utility mandated reductions on crisis days (or pay more all year)?
- Still true in future as Hardware costs fall and Power costs rise?

Example Monthly Costs

- 50,000 servers @ $1k/server
- 15MW facility @ $200M, $0.10 per KWH
- Power$ = Servers $, >Power, cooling infra.



3yr server & 15 yr infrastructure amortization

DatacenterS Reduce Cost?

- Rather than elaborate, expensive batteries and diesel generators, rely on other datacenters to take over on failure
- Reduces cooling and power infrastructure costs per datacenter, making power a larger fraction of monthly costs

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- But…

- What is cloud computing, exactly?

"It's nothing (new)"

"...we've redefined Cloud Computing to include everything that we already do... I don't understand what we would do differently ... other than change the wording of some of our ads."

Larry Ellison, CEO, Oracle (Wall Street Journal, Sept. 26, 2008)

Above the Clouds: A Berkeley View of Cloud Computing

abovetheclouds.cs.berkeley.edu

- 2/09 White paper by RAD Lab PI's and students
  - Clarify terminology around Cloud Computing
  - Quantify comparison with conventional computing
  - Identify Cloud Computing challenges and opportunities
- Why can we offer new perspective?
  - Strong engagement with industry
  - Users of cloud computing in research and teaching last 18 months
- Goal: stimulate discussion on *what's really new*
  - Without resorting to weather analogies *ad nauseam*

Utility Computing Arrives

- Amazon Elastic Compute Cloud (EC2)
- "Compute unit" rental: $0.10-0.80/hr.
  - 1 CU ≈ 1.0-1.2 GHz 2007 AMD Opteron/Xeon core

"Instances"	Platform	Cores	Memory	Disk
Small - $0.10 / hr	32-bit	1	1.7 GB	160 GB
Large - $0.40 / hr	64-bit	4	7.5 GB	850 GB – 2 spindles
XLarge - $0.80 / hr	64-bit	8	15.0 GB	1690 GB – 3 spindles

- No up-front cost, no contract, no minimum
- Billing rounded to nearest hour; pay-as-you-go storage also available
- A new paradigm (!) for deploying services?

What Is it? What's New?

- Old idea: Software as a Service (SaaS)
  - Basic idea predates MULTICS
  - Software hosted in the infrastructure vs. installed on local servers or desktops; dumb (but brawny) terminals
  - Recently: "[HW, Infrastructure, Platform] as a service" ?? HaaS, IaaS, PaaS poorly defined, so we avoid
- **New:** pay-as-you-go *utility computing*
  - Illusion of infinite resources on demand
  - Fine-grained billing: release == don't pay
  - Earlier examples: Sun, Intel Computing Services—longer commitment, more $$$/hour, no storage
  - *Public (utility)* vs. *private* clouds

Why Now (Not Then)?

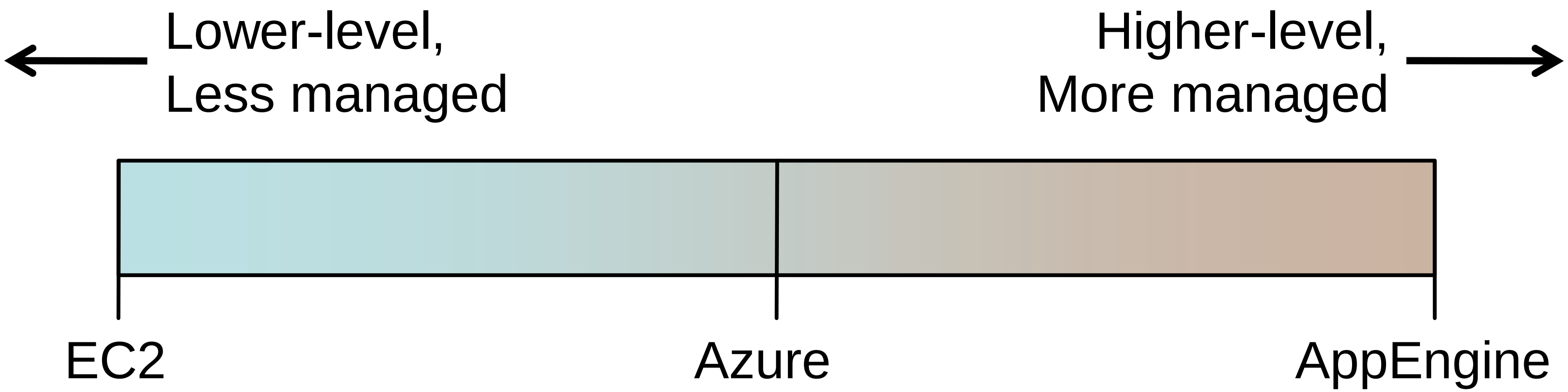
- "The Web Space Race": Build-out of extremely large datacenters (10,000s of ***commodity*** PCs)
  - Build-out driven by growth in demand (more users)

    => Infrastructure software: e.g., Google File System

    => Operational expertise: failover, DDoS, firewalls...
  - Discovered economy of scale: 5-7x cheaper than provisioning a medium-sized (100s machines) facility
- More pervasive broadband Internet
- Commoditization of HW & SW
  - Fast Virtualization
  - Standardized software stacks

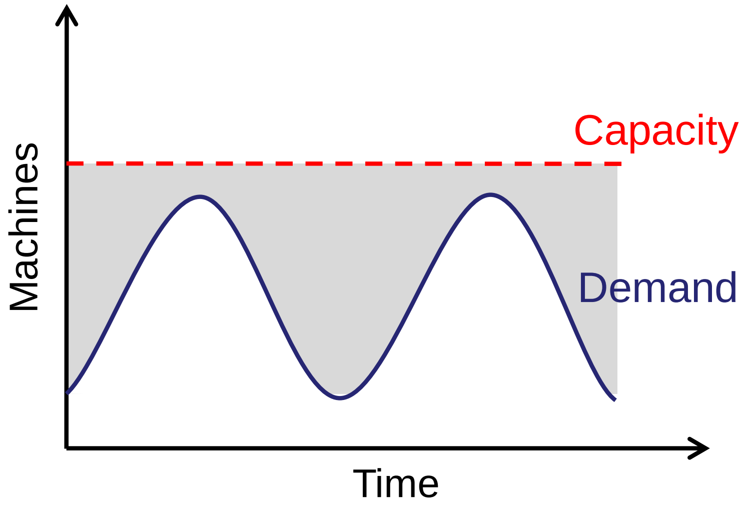
Classifying Clouds

- Instruction Set VM (Amazon EC2, 3Tera)
- Managed runtime VM (Microsoft Azure)
- Framework VM (Google AppEngine)
- *Tradeoff: flexibility/portability vs. "built in" functionality*

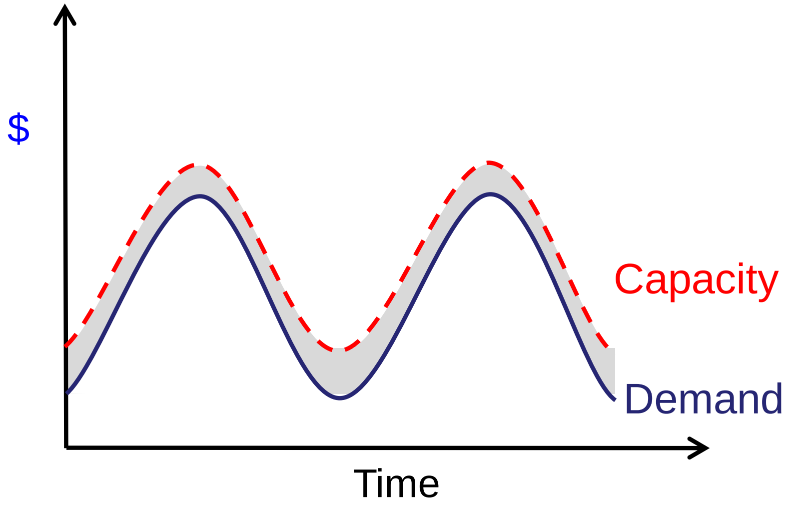


Cloud Economics 101

- Cloud Computing User: Static provisioning for peak - wasteful, but necessary for SLA



"Statically provisioned" data center

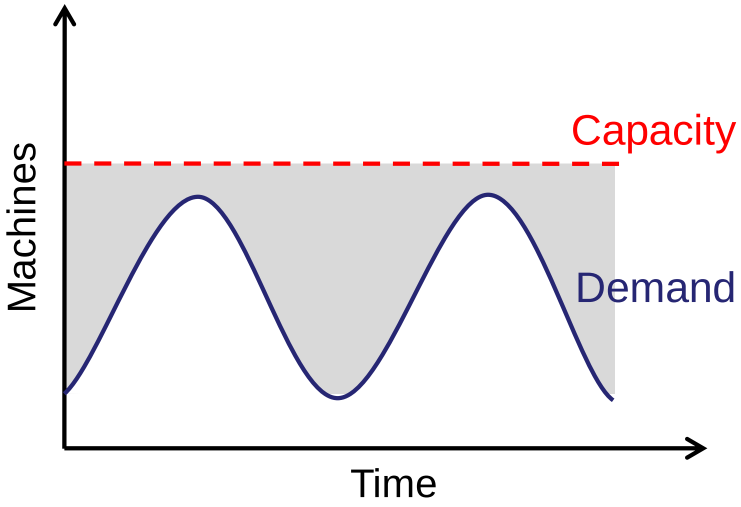


"Virtual" data center in the cloud

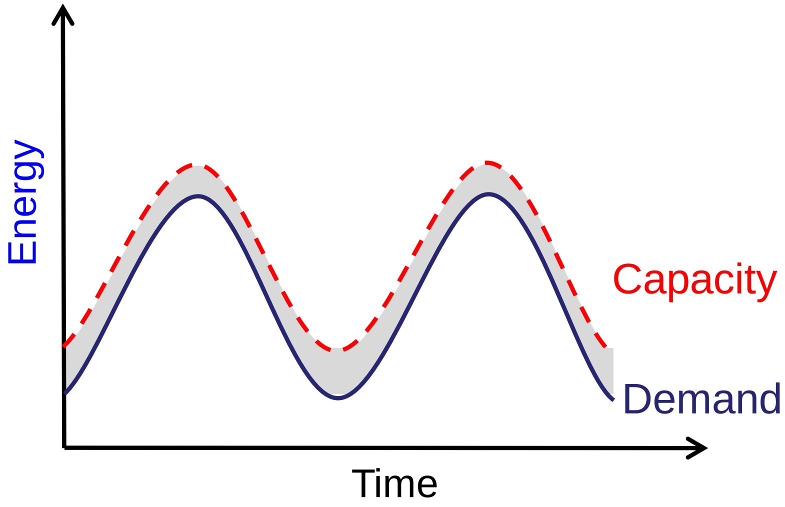
Unused resources

Cloud Economics 101

- Cloud Computing Provider: Could save energy



"Statically provisioned" data center

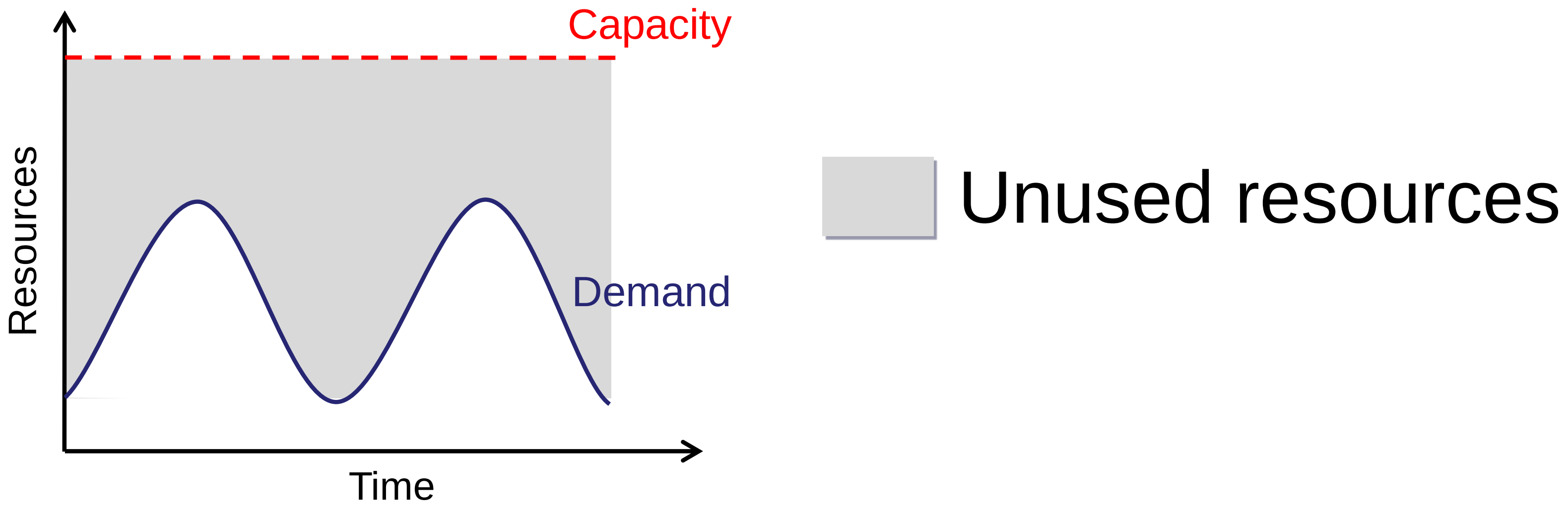


Real data center in the cloud

Unused resources

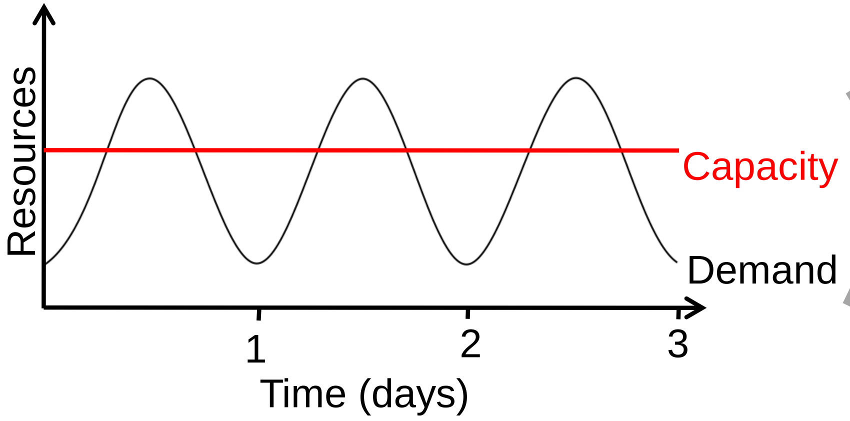
Risk of Under-utilization

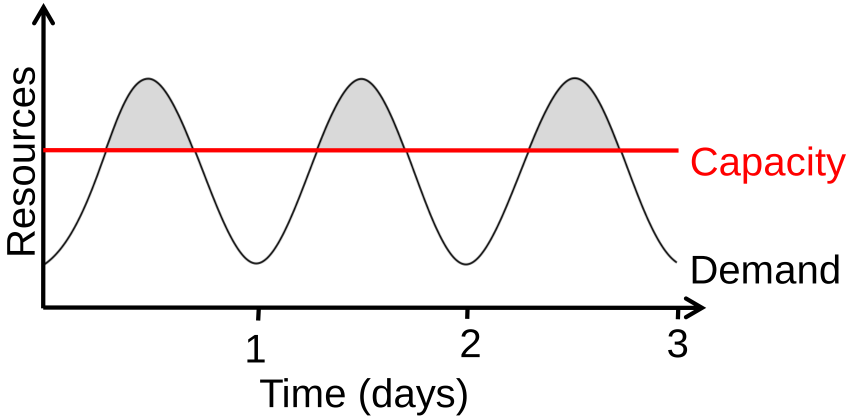
- Under-utilization results if “peak” predictions are too optimistic



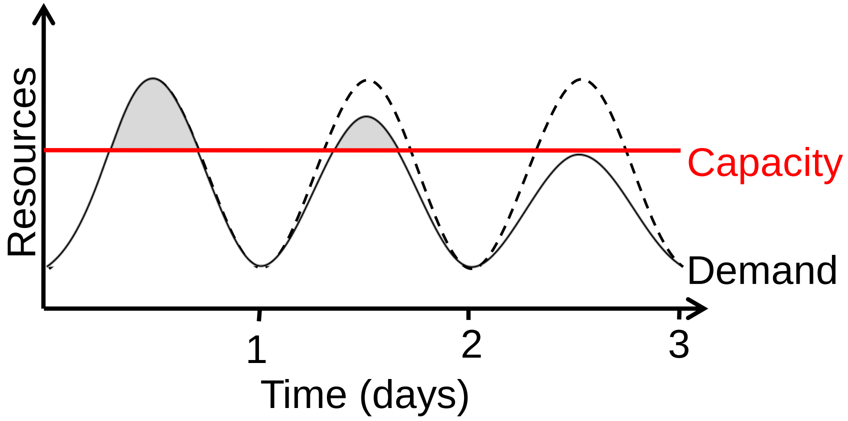
Static data center

Risks of Under Provisioning





Lost revenue



Lost users

New Scenarios Enabled by "Risk Transfer" to Cloud

- Not (just) Capital Expense vs. Operation Expense!
- "Cost associativity": 1,000 CPUs for 1 hour same price as 1 CPUs for 1,000 hours (@$0.10/hour)
  - Washington Post converted Hillary Clinton's travel documents to post on WWW **<1 day** after released
  - RAD Lab graduate students demonstrate improved Hadoop (batch job) scheduler—on 1,000 servers
- *Major enabler* for SaaS startups
  - *Animoto* traffic doubled every 12 hours for 3 days when released as Facebook plug-in
  - Scaled from 50 to >3500 servers
  - ***...then scaled back down***

Hybrid / Surge Computing

- Keep a local "private cloud" running same protocols as public cloud
- When need more, "surge" onto public cloud, and scale back when need fulfilled
- Saves energy (and capital expenditures) by not buying and deploying power distribution, cooling, machines that are mostly idle

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RAD Lab 5-year Mission

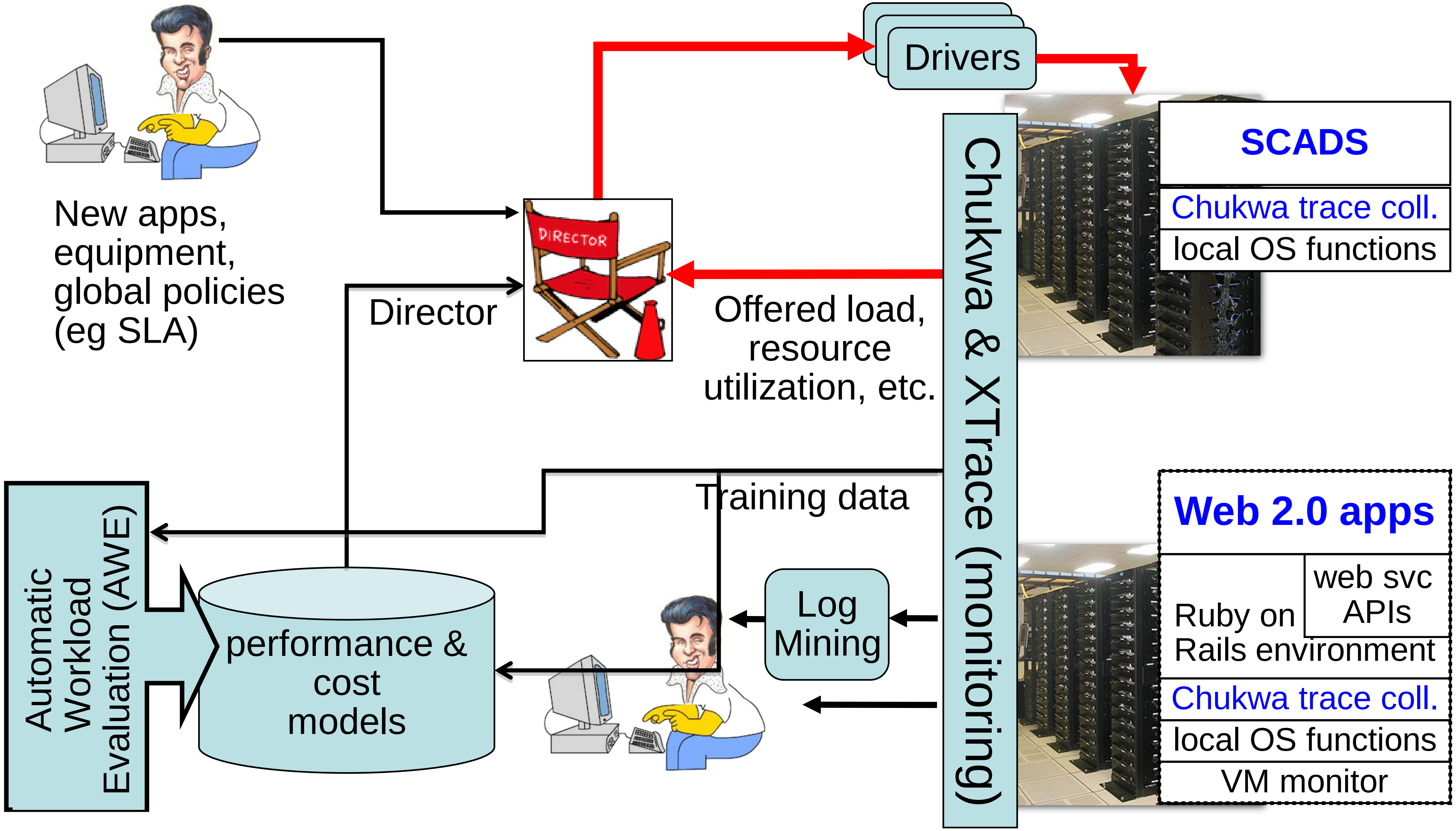
*Enable **1 person** to develop, deploy, operate next -generation Internet application*

- Key enabling technology: statistical machine learning
  - debugging, power management, performance prediction, …
- Highly interdisciplinary faculty and students
  - PI’s: Fox/Katz/Patterson (systems/networks), Jordan (machine learning), Stoica (networks & P2P), Joseph (systems/security), Franklin (databases)
  - 2 postdocs, ~30 PhD students, ~5 undergrads

Successes

- Predict performance of complex software system when demand is scaled up
- Automatically add/drop servers to fit demand, without violating Service Level Agreement (SLA)
- Distill millions of lines of log messages into an operator-friendly “decision tree” that pinpoints “unusual” incidents/conditions
- **Recurring theme**: cutting-edge Statistical Machine Learning (SML) works where simpler methods have failed

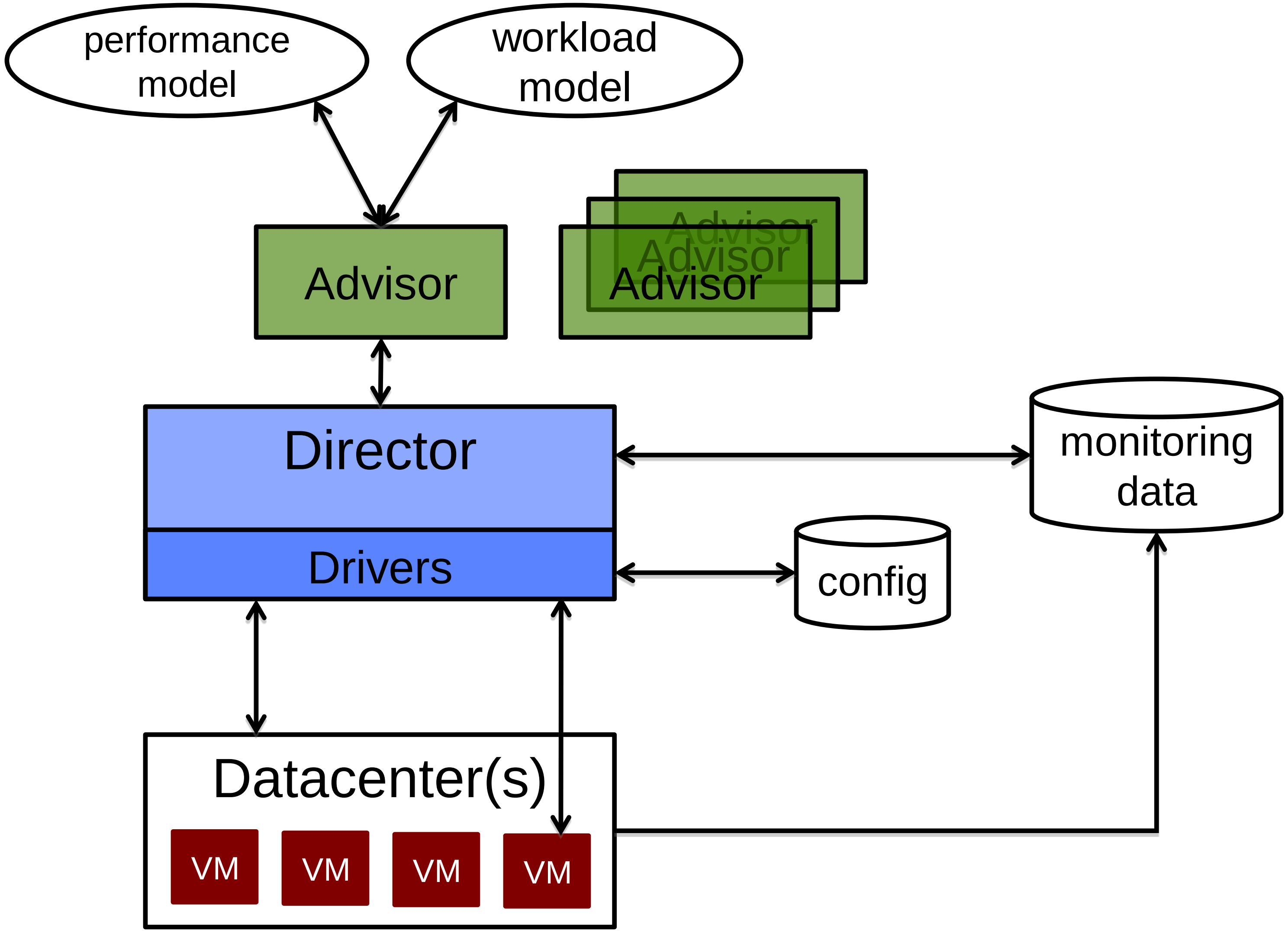
RAD Lab Prototype: System Architecture



Automatic Management of a Datacenter

- As datacenters grow, need to automatically manage the applications and resources
  - examples:
    - deploy applications
    - change configuration, add/remove virtual machines
    - recover from failures
- Director:
  - mechanism for executing datacenter actions
- Advisors:
  - intelligence behind datacenter management

Director Framework



Director Framework

- Director
  - issues low-level/physical actions to the DC/VMs
    - request a VM, start/stop a service
  - manage configuration of the datacenter
    - list of applications, VMs, …
- Advisors
  - update performance, utilization metrics
  - use workload, performance models
  - issue logical actions to the Director
    - start an app, add 2 app servers

What About Storage?

- Easy to imagine how to scale up and scale down computation
- Database don’t scale down, usually run into limits when scaling up
- What would it mean to have datacenter storage that could scale up and down as well so as to save energy for storage in idle times?

SCADS: Scalable, Consistency-Adjustable Data Storage

- Goal: Provide web application developers with *scale independence* as site grows
  - No changes to application
  - Cost / User doesn't increase as users increase
  - Latency / Request doesn't increase as users
- Key Innovations
  - Performance safe query language
  - Declarative performance/consistency tradeoffs
  - Automatic scale up and down using machine learning (Director/Advisor)

Beyond 2/3 Energy Conservation Upper Bound?

- What if heterogeneous servers in data center?
  - Performance nodes: 1U to 2U servers, 2-4 sockets, 16 GB DRAM, 4 disks
  - Storage nodes: 4U to 8U servers, 2-4 sockets, 32 GB - 64 GB DRAM, 48 disks (e.g., Sun Thumper)
- 1 replica on Storage node,
  2 or more replicas on Performance nodes
- If 10 Watts / disk, 250W per node (no disks):
  1*250 + 48*10 = 730 Watts

  vs. 12*(250 + 4*10) = 3480 Watts
- Could save 80% heterogeneous vs. 67% homogenous when trying to save power

Overall Power Savings?

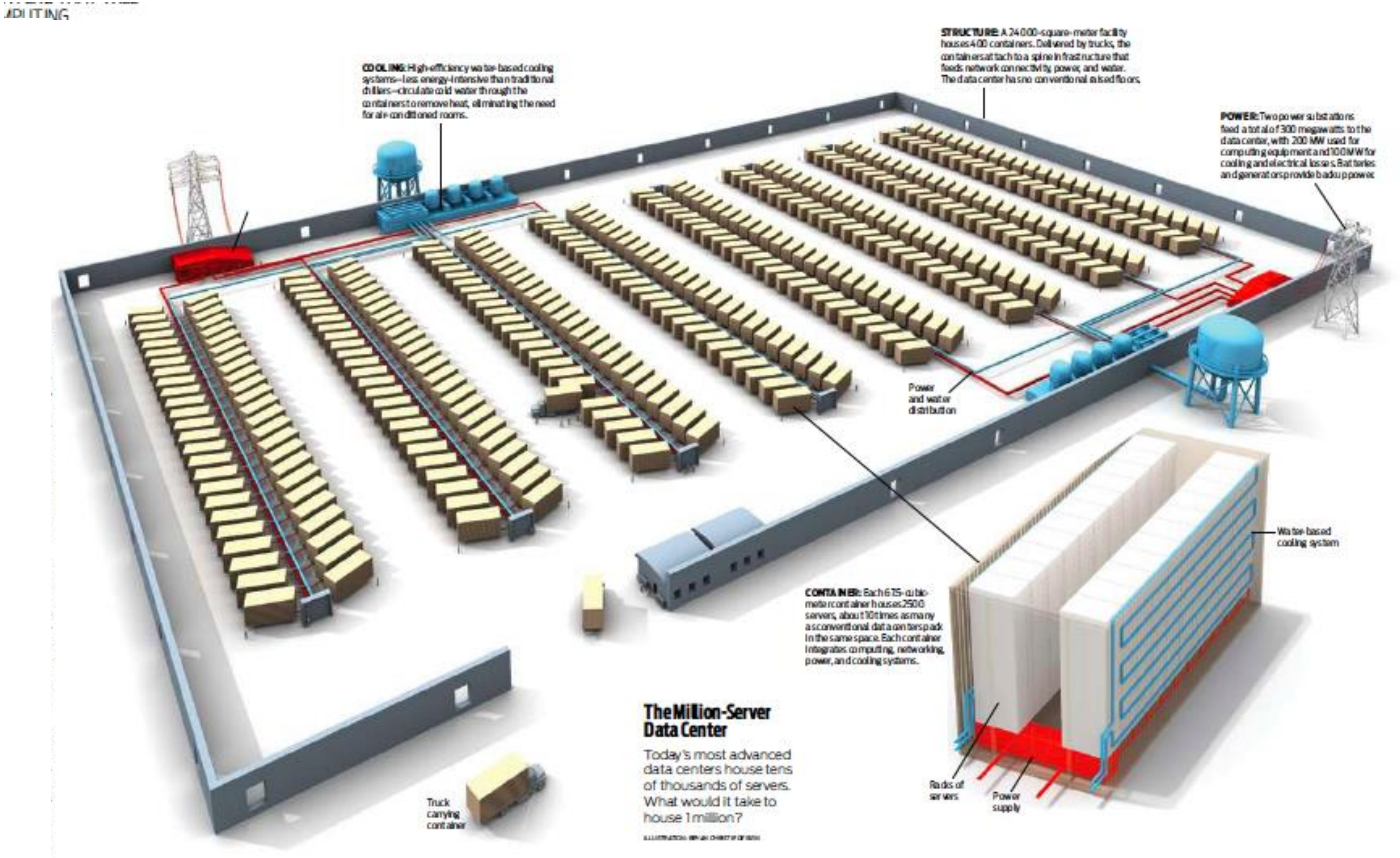
- Assumptions: Peak needs 10X servers,
  50 hours per week is peak load,
  rest week 10% utilization (=> 2/3 power)
- Homogeneous, Everything on power:
  50 hrs @ Full load
  + 118 hrs @ 67% load
  = 130 hrs @ Full load
- Heteregeneous, turn off when load is low
  50 hrs @ Full load
  + 118 hrs * 10% servers @ 100% load
  = 62 hrs @ Full load
- Saves 1/2 of power bill of data center

Conclusion

- Long way before Energy Proportionality
  ≈ ½ peak power when (benchmark) system idle
- Scaling down helps energy conservation
- Cloud Computing will transform IT industry
  - Pay-as-you-go utility computing leveraging economies of scale of Cloud provider
  - 1000 CPUs for 1 hr = 1 CPU for 1000 hrs
- Cloud Computing offers financial incentive for systems to scale down as well as up
  - New CC challenges: Director, Scalable Store

Backup Slides

Microsoft's Chicago Modular Datacenter



The Million Server Datacenter

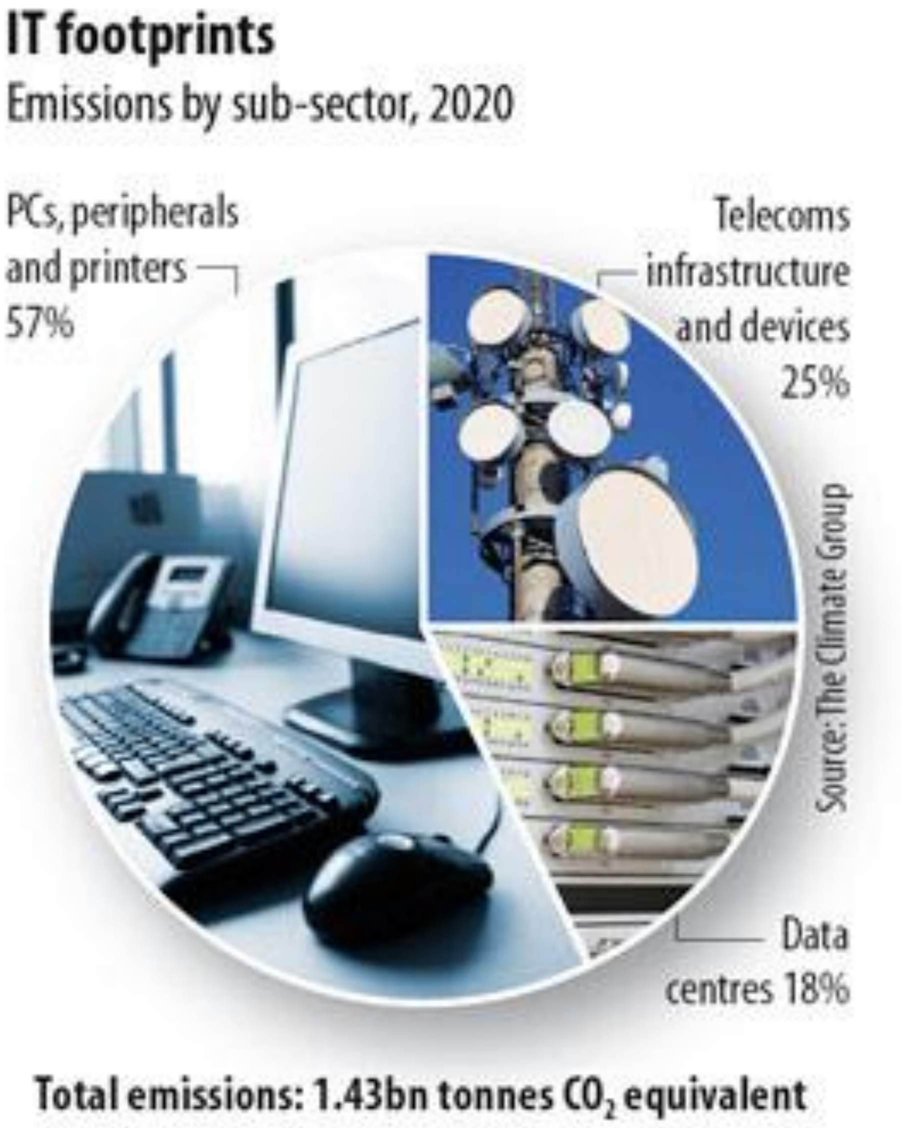
- 24000 square meter housing 400 containers
  - Each container contains 2500 servers
  - Integrated computing, networking, power, cooling systems
- 300 MW supplied from two power substations situated on opposite sides of the datacenter
- Dual water-based cooling systems circulate cold water to containers, eliminating need for air conditioned rooms

2020 IT Carbon Footprint

820m tons CO_2

2007 Worldwide IT carbon footprint:
2% = 830 m tons CO_2
Comparable to the global aviation industry

Expected to grow to 4% by 2020

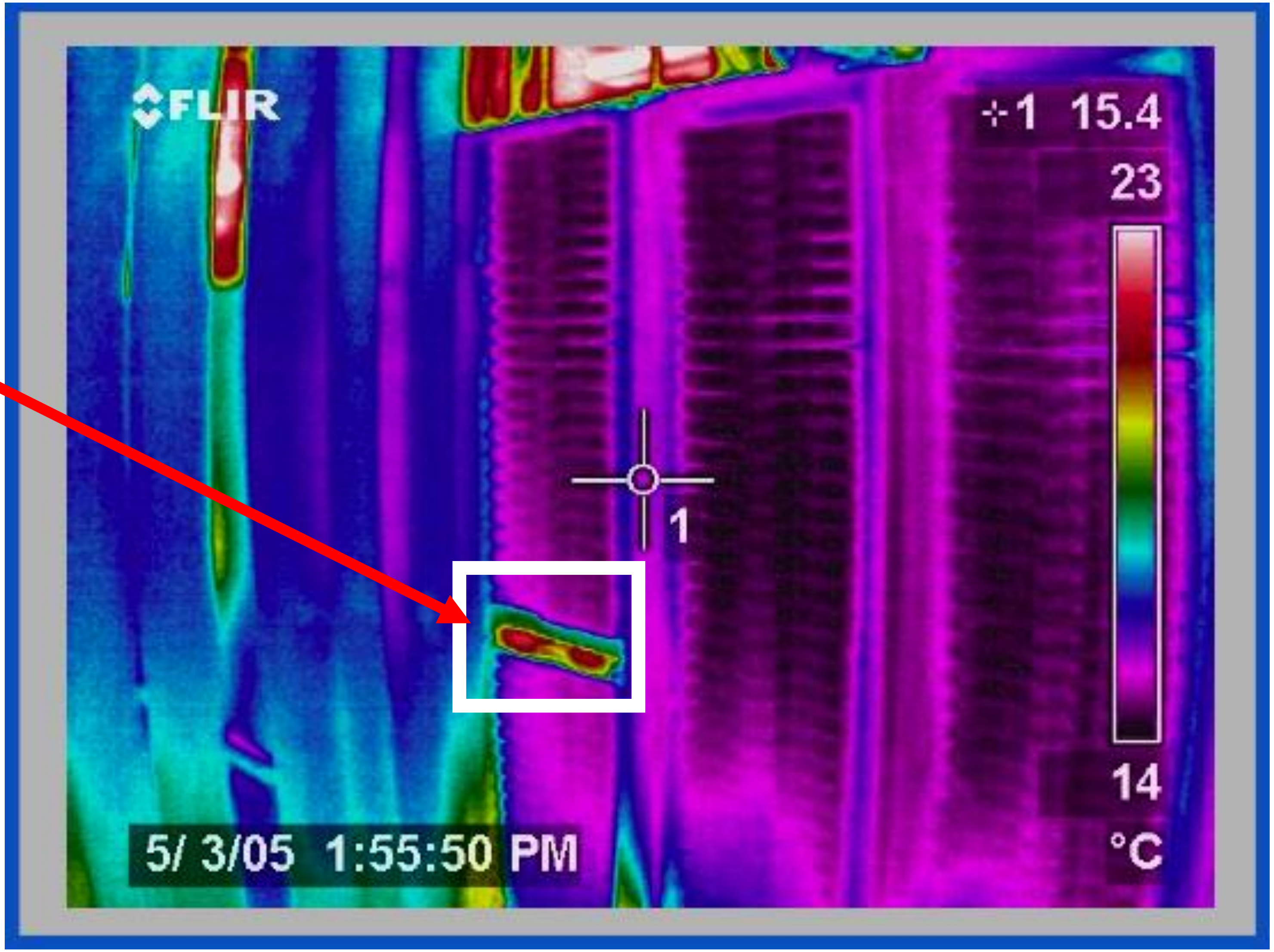


360m tons CO_2

260m tons CO_2

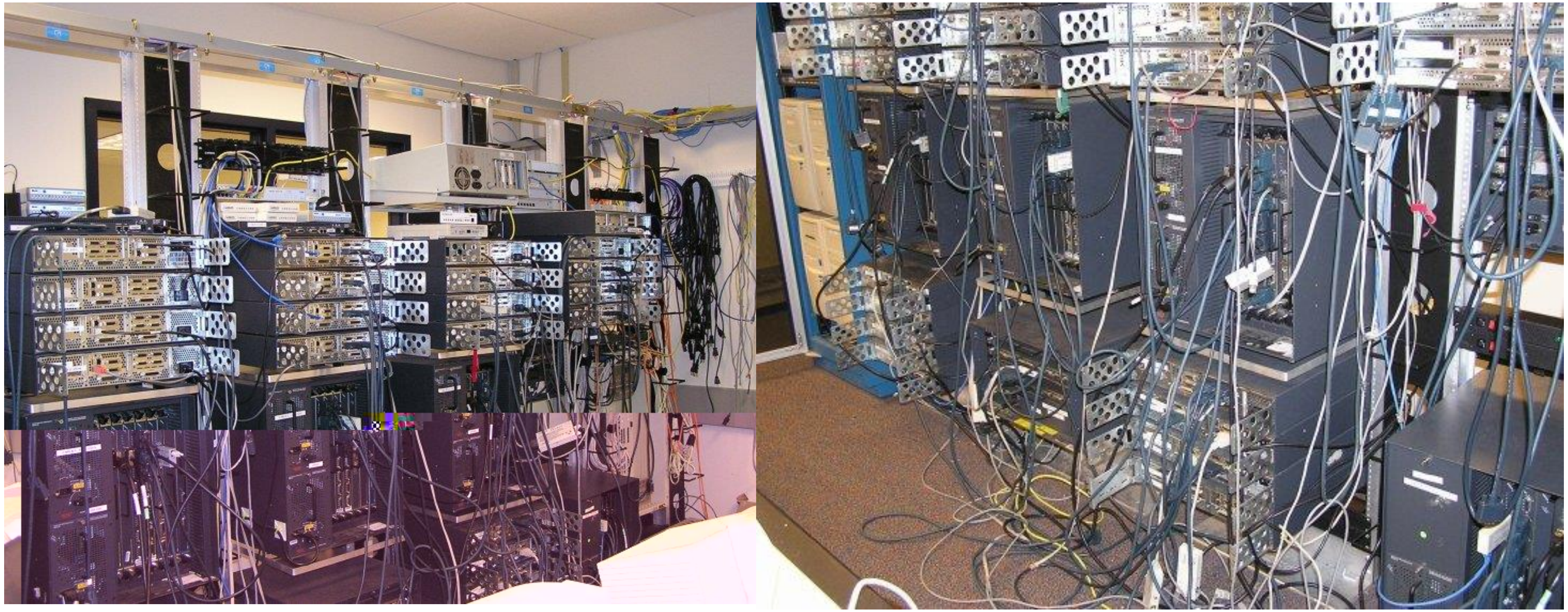
Thermal Image of Typical Cluster Rack

Rack Switch



M. K. Patterson, A. Pratt, P. Kumar,
"From UPS to Silicon: an end-to-end evaluation of datacenter efficiency", Intel Corporation

DC Networking and Power



- 96 x 1 Gbit port Cisco datacenter switch consumes around 15 kW -- approximately 100x a typical dual processor Google server @ 145 W
- High port density drives network element design, but such high power density makes it difficult to tightly pack them with servers
- Alternative distributed processing/communications topology under investigation by various research groups

DC Networking and Power

- Within DC racks, network equipment often the “hottest” components in the hot spot
- Network opportunities for power reduction
  – Transition to higher speed interconnects (10 Gbs) at DC scales and densities
  – High function/high power assists embedded in network element (e.g., TCAMs)
- Recent Work:
  – Y. Chen, T. Wang, R. H. Katz, “Energy Efficient Ethernet Encodings,” IEEE LCN, 2008.
  – G. Ananthanarayanan, R. H. Katz, “Greening the Switch,” Usenix HotPower’08 Workshop.