Cloud Computing

COMP / ECPE 293A

Overview

Based on “Above the Clouds: A Berkeley View of Cloud Computing”, 2009

Schedule

- Friday 13th – What is Cloud Computing?
  - Continuation of today's discussion
  - **Your Homework:** Pick 2-3 papers from the approved reading list that you could present and **email me**
- Monday 16th – **No class** (MLK day)
- Wednesday 18th – First paper presentation
  - Presenter: Dr. Shafer *(use an an example)*
  - MapReduce paper *(used for your first project)*
  - **Your Homework 3:** Audience members role
    - Read paper and prepare summary document
- Friday 20th – First student paper presentation

Cloud Computing

- How are we defining cloud computing again?
- And why do people use it?

What is Old and What is New?

- Old idea – **utility computing**
  - What if computing was as ubiquitous as the power grid? Just flip a switch, and (presto!) computation!
  - Billed for only the resources you consume
  - This vision took decades to be achieved!

"If computers of the kind I have advocated become the computers of the future, then computing may someday be organized as a public utility just as the telephone system is a public utility... The computer utility could become the basis of a new and important industry."

—1961, *John McCarthy* (inventor of Lisp, Turing Award winner)

What is Old and What is New?

- New ideas:
  - No up-front cost
  - Fine-grained billing (hourly)
  - Illusion of infinite resources

Why Now for Cloud Computing?

- First .com boom created companies with experience in very large datacenters
  - Economies of scale – 5-7 times cheaper (going from a 1000 machine to 50,000 machine datacenter)

Table 2: Economies of scale in 2006 for medium-sized datacenter (≈1000 servers) vs. very large datacenter (≈50,000 servers). [24]

Technology	Cost in Medium-sized DC	Cost in Very Large DC	Ratio
Network	$95 per Mbit/sec/month	$13 per Mbit/sec/month	7.1
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Datacenter

Apple's new 1 billion dollar datacenter in North Carolina

- Warehouse for computers
- Design goals
  - Maximum density for minimum space
  - Economy of scale – few people managing large numbers of computers
  - Security
  - Network and power redundancy

Datacenter Designs – Traditional Racks

42U rack = 42 “1U” servers

Datacenter Designs – Traditional Racks

Datacenter Design – Innovative

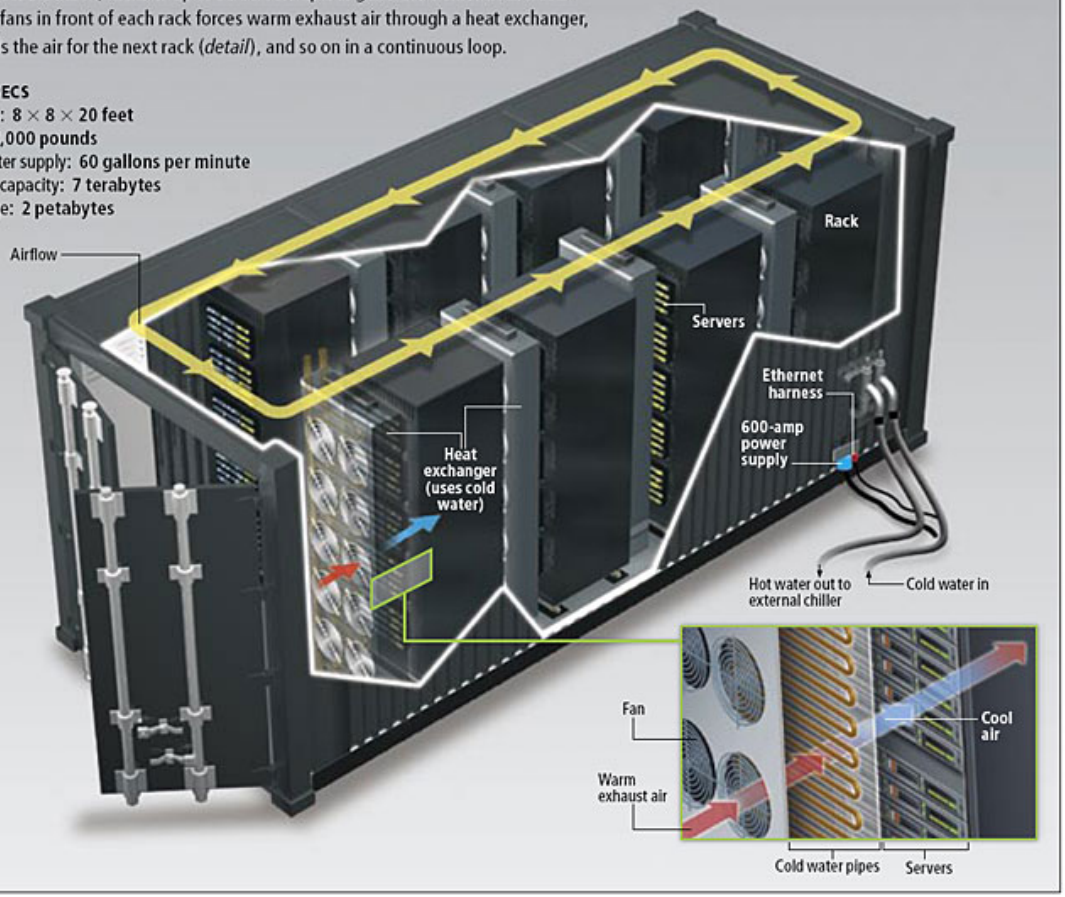
- Shipping containers with 2000+ servers pre-installed?
- Water cooled?

[HOW IT WORKS]

KEEPING COMPUTERS COOL

Inside Project Blackbox, racks of up to 38 servers apiece generate tremendous heat. A panel of fans in front of each rack forces warm exhaust air through a heat exchanger, which cools the air for the next rack (*detail*), and so on in a continuous loop.

DESIGN SPECS
Dimensions: 8 × 8 × 20 feet
Weight: 20,000 pounds
Cooling water supply: 60 gallons per minute
Computing capacity: 7 terabytes
Data storage: 2 petabytes



Datacenter Design – Innovative

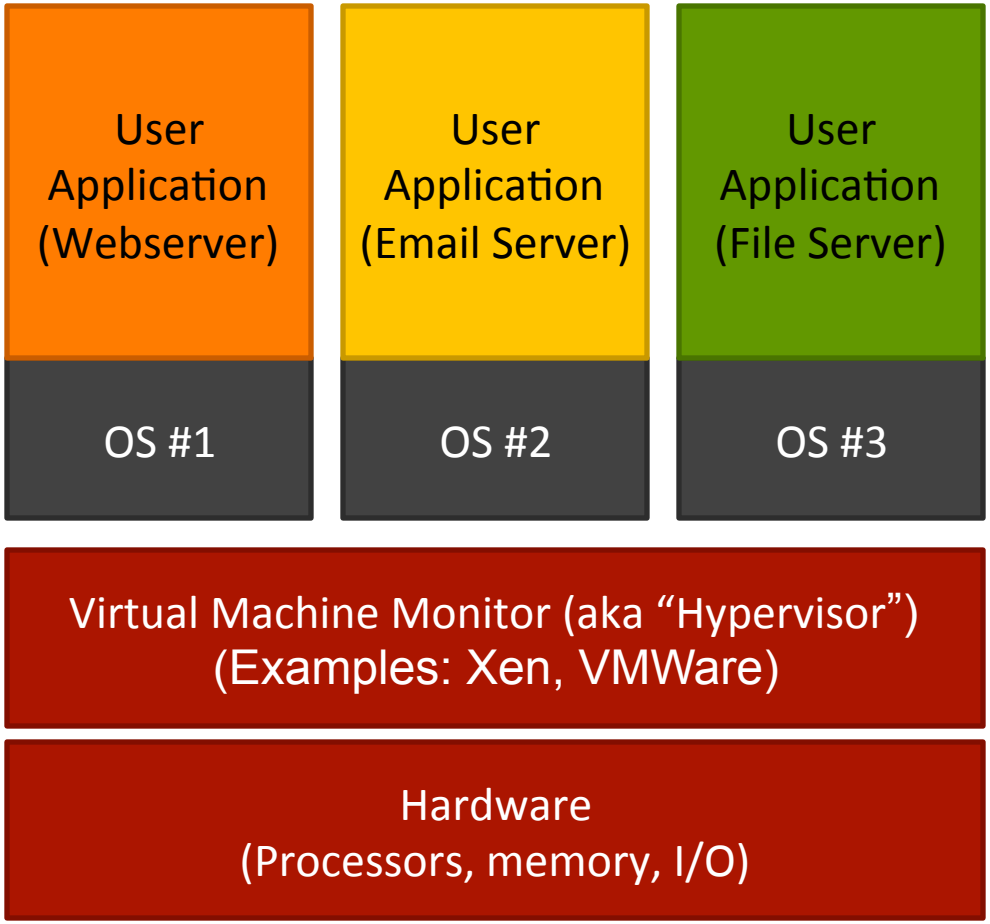
- Traditional cooling (chilled water or air) is expensive and bad for the environment
- Can we run servers hotter and use ambient air instead?

Why Now for Cloud Computing?

- Pervasive broadband Internet
- Standard hardware/software stack
- Fast x86 / x86-64 virtualization

x86 Virtualization

- **Virtual machine monitor** controls several guest domains
- Services
  - CPU scheduling
  - Memory allocation
  - Resource sharing
  - Protection/Isolation
- A virtual machine provides the same type of services to a guest domain that a general OS provides to individual processes!



Sharing Homogeneous Resources

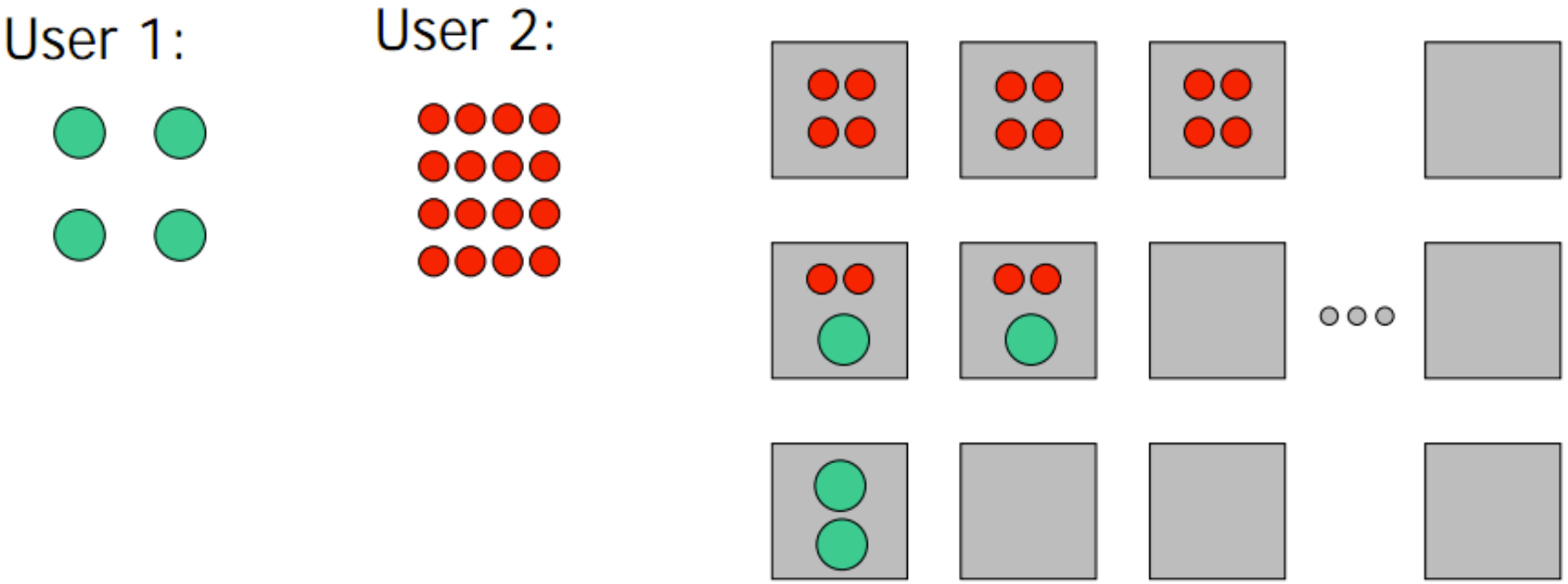


Figure from http://www.qatar.cmu.edu/~msakr/15319-s10/lectures/lecture02.pdf

Sharing Heterogeneous Resources

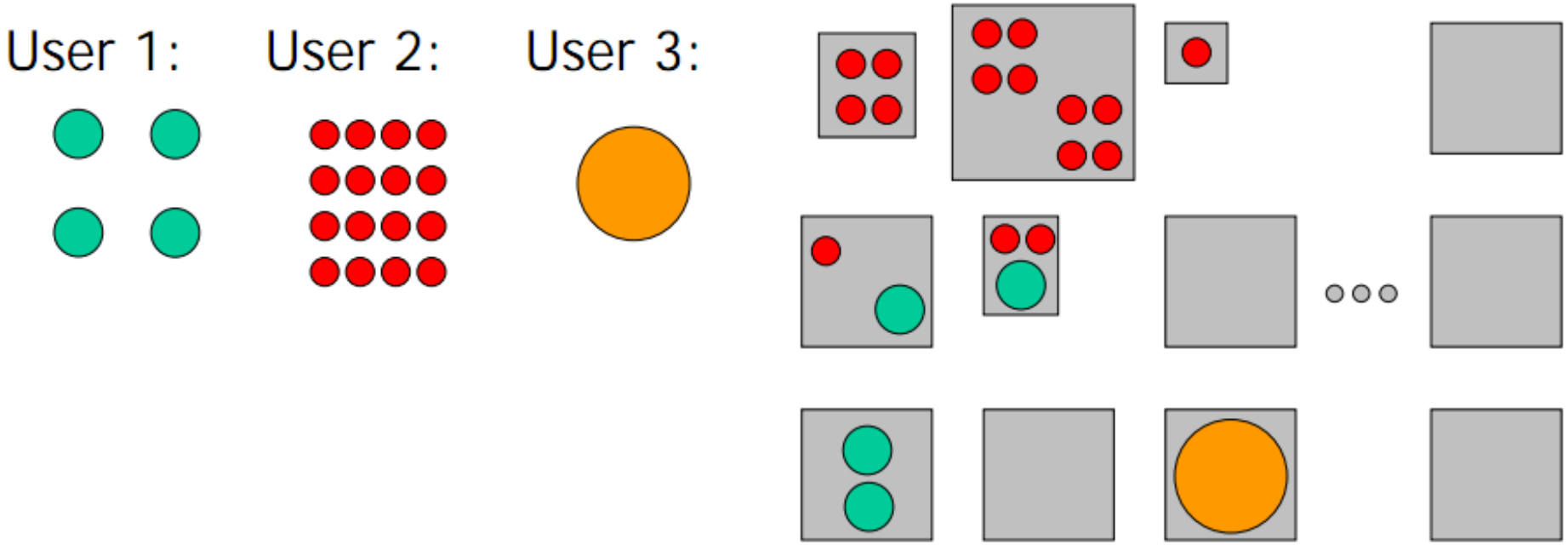


Figure from http://www.qatar.cmu.edu/~msakr/15319-s10/lectures/lecture02.pdf

More Virtualization

Virtual Networks

- One physical datacenter network that is shared
  - Each customer thinks that their virtual machines are in the same rack connected to the same private network
  - But in reality, they could be widely separated!
- **Why is this useful?**

Virtual Disks

- One storage array in datacenter that is shared
  - Each customer OS thinks it is managing its own private disk
  - But in reality, it's just a file spread out across many disks of a large array!
- **Why is this useful?**

Spectrum of Cloud Designs

- Virtualization provides **isolation** between customers
  - Share CPU, memory, disk dynamically
- Tradeoff: Flexibility/portability versus built-in features
  - Amazon EC2
    - Virtualization at the **instruction/hardware level**
  - Microsoft Azure
    - Virtualization at the **bytecode level**
  - Google AppEngine
    - Virtualization at the **framework level**

Amazon EC2

- Amazon sells you one virtual machine instance (or a thousand!)
  - You configure the OS
  - You configure the application software
  - Thin API (related to starting/stopping machines)
  - Virtualization: raw CPU cycles, block-device storage, IP-level connectivity
- **Advantages?**
- **Disadvantages?**

Specs as of Jan 2012
1 "unit" = One 1.0 GHz "2007-era" Xeon/Opteron CPU

Amazon EC2 – Instance Types

Node Type	RAM	CPU	Storage (local)	Notes
Micro	613 MB	2 units (**burst** only!)	None	
Small	1.7 GB	1 unit (1 core)	160 GB	
Large	7.5 GB	4 units (2 cores / 2)	850 GB	
Extra-Large	15 GB	8 units (4 cores / 2)	1690 GB	
High-Mem XL	17.1 GB	6.5 units (2 cores / 3.25)	420 GB	Greater RAM
High-Mem 2XL	34.2 GB	13 units (4 cores / 3.25)	850 GB	
High-Mem 4XL	68.4 GB	26 units (8 cores / 3.25)	1690 GB	
High-CPU Med	1.7 GB	5 units (2 cores / 2.5)	350 GB	Greater CPU
High-CPU XL	7 GB	20 units (8 cores / 2.5)	1690 GB	
Cluster 4XL	23 GB	33.5 units	1690 GB	10 GigE net!
Cluster 8XL	60.5 GB	88 units	3370 GB	

Amazon EC2 – January 2012 Pricing

- **Why are the Windows instances more expensive?**

Region: US East (Virginia)

	Linux/UNIX Usage	Windows Usage
Standard On-Demand Instances		
Small (Default)	$0.085 per hour	$0.12 per hour
Large	$0.34 per hour	$0.48 per hour
Extra Large	$0.68 per hour	$0.96 per hour
Micro On-Demand Instances		
Micro	$0.02 per hour	$0.03 per hour
Hi-Memory On-Demand Instances		
Extra Large	$0.50 per hour	$0.62 per hour
Double Extra Large	$1.00 per hour	$1.24 per hour
Quadruple Extra Large	$2.00 per hour	$2.48 per hour
Hi-CPU On-Demand Instances		
Medium	$0.17 per hour	$0.29 per hour
Extra Large	$0.68 per hour	$1.16 per hour
Cluster Compute Instances		
Quadruple Extra Large	$1.30 per hour	$1.61 per hour
Cluster Compute Eight Extra Large	$2.40 per hour	$2.97 per hour
Cluster GPU Instances		
Quadruple Extra Large	$2.10 per hour	$2.60 per hour

Amazon EC2 – January 2012 Pricing

Region: US East (Virginia)

	Pricing
Data Transfer IN	
All data transfer in	$0.000 per GB
Data Transfer OUT	
First 1 GB / month	$0.000 per GB
Up to 10 TB / month	$0.120 per GB
Next 40 TB / month	$0.090 per GB
Next 100 TB / month	$0.070 per GB
Next 350 TB / month	$0.050 per GB
Next 524 TB / month	Contact Us
Next 4 PB / month	Contact Us
Greater than 5 PB / month	Contact Us

There is no Data Transfer charge between Amazon EC2 and other Amazon Web Services within the same region (i.e. between Amazon EC2 US West and Amazon S3 in US West). Data transferred between Amazon EC2 instances located in different Availability Zones in the same Region will be charged Regional Data Transfer. Data transferred between AWS services in different regions will be charged as Internet Data Transfer on both sides of the transfer.

Microsoft Azure

- Microsoft sells you a "platform"
  - You write your application in **.NET**, Java, PHP, JavaScript (node.js), C++, or Python and compile to a common language runtime
  - No control over underlying framework and OS beyond what their API allows
- Application model
  - Web role – HTTP request comes in, your app runs (on one of ∞ nodes), and then finishes
  - Worker role – Background program (not triggered by user)
  - VM role – New! (Amazon EC2 style, gives you a Windows Server VM that can be customized)

Microsoft Azure

- Data storage options
  - Blobs (unstructured data = doc, picture, video, etc..)
  - Tables (non-relational database: key and many values)
    - Imagine a row in Excel, but each row could have different columns
  - Azure SQL: Full-fledged parallel relational SQL database
  - Local storage: Like Amazon's (doesn't move with your VM!)
- **Advantages? Disadvantages?**

Google AppEngine

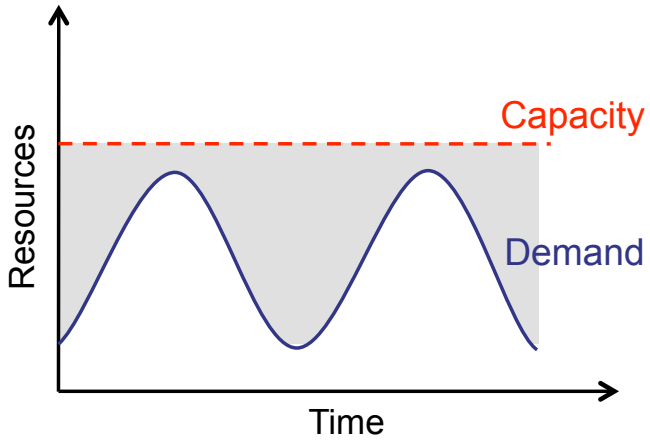
- Google (also) sells you a "platform" targeted at web apps
  - Supports Python, Java, and Go
  - Stateless computation, stateful storage
  - Request/reply operation
- Constraints (your app is in a sandbox)
  - No writing to files
  - No network sockets
  - 60 seconds max execution after a request
- **Advantages? Disadvantages?**

Analogy with Programing Languages

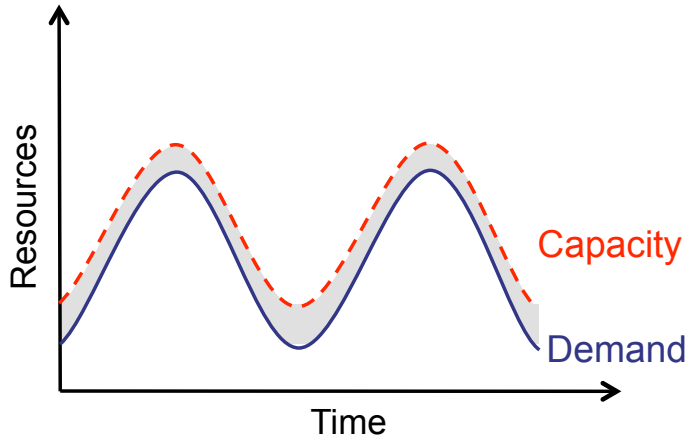
- Assembly or C programming provides you with hardware-level access and fine grained control
- But writing a web app is tedious!
  - Managing sockets, memory, threads, etc…
  - Good libraries help but it's still hard work
- Ruby on Rails makes this very easy!
  - As long as my web app has a request-then-response structure

Cloud Economics

- Pay per use instead of provisioning for peak usage



Static data center

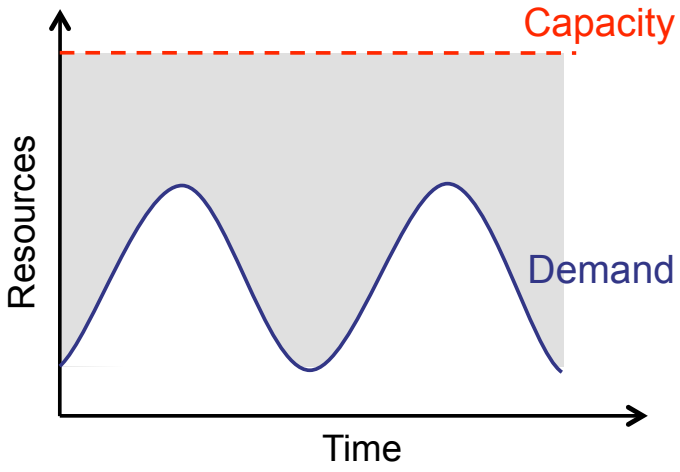


Data center in the cloud

Unused resources

Cloud Economics

- What if we **over**-provision?

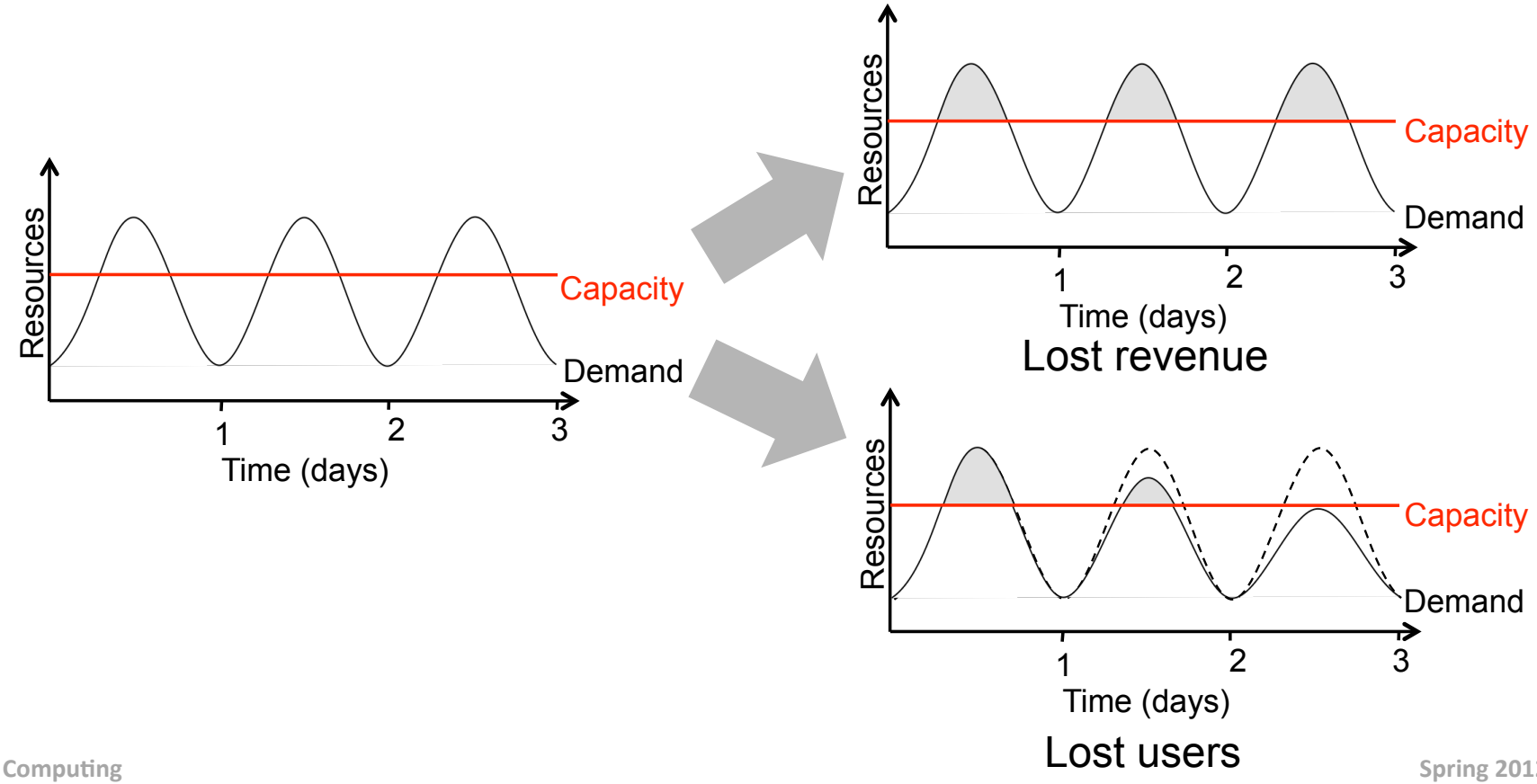


Unused resources

Static data center

Cloud Economics

- What if we **under**-provision?



Cloud Economics

- Note that it is just as important to be able to scale **down** as it is to scale **up – why?**
- Typical usage case
  - You're a startup and need 10 servers for your average traffic
  - Your website is suddenly mentioned on *Good Morning America!* and traffic spikes 10x
  - 24 hours later, traffic is back to your usual average

Cloud Economics

- Cheaper to ship photons than electrons
  - Place your datacenter close to cheap power (hydro dams in rural areas?)
  - Link to the national fiber optic network
- Cheaper to go **LARGE**!

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Why be a Cloud Vendor?

- **Why have Amazon, Google, Microsoft entered this market?**
- Amazon and Google
  - Utilize off-peak capacity in datacenter
  - Reuse existing infrastructure and technical know-how
  - Grow datacenters even larger, and achieve even greater economies of scale (which benefits both them and their customers)
- Microsoft
  - Sell .NET tools (defend the franchise!)

Cloud Challenges & Opportunities

- Challenge 1: Availability of Service (avoiding downtime)
- **Challenges? *(for you as a customer of cloud services)***
  - Single point of failure
    - What if your rack fails?
    - What if the entire datacenter is cut offline?
    - What if all of Amazon EC2 goes offline due to common bug?
    - What if Amazon goes out of business?
  - DDOS attacks
- **Solutions / Opportunities?**
  - Use multiple cloud providers to provide business continuity
  - Use elasticity to defend against DDOS attack

Cloud Challenges & Opportunities

- Challenge 2: Data Lock-in
- **Why is this a problem?** ***(for you as a customer of cloud services)***
  - Your vendor might start raising prices, decrease quality, or go out of business, and you can't easily take your data and go elsewhere
- **What can be done about it?**
  - Standardized APIs?
    - Example: Eucalyptus

Cloud Challenges & Opportunities

- Challenge 3: Data Confidentiality and Auditability
- **Why is this a problem?** ***(for you as a customer of cloud services)***
  - Who can access my data?
  - How can my data be audited if it is stored outside my organization?
  - Regulatory compliance?
  - Access by foreign governments?
- **What can be done about it?**
  - Encrypt (storage), encrypt (network/VPN)
  - Storage within country boundaries
  - Have the cloud provider (in the VM itself) guarantee data

Cloud Challenges & Opportunities

- Challenge 4: Data Transfer Bottlenecks
- **Why is this a problem?**
  - Limited upload/download bandwidth to cloud (at least, relative to the TBs of data you might like to move)
- **What can be done about it?**
  - FedEx your hard drives!
  - Do all of your data processing internal to the cloud system (i.e. inside Amazon's datacenter)
  - Better network architectures?

Cloud Challenges & Opportunities

- Challenge 5: Performance Unpredictability
- **Why does this problem exist?**
  - CPU and main memory is easy to virtualize (high bandwidth + context switches between users are quick)
  - Disks are hard to virtualize (hard drive bandwidth shared among 10 users is paltry + seek times are high)
- **What can be done about it?**
  - SSDs?
  - More disks = more spindles?
  - Better VM software to manage disks?

Cloud Challenges & Opportunities

- Challenge 6: Scalable Storage
- **Why is this a problem?**
  - As long as my data is in Amazon's cloud, I'm paying for it, regardless of whether or not I'm actively using it
- **What can be done about it?**
  - Nothing?

Cloud Challenges & Opportunities

- Challenge 7: Bugs in Large-Scale Distributed Systems
- **Why is this a problem?**
  - How do you debug a problem that only occurs when you have > 100, > 1000, > 10000 machines working together?
- **What can be done about it?**
  - Log, log, log! (and have automated log analysis tools)
  - Can the VM help capture information beyond the view of the application?

Cloud Challenges & Opportunities

- Challenge 8: Scaling Quickly
- **Why is this a problem?**
  - Not every cloud service will automatically scale up/ down resources depending on your current load
- **What can be done about it?**
  - Better software

Cloud Challenges & Opportunities

- Challenge 9: Reputation Fate Sharing (with other customers of your cloud provider)
- **Why is this a problem?**
  - If some jerk sends spam from an Amazon EC2 instance, those IPs are probably blacklisted for all future customers
- **What can be done about it?**
  - Can the blacklists adapt?

Cloud Challenges & Opportunities

- Challenge 10: Software Licensing
- **Why is this a problem?**
  - How many licenses of Windows (or Oracle, etc..) do you need to buy if you run between 10 and 100 concurrent EC2 servers on any given day?
- **What can be done about it?**
  - Hope the software vendors offer better license terms? (Pay-per-use, bulk sales, etc…)
  - Open-source software?

What does the Cloud Change?

- **Application software** has to change
- New apps should be written in two pieces
  - Client piece (local) – must be useful if disconnected (temporarily) from the cloud
  - Cloud piece (remote)

What does the Cloud Change?

- **Infrastructure software** has to change
- Should be aware that it is running inside of a virtual machine (i.e. sharing a machine, instead of owning the hardware)
- Integrated billing/accounting system

What does the Cloud Change?

- **Hardware** has to change
- Larger scale! (Not just one machine, but dozens as the minimum unit)
- Energy efficiency (this was already becoming an issue)
  - Put N% of the CPU, memory, and disks to sleep when not needed (*energy proportionality*)
- Integrate virtualization into the system? (no such thing as bare hardware anymore?)

Is Every App Suitable for the Cloud?

- **What apps are good for the cloud?**
  - Web-style apps
  - Desktop apps (e.g. Google docs)
  - Batch processing
- **What apps are not good? (or "challenged"?)**
  - Jitter-sensitive apps
    - Latency over the Internet
    - Virtualization-imposed latency
  - Bulk data apps (unless the data is already in the cloud)

Public and Private Clouds

- **Public cloud**
  - Commercially available in a pay-as-you-go manner
  - Example: i.e. Amazon EC2
- **Private cloud**
  - Built by and available for only your company (or government)

Cloud Benefits: Public versus Private

Benefit	Public	Private
Economy of scale	Yes	No
Illusion of infinite resources on-demand	Yes	Unlikely
Eliminate up-front commitment by users*	Yes	No
True fine-grained pay-as-you-go **	Yes	??
Better utilization (workload multiplexing)	Yes	Depends on size**
Better utilization & simplified operations through virtualization	Yes	Yes

* What about nonrecoverable engineering/capital costs?

** Implies ability to meter & incentive to release idle resources

Public, Private, Hybrid Clouds

- **Public cloud**
  - Commercially available in a pay-as-you-go manner
  - Example: i.e. Amazon EC2
- **Private cloud**
  - Built by and available for only your company (or government)
- **Hybrid cloud – what's this?**
  - Using your local (private) computing resources first, but bursting (scaling up) to public cloud resources in periods of high demand
  - **Strengths and weaknesses?**