

CS 425 / ECE 428  
Distributed Systems  
Fall 2023

Indranil Gupta (Indy)

W/ Aishwarya Ganesan

*Lecture 2-3: Introduction to Cloud  
Computing*

All slides © IG

What was the world's first bug in a program?

# World's First Bug

9/9


0800 Antan started  
 1000 " stopped - antan ✓

13<sup>00</sup> (033) MP-MC { 1.2700 9.037 847 025  
 (033) PRO 2 2.130476415 } 9.037 846 995 correct  
 correct 2.130676415 } 4.615925059(-2)

Relays 6-2 in 033 failed special speed test  
 in relay 10,000 test.

(Relays changed)

1100 Started Cosine Tape (Sine check)  
 1525 Started Multi Adder Test.

1545  Relay #70 Panel F  
 (moth) in relay.

First actual case of bug being found.

1630 Antan started.  
 1700 closed down.

Relay 3145  
 Relay 8371

- <https://education.nationalgeographic.org/resource/worlds-first-computer-bug/>

# Quiz: Where is the World's Largest Datacenter?

# Quiz: Where is the World's Largest Datacenter?

- (2018-2023) China Telecom. 10.7 Million sq. ft.
- (2017) “The Citadel” Nevada. 7.2 Million sq. ft.
- (2015) In Chicago!
  - 350 East Cermak, Chicago, 1.1 MILLION sq. ft.
  - Shared by many different “carriers”
  - Critical to Chicago Mercantile Exchange
- See:
  - <http://ict-price.com/top-10-biggest-data-centres-from-around-the-world/>
  - <https://www.gigabitmagazine.com/top10/top-10-biggest-data-centres-world>
  - <https://www.racksolutions.com/news/data-center-news/top-10-largest-data-centers-world/>



# (There was) The Hype!

- Forrester in 2010 – Cloud computing will go from **\$40.7 billion** in 2010 to **\$241 billion** in 2020.
- Today: Cloud Market is **\$545B** (expected to reach **\$1.2T** by 2027)
- Companies and even Federal/state governments using cloud computing now: **fbo.gov**

# Many Cloud Providers

- AWS: Amazon Web Services
  - EC2: Elastic Compute Cloud
  - S3: Simple Storage Service
  - EBS: Elastic Block Storage
- Microsoft Azure
- Google Cloud/Compute Engine/AppEngine
- Rightscale, Salesforce, EMC, Gigaspaces, 10gen, Datastax, Oracle, VMWare, Yahoo, Cloudera
- And many many more!



# Two Categories of Clouds

- Can be either a (i) public cloud, or (ii) private cloud
- Private clouds are accessible only to company employees
- Public clouds provide service to any paying customer:
  - Amazon S3 (Simple Storage Service): store arbitrary datasets, pay per GB-month stored
    - Recently: 0.09c to 2 c per GB month
  - Amazon EC2 (Elastic Compute Cloud): upload and run arbitrary OS images, pay per CPU hour used
    - Recently: 2 c per CPU hr to 40c per CPU hr (depending on strength), only CPUs not GPUs
  - Google cloud: similar pricing ranges as above
  - Google AppEngine/Compute Engine: develop applications within their appengine framework, upload data that will be imported into their format, and run

# Customers Save Time and \$\$\$

- (Stories from mid-2010s)
- Dave Power, Associate Information Consultant at Eli Lilly and Company: “With AWS, Powers said, a new server can be up and running in **three minutes** (it used to take Eli Lilly **seven and a half weeks** to deploy a server internally) and a **64-node Linux cluster** can be online in five minutes (compared with three months internally). ... It's just shy of instantaneous.”
- Ingo Elfering, Vice President of Information Technology Strategy, GlaxoSmithKline: “With Online Services, we are able to reduce our IT **operational costs** by roughly **30%** of what we’re spending”
- Jim Swartz, CIO, Sybase: “At Sybase, a private cloud of virtual servers inside its datacenter has saved nearly **\$US2 million annually** since 2006, Swartz says, because the company can share computing power and storage resources across servers.”
- 100s of startups in Silicon Valley can harness large computing resources without buying their own machines.

But what exactly IS a cloud?

# What is a Cloud?

- It's a cluster!
- It's a supercomputer!
- It's a datastore!
- It's superman!



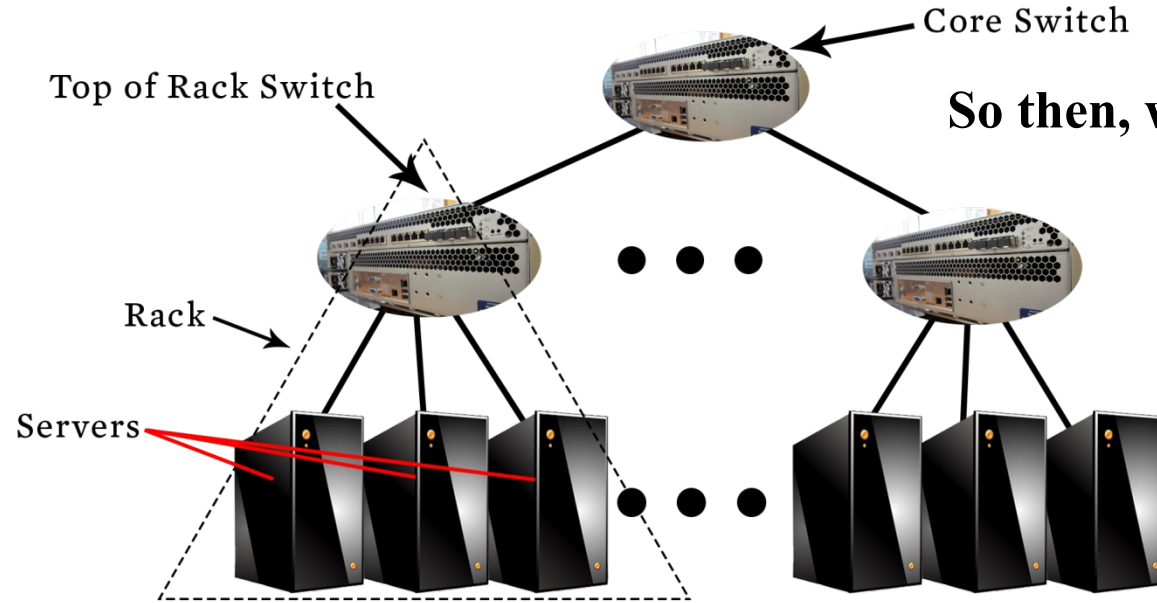
- None of the above
- All of the above

- Cloud = Lots of storage + compute cycles nearby

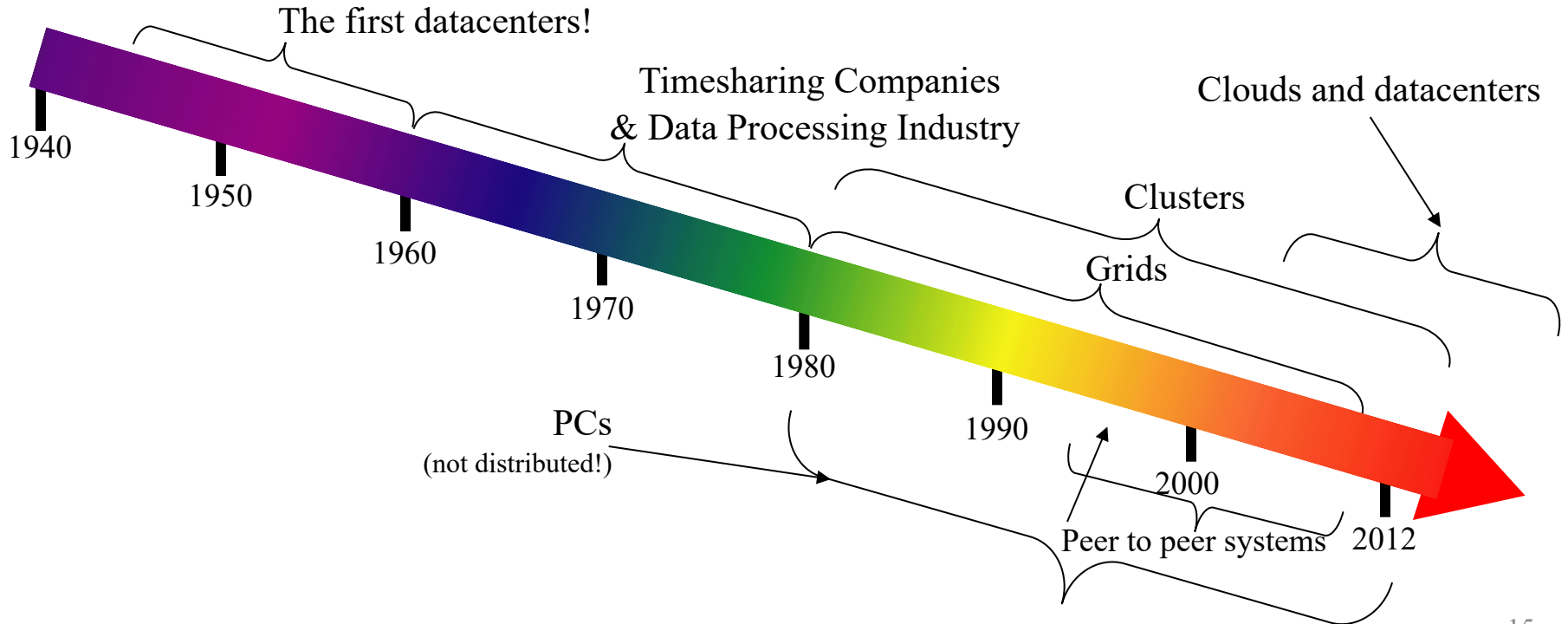
# What is a Cloud?

- A single-site cloud (aka “Datacenter”) consists of
  - Compute nodes (grouped into racks) (2)
  - Switches, connecting the racks
  - A network topology, e.g., hierarchical
  - Storage (backend) nodes connected to the network (3)
  - Front-end for submitting jobs and receiving client requests (1)
  - (1,2,3: Often called “three-tier architecture”)
  - Software Services
- A geographically distributed cloud consists of
  - Multiple such sites
  - Each site perhaps with a different structure and services

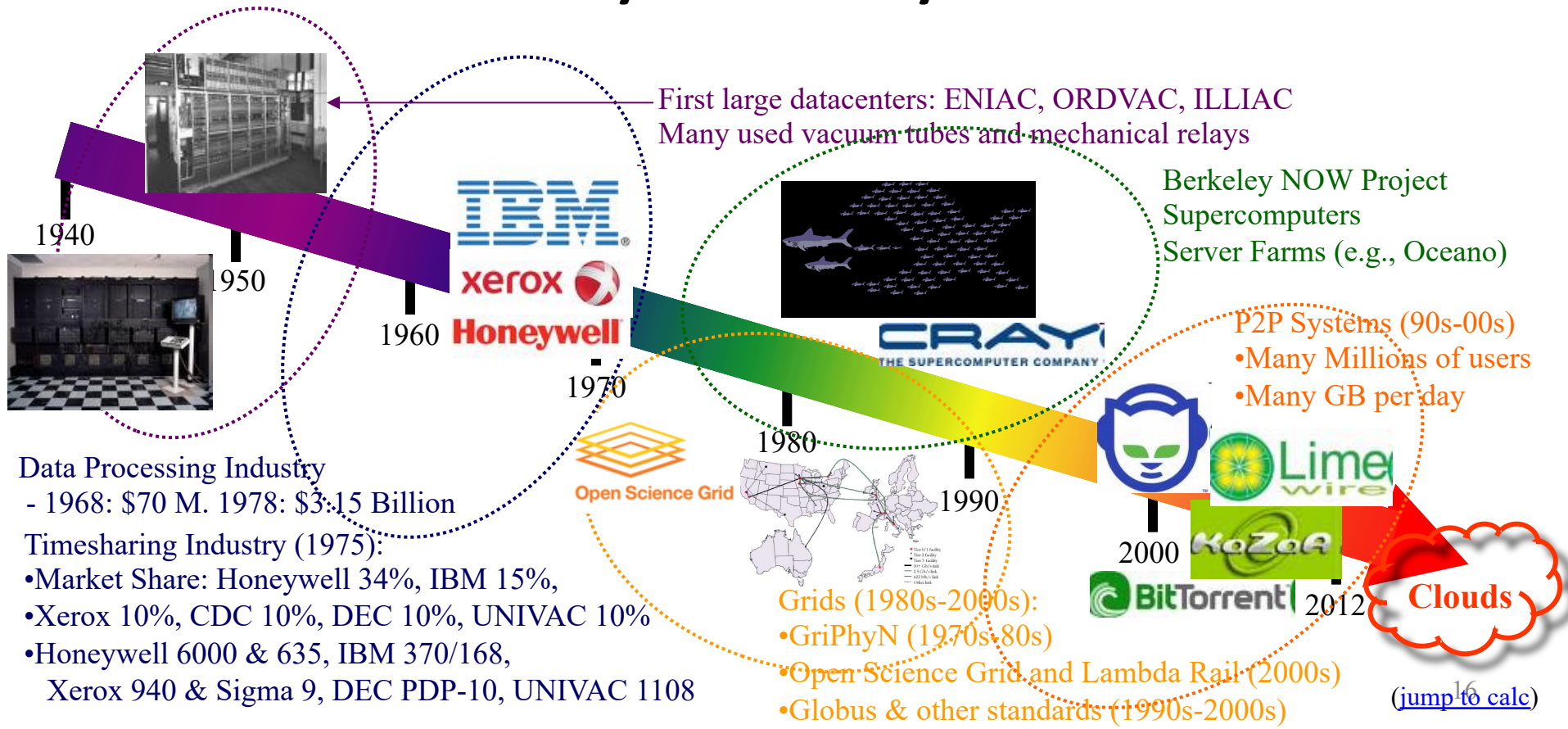
# A Sample Cloud Topology



# “A Cloudy History of Time”



# “A Cloudy History of Time”





# Trends: Technology

- Doubling Periods – storage: 12 mos, bandwidth: 9 mos, and (what law is this?) cpu compute capacity: 18 mos
- Then and Now
  - Bandwidth
    - 1985: mostly 56Kbps links nationwide
    - Today: Tbps links widespread
  - Disk capacity
    - Today's PCs have TBs, far more than a 1990 supercomputer

# Trends: Users

- Then and Now

- Biologists:

- 1990: were running small single-molecule simulations
    - Today: CERN's Large Hadron Collider producing many PB/year

# Prophecies

- In 1965, MIT's Fernando Corbató and the other designers of the Multics operating system envisioned a computer facility operating “like a power company or water company”.
- **Plug** your thin client into the computing Utility **and Play** your favorite Intensive Compute & Communicate Application
  - Have today’s clouds brought us closer to this reality? Think about it.

# Four Features New in Today's Clouds

I. **Massive scale.**

II. **On-demand access:** Pay-as-you-go, no upfront commitment.

- And anyone can access it

III. **Data-intensive Nature:** What was MBs has now become TBs, PBs and XBs.

- Daily logs, forensics, Web data, etc.
- Humans have data numbness: Wikipedia (large) compressed is only about 10 GB!

IV. **New Cloud Programming Paradigms:** MapReduce/Hadoop, NoSQL/Cassandra/MongoDB and many others.

- High in accessibility and ease of programmability
- Lots of open-source

**Combination of one or more of these gives rise to novel and unsolved distributed computing problems in cloud computing.**

# I. Massive Scale

- Facebook [GigaOm, 2012]
  - 30K in 2009 -> 60K in 2010 -> 180K in 2012
- Microsoft [NYTimes, 2008]
  - 150K machines
  - Growth rate of 10K per month
  - 80K total running Bing
  - In 2013, Microsoft Cosmos had 110K machines (4 sites)
- Yahoo! [2009]:
  - 100K
  - Split into clusters of 4000
- AWS EC2 [Randy Bias, 2009]
  - 40K machines
  - 8 cores/machine
- eBay [2012]: 50K machines
- HP [2012]: 380K in 180 DCs
- Google [2011, Data Center Knowledge] : 900K

# What does a datacenter look like from inside?

- A virtual walk through a datacenter (Facebook Prineville Datacenter, Mid 2010s)
- References:
  - [https://www.youtube.com/watch?v=4A\\_A-CmrqpQ](https://www.youtube.com/watch?v=4A_A-CmrqpQ)
  - <http://gigaom.com/cleantech/a-rare-look-inside-facebooks-oregon-data-center-photos-video/>

# Servers



Front



Back



In



Some highly secure (e.g., financial info)<sup>23</sup>

# Cooling



Air sucked in from top (also, Bugzappers)



Water purified



Water sprayed into air



15 motors per server bank



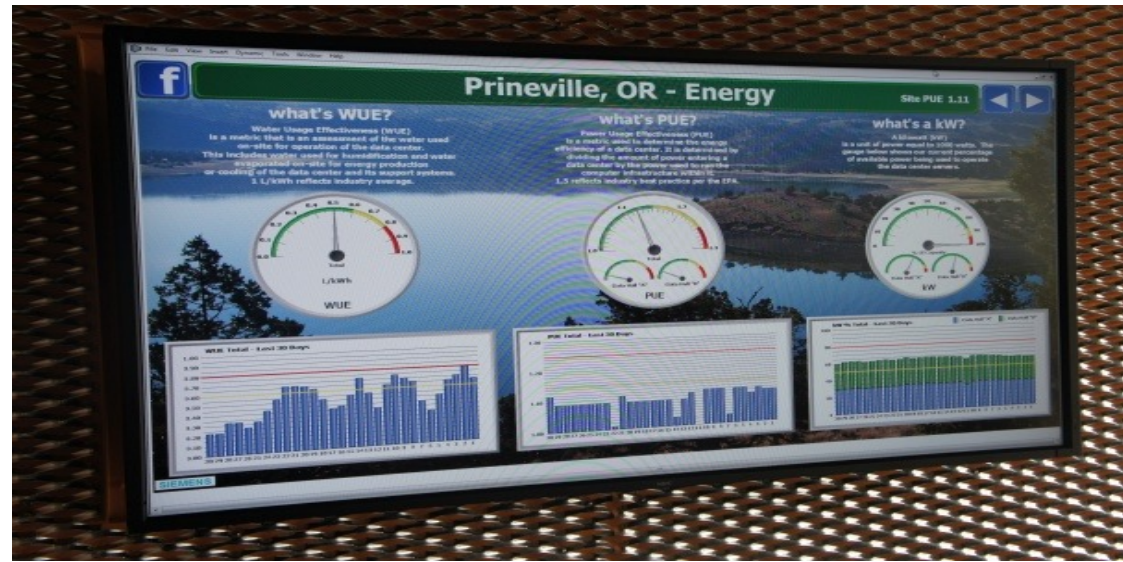
# Power



Off-site



On-site



- WUE = Annual Water Usage / IT Equipment Energy (L/kWh) – low is good
- PUE = Total facility Power / IT Equipment Power – low is good (e.g., Google~1.1)

# Extra - Fun Videos to Watch

- [Microsoft GFS Datacenter Tour \(Youtube\)](#)
  - <http://www.youtube.com/watch?v=hOxA111pQIw>
- [Timelapse of a Datacenter Construction on the Inside \(Fortune 500 company\)](#)
  - <http://www.youtube.com/watch?v=ujO-xNvXj3g>

# II. On-demand access: \*aaS

## Classification

On-demand: renting a cab vs. (previously) renting a car, or buying one. E.g.:

- AWS Elastic Compute Cloud (EC2): a few cents to a few \$ per CPU hour
- AWS Simple Storage Service (S3): a few cents per GB-month
- HaaS: Hardware as a Service
  - You get access to barebones hardware machines, do whatever you want with them, Ex: Your own cluster
  - Not always a good idea because of security risks
- IaaS: Infrastructure as a Service
  - You get access to flexible computing and storage infrastructure. Virtualization or containerization is one way of achieving this (cgroups, Kubernetes, Dockers, VMs,...). Often said to subsume HaaS.
  - Ex: Amazon Web Services (AWS: EC2 and S3), OpenStack, Eucalyptus, Rightscale, Microsoft Azure, Google Cloud.

# II. On-demand access: \*aaS

## Classification

- PaaS: Platform as a Service
  - You get access to flexible computing and storage infrastructure, coupled with a software platform (often tightly coupled)
  - Ex: Google's AppEngine (Python, Java, Go)
- SaaS: Software as a Service
  - You get access to software services, when you need them. Often said to subsume SOA (Service Oriented Architectures).
  - Ex: Google docs, MS Office 365 Online
- And new recently: FaaS = Function as a Service
  - e.g., AWS Lambda, Azure Functions, etc.

# III. Data-intensive Computing

- Computation-Intensive Computing
  - Example areas: MPI-based, High-performance computing, Grids
  - Typically run on supercomputers (e.g., NCSA Blue Waters)
- Data-Intensive
  - Typically store data at datacenters
  - Use compute nodes nearby
  - Compute nodes run computation services
- In data-intensive computing, the **focus shifts from computation to the data**: CPU utilization no longer the most important resource metric, instead I/O is (disk and/or network)

# IV. New Cloud Programming Paradigms

- Easy to write and run highly parallel programs in new cloud programming paradigms:
  - Google: MapReduce and Sawzall
  - Amazon: Elastic MapReduce service (pay-as-you-go)
  - Google (MapReduce)
    - Indexing: a chain of 24 MapReduce jobs
    - ~200K jobs processing 50PB/month (in 2006)
  - Yahoo! (Hadoop + Pig)
    - WebMap: a chain of several MapReduce jobs
    - 300 TB of data, 10K cores, many tens of hours (~2008)
  - Facebook (Hadoop + Hive)
    - ~300TB total, adding 2TB/day (in 2008)
    - 3K jobs processing 55TB/day
  - Similar numbers from other companies, e.g., Yieldex, eharmony.com, etc.
  - NoSQL: MySQL is an industry standard, but Cassandra is 2400 times faster!

# Two Categories of Clouds

- Can be either a (i) public cloud, or (ii) private cloud
- Private clouds are accessible only to company employees
- Public clouds provide service to any paying customer
  
- You're starting a new service/company: should you use a public cloud or purchase your own private cloud?

# Single site Cloud: to Outsource or Own?

- Medium-sized organization: wishes to run a service for  $M$  months
  - Service requires 128 servers (1024 cores) and 524 TB
  - Same as UIUC CCT (Cloud Computing Testbed) cloud site (bought in 2009, now decommissioned)
- **Outsource** (e.g., via AWS): *monthly* cost
  - S3 costs: \$0.12 per GB month. EC2 costs: \$0.10 per CPU hour (costs from 2009)
  - Storage = \$ 0.12 X 524 X 1000 ~ \$62 K
  - Total = Storage + CPUs = \$62 K + \$0.10 X 1024 X 24 X 30 ~ \$136 K
- **Own**: monthly cost
  - Storage ~ \$349 K /  $M$
  - Total ~ \$ 1555 K /  $M$  + 7.5 K (includes 1 sysadmin / 100 nodes)
    - using 0.45:0.4:0.15 split for hardware:power:network and 3 year lifetime of hardware



# Single site Cloud: to Outsource or Own?

- Breakeven analysis: **more preferable to own if:**
  - $\$349 \text{ K} / M < \$62 \text{ K}$  (storage)
  - $\$1555 \text{ K} / M + 7.5 \text{ K} < \$136 \text{ K}$  (overall)
- Breakeven points*
  - $M > 5.55$  months (storage)
  - $M > 12$  months (overall)
- As a result
  - **Startups use clouds a lot**
  - **Cloud providers benefit monetarily most from storage**

# Academic Clouds: Emulab/CloudLab

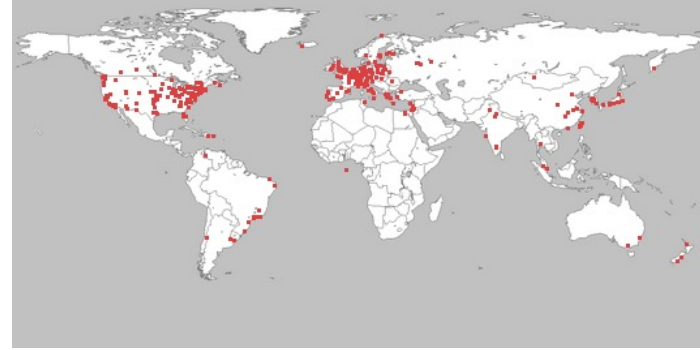


- A community resource open to researchers in academia and industry. Very widely used by researchers everywhere today.
- <https://www.emulab.net/>
- A cluster, with currently ~500 servers
- Founded and owned by University of Utah (led by Late Prof. Jay Lepreau)
- As a user, you can:
  - Grab a set of machines for your experiment
  - You get root-level (sudo) access to these machines
  - You can specify a network topology for your cluster
  - You can emulate any topology



# PLANETLAB

An open platform for developing, deploying, and accessing planetary-scale services



All images © PlanetLab

- A community resource open to researchers in academia and industry
- <http://www.planet-lab.org/>
- Currently, ~ 1077 nodes at ~500 sites across the world
- Founded at Princeton University (led by Prof. Larry Peterson), but owned in a federated manner by the sites
  
- Node: Dedicated server that runs components of PlanetLab services.
- Site: A location, e.g., UIUC, that hosts a number of nodes.
- **Sliver**: Virtual division of each node. Currently, uses VMs, but it could also other technology. Needed for timesharing across users.
- **Slice**: A spatial cut-up of the PL nodes. Per user. A slice is a way of giving each user (Unix-shell like) access to a subset of PL machines, selected by the user. A slice consists of multiple slivers, one at each component node.
- Thus, PlanetLab allows you to run real world-wide experiments.
- Many services have been deployed atop it, used by millions (not just researchers): Application-level DNS services, Monitoring services, CoralCDN, etc.
- PlanetLab is basis for NSF GENI <https://www.geni.net/>

# Public Research Clouds

- Accessible to researchers with a qualifying grant
- Chameleon Cloud: <https://www.chameleoncloud.org/>
  - HaaS
  - OpenStack (~AWS)
- CloudLab: <https://www.cloudlab.us/>
  - Build your own cloud on their hardware

# Summary

- Clouds build on many previous generations of distributed systems
- Especially the timesharing and data processing industry of the 1960-70s.
- Need to identify unique aspects of a problem to classify it as a new cloud computing problem
  - Scale, On-demand access, data-intensive, new programming
- Otherwise, the solutions to your problem may already exist!
- Next: Mapreduce!

# Announcements

- **4 cr only: MP Groups Form DUE this week Mon Aug 28<sup>th</sup> @ 5 pm** (see course webpage).
  - **Hard deadline, as Engr-IT will create and assign VMs tomorrow!**
- **DO NOT**
  - Change MP groups unless your partner has dropped
  - Leave your MP partner hanging: Both MP partners should contribute equally (we will ask!)
- **All: Please fill out Student Survey by 8/31 (see course webpage).**
- MP1 due Sep 10<sup>th</sup>
  - VMs being distributed soon (watch Piazza)
  - Demos will be Monday Sep 11<sup>th</sup> (schedule and details will be posted soon on Piazza)
- HW1 due Sep 13<sup>th</sup>: Solve problems right after lecture covers topic!
- Check Piazza often! It's where all the announcements are at!