CS 525
Advanced Distributed Systems
Spring 2017

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Lecture 2

What('s in) the Cloud?

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amazon web services

Google Cloud Platform

Microsoft Azure

Google App Engine

RightScale

ORACLE

GridGain 2.0

Elastic Server

VirtualBox

virtualLogix

vmware

force.com platform as a service

CITRIX

OpenVZ

KVM

10gen

parascale Powering Cloud Storage

hp

Microsoft

Xen

GIGASPACES

Parallels Optimized Computing

RightScale

enomaly

elastra

ORACLE

BUNGEEconnect

PowerVM

Virtualiron

The Hype!

- Gartner (2016) – Cloud shift will affect $1 Trillion in IT by 2020
  - http://www.gartner.com/newsroom/id/3384720
- Public Cloud Market $208 B by 2016 end
  - http://www.informationweek.com/cloud/public-cloud-market-worth-$208-billion-by-end-of-2016/d/d-id/1326923
- Hadoop market size to reach $40.6 B by 2021
  - http://www.marketsandmarkets.com/PressReleases/hadoop.asp
- Everyone is using public clouds: startups, large companies, non-profits, governments

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
- 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
  - Amazon EC2 (Elastic Compute Cloud): upload and run arbitrary OS images, pay per CPU hour used
  - 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 $$$

- (Anecdotes from around 2012)
- 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!

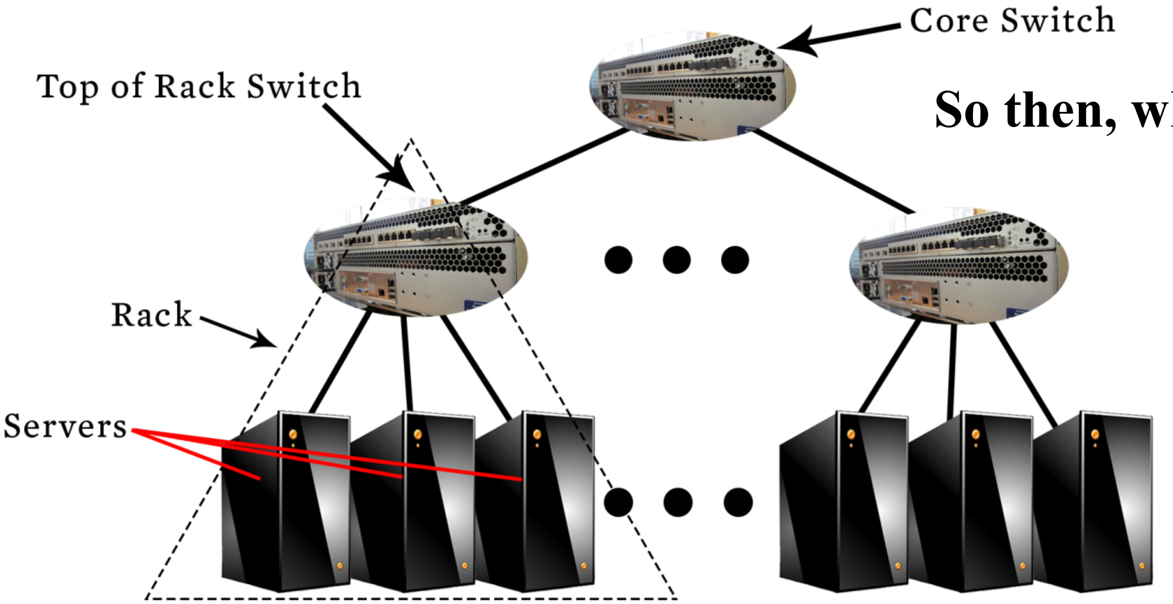
- None of the above
- All of the above

- Cloud = Lots of storage + compute cycles nearby

What is a Cloud?

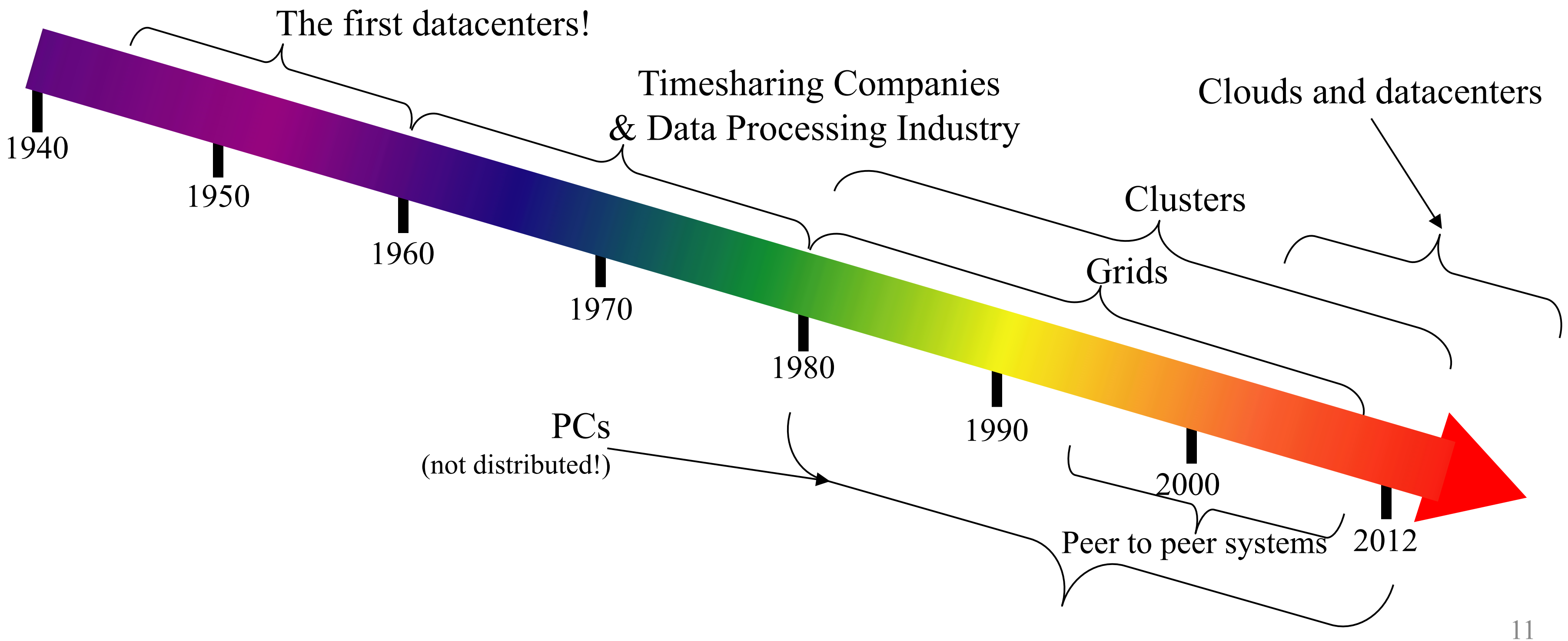
- A single-site cloud (aka “Datacenter”) consists of
  - Compute nodes (grouped into racks)
  - Switches, connecting the racks
  - A network topology, e.g., hierarchical
  - Storage (backend) nodes connected to the network
  - Front-end for submitting jobs and receiving client requests
  - (Often called 3-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



So then, what is a cluster?

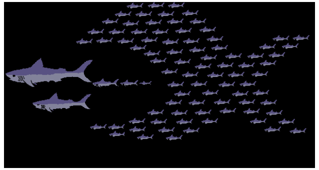
"A Cloudy History of Time"



“A Cloudy History of Time”

First large datacenters: ENIAC, ORDVAC, ILLIAC
Many used vacuum tubes and mechanical relays

1940 1950 1960 1970 1980 1990 2000 2012

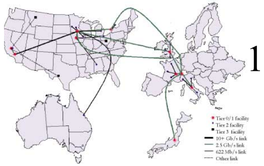


Berkeley NOW Project
Supercomputers
Server Farms (e.g., Oceano)

P2P Systems (90s-00s)
- Many Millions of users
- Many GB per day

Data Processing Industry
- 1968: $70 M. 1978: $3.15 Billion

Timesharing Industry (1975):
- Market Share: Honeywell 34%, IBM 15%,
- Xerox 10%, CDC 10%, DEC 10%, UNIVAC 10%
- Honeywell 6000 & 635, IBM 370/168, Xerox 940 & Sigma 9, DEC PDP-10, UNIVAC 1108



Grids (1980s-2000s):
- GriPhyN (1970s-80s)
- Open Science Grid and Lambda Rail (2000s)
- Globus & other standards (1990s-2000s)

Clouds

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
    - 2017: 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
  - 2017: CERN’s Large Hadron Collider producing 30 PB/year
    - https://home.cern/about/computing

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
- 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: A lot

What does a datacenter look like from inside?

- A virtual walk through a datacenter
- Reference: http://gigaom.com/cleantech/a-rare-look-inside-facebooks-oregon-data-center-photos-video/

Servers

Front

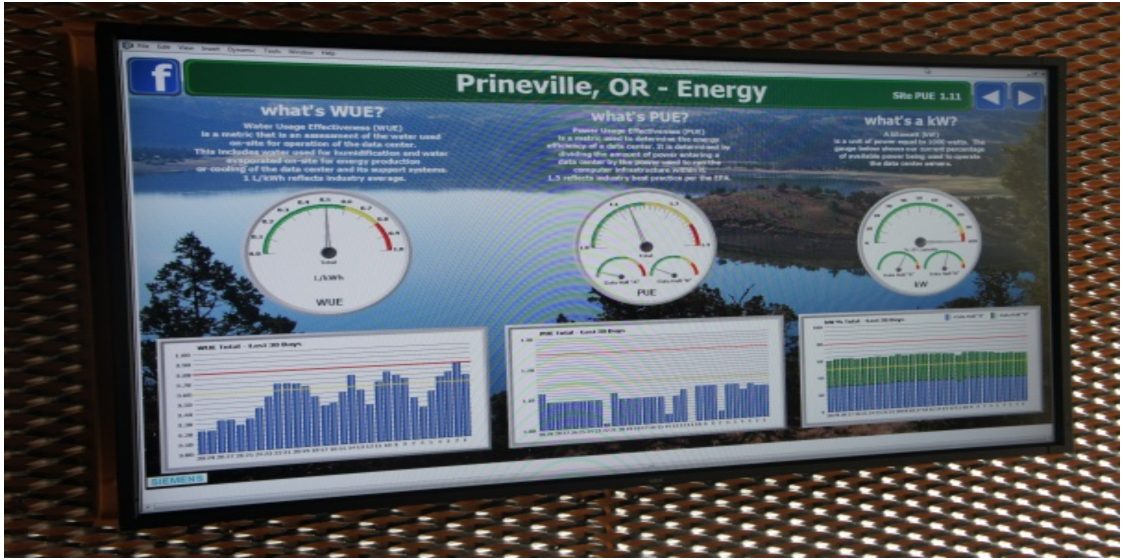
Back

In

Some highly secure (e.g., financial info)

Power

Off-site



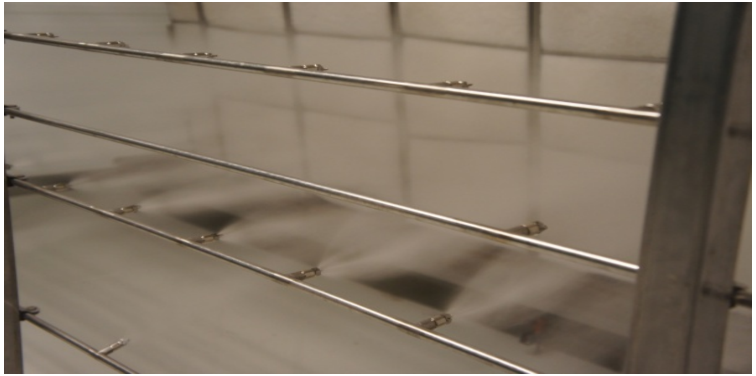
On-site

- 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)

Cooling

Air sucked in from top (also, Bugzappers)

Water purified



Water sprayed into air

15 motors per server bank

Extra - Fun Videos to Watch

- [Microsoft GFS Datacenter Tour (Youtube)](http://www.youtube.com/watch?v=hOxA1l1pQIw)
  - http://www.youtube.com/watch?v=hOxA1l1pQIw

- [Timelapse of a Datacenter Construction on the Inside (Fortune 500 company)](http://www.youtube.com/watch?v=ujO-xNvXj3g)
  - 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 is one way of achieving this (other ways: cgroups, Kubernetes, Dockers, VMs,…).
  - Ex: Amazon Web Services (AWS: EC2 and S3), 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 on demand

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)
  - Hadoop clusters in some companies typically have CPU utilization rates of around 20% (while I/O-–either network or disk—is being maxed out)

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
  - Facebook (Hadoop + Hive)
    - ~300TB total, adding 2TB/day (in 2008)
    - 3K jobs processing 55TB/day
  - Many other frameworks: Storm/Flink/Samza, Spark, TensorFlow, …
  - 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
- All costs circa 2009
- 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

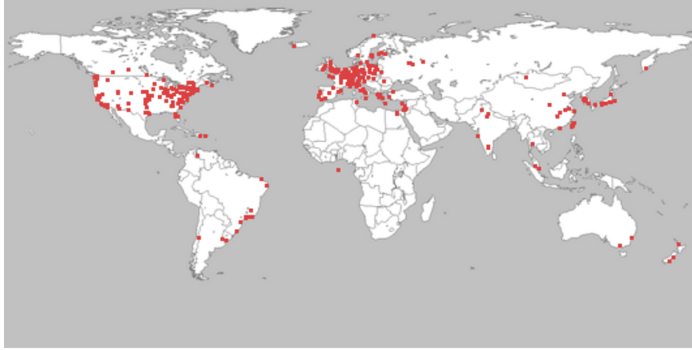
- A community resource open to researchers in academia and industry. Very widely used by researchers everywhere today.
- https://www.emulab.net/
- A cluster, with currently ~500 servers
- Founded and owned by University of Utah (led by Late Prof. Jay Lepreau)

- 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

All images © Emulab

PLANETLAB

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



- 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

All images © PlanetLab

- 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 and projects have been deployed atop it, used by millions (not just researchers): Application-level DNS services, Monitoring services, CoralCDN, etc.

Speaking of Projects…

- For now, it's important to start thinking of who's going to be on your project team…

Projects

- Groups of 2-3.
- We'll start detailed discussions "soon" (early Feb), but start discussing ideas now (start by browsing the Course Schedule)
  - Read ahead, especially the "More papers" in sections later in the course (and sections not covered in the course, i.e., marked "Leftover")

Selecting your Team is Important

- Selecting your partner is important: select someone with a complementary personality to yours!
  - Apple: Wozniak loved being an engineer and hated interacting with people, Jobs loved making calls, doing sales and preferred engineering much less
  - Flickr: Stewart was improvisational, Fake was goal-driven
  - Paypal: Levchin loved to program and break things, Thiel talked to VCs and did sales.
  - RoR: Hansson says that development of Ruby on Rails benefited from having a small team and a small budget that kept them focused – this is why the big giants could not beat them.
- The upshot is that you have to select a team with complementary characteristics
- Selecting your team – 1) DIY or 2) use Piazza or 3) just hang back after class today
- Piazza is up (link from course website)

Presentations and Scribes

Student-led paper presentations (see instructions on website)

- **Start from February 9th**
- **Groups of up to 2 students present** each class, responsible for a set of 2 "Main Papers" on a topic
  - 45 minute presentations (total) followed by discussion
  - ***Email me slides at least 24 hours before the presentation time***
  - **Select your topic by Jan 31st - visit me in OH to sign up**
- **Plus one Scribe**
  - summarize Piazza, lead discussion at end of class, and post a scribe summary after class
  - **Sign up by Jan 31st**
- **Everyone in the class must participate as a presenter or scribe for at least one session**
- List of papers is up on the website – these are the papers that will be presented.

Administrative Announcements (2)

- Each of the *other* students (non-presenters/scribers) expected to **read the papers before class** and turn in a one to two page **review** of the **two** main papers (summary, comments, criticisms and possible future directions)
  - Post review on Piazza **before noon** on day of class
  - Reviews are not due until student presentations start
- You must review all sessions on+after 2/9 (except the one your present/scribe in)
- We highly recommend doing a presentation – you learn more and it's overall less work
  - But sign up early before the slots are gone!

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!