The Hype!

• Forrester in 2010 – Cloud computing will go from $40.7 billion in 2010 to $241 billion in 2020.
• Goldman Sachs says cloud computing will grow at annual rate of 30% from 2013-2018
• Hadoop market to reach $20.8 B by by 2018: Transparency Market Research
• 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
• 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 $$$

• 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"

1940: The first datacenters!

1950: Timesharing Companies & Data Processing Industry

1960: Clusters

1970: Grids

1980: Clouds and datacenters

1990: PCs (not distributed!)

2000: Peer to peer systems

2012: Clouds and datacenters
“A Cloudy History of Time”


Clouds

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

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

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

Berkeley NOW Project
Supercomputers
Server Farms (e.g., Oceano)
P2P Systems (90s-00s)
• Many Millions of users
• Many GB per day

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

1980

Globus & other standards (1990s-2000s)

1970

GriPhyN (1970s-80s)

1960

Open Science Grid

1950

1940

IBM

Honeywell

xerox

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

1970

CRAY

1980

1990

2000

BitTorrent

2012

LimeWire

KazaA

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

First large datacenters: ENIAC, ORDVAC, ILLIAC
Many used vacuum tubes and mechanical relays
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
    • 2014: 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
    – 2012: 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
- 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:
Servers

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~1.11)
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=hOxA11lpQIw](http://www.youtube.com/watch?v=hOxA11lpQIw)

- **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 (cgroups, Kubernetes, Dockers, VMs,…). Often said to subsume HaaS.
  - 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)
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
  - 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
  - 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 \times 524 \times 1000 \sim $62 K
  - Total = Storage + CPUs = $62 K + $0.10 \times 1024 \times 24 \times 30 \sim $136 K
- **Own**: monthly cost
  - Storage \sim $349 K / M
  - Total \sim $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 \text{ months (storage)}$
- $ M > 12 \text{ 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/](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
• A community resource open to researchers in academia and industry
• [http://www.planet-lab.org/](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 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”)

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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 11th**
- **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 28th - 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 28th
- **Everyone in the class must participate as a presenter or scribe for at least one session**
- **List of papers is up on the website**
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 2/11 (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!