What was the world’s first bug in a program?
Quiz: Where is the World’s Largest Datacenter?
Quiz: Where is the World’s Largest Datacenter?

• (2020) Range International Info Group, China, 6.3 Million sq. ft.
• (2018) China Telecom. 10.7 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:
(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 $200B

- 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
    • As of 2022: 0.09c-2 c per GB month
  – Amazon EC2 (Elastic Compute Cloud): upload and run arbitrary OS images, pay per CPU hour used
    • As of 2022: 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 $$$

- 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)
    – (1-3: 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
So then, what is a cluster?
“A Cloudy History of Time”

1940
1950
1960
1970
1980
1990
2000
2012

The first datacenters!
Timesharing Companies & Data Processing Industry
Clusters
Grids
Clouds and datacenters

PCs
(not distributed!)

Peer to peer systems
“A Cloudy History of Time”

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

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)

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
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
    • 2015: 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
Servers

In some highly secure (e.g., financial info)
Cooling

Air sucked in from top (also, Bugzappers)

Water sprayed into air

Water purified

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](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](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 K / M < $62 K (storage)
  - $ 1555 K / M + 7.5 K < $136 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/](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
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/](https://www.chameleoncloud.org/)
  - HaaS
  - OpenStack (~AWS)
- CloudLab: [https://www.cloudlab.us/](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!
(Joke Transition slide) Today’s Agenda

WHEN CLOUD
Why Outsourcing is Bad for Business

Map

(Mercator Map)

Reduce