Electrical Engineering & Computer Science

COLLEGE OF ENGINEERING

Introduction to Cloud Computing

ECE 599 / CS 519 – SPRING 2015

Material based on Lectures by Indy Gupta (IG)

Recap: What is a distributed system?

FOLDOC definition

A collection of (probably heterogeneous) automata whose distribution is transparent to the user so that the system appears as one local machine. This is in contrast to a network, where the user is aware that there are several machines, and their location, storage replication, load balancing and functionality is not transparent. Distributed systems usually use some kind of client-server organization.

Textbook definitions

- A distributed system is a collection of independent computers that appear to the users of the system as a single computer.

  [Andrew Tanenbaum]

- A distributed system is several computers doing something together. Thus, a distributed system has three primary characteristics: multiple computers, interconnections, and shared state.

  [Michael Schroeder]

A working definition for us

A distributed system is a collection of entities, each of which is autonomous, programmable, asynchronous and failure-prone, and which communicate through an unreliable communication medium.

- Entity=a process on a device (PC, PDA)
- Communication Medium=Wired or wireless network
- Our interest in distributed systems involves
  - design and implementation, maintenance, algorithms

Some examples of Distributed Systems

- Client-Server (NFS)
- The Web
- The Internet
- A wireless network
- DNS
- Gnutella or BitTorrent (peer to peer overlays)
- A "cloud", e.g., Amazon EC2/S3, Microsoft Azure
- A datacenter, e.g., NCSA, a Google datacenter, The Planet

"Important" Distributed Systems Issues

- No global clock; no single global notion of the correct time (asynchrony)
- Unpredictable failures of components: lack of response may be due to either failure of a network component, network path being down, or a computer crash (failure-prone, unreliable)
- Highly variable bandwidth: from 16Kbps (slow modems or Google Balloon) to Gbps (Internet2) to Tbps (in between DCs of same big company)
- Possibly large and variable latency: few ms to several seconds
- Large numbers of hosts: 2 to several million

Many Interesting Design Problems

- Real distributed systems
  - Cloud Computing, Peer to peer systems, Hadoop, key-value stores/NoSQL, distributed file systems, sensor networks, measurements, graph processing, stream processing, …
- Classical Problems
  - Failure detection, Asynchrony, Snapshots, Multicast, Consensus, Mutual Exclusion, Election, …
- Concurrency
  - RPCs, Concurrency Control, Replication Control, …
- Security
  - Byzantine Faults, …
- Others…

Typical Distributed Systems Design Goals

- Common Goals:
  - Heterogeneity – can the system handle a large variety of types of PCs and devices?
  - Robustness – is the system resilient to host crashes and failures, and to the network dropping messages?
  - Availability – are data+services always there for clients?
  - Transparency – can the system hide its internal workings from the users?
  - Concurrency – can the server handle multiple clients simultaneously?
  - Efficiency – is the service fast enough? Does it utilize 100% of all resources?
  - Scalability – can it handle 100 million nodes without degrading service? (nodes=clients and/or servers) How about 6 B? More?
  - Security – can the system withstand hacker attacks?
  - Openness – is the system extensible?

What is Cloud Computing?


Google App Engine
amazon webservices
RIGHTSCALE
ORACLE
GridGain 2.0
Elastic Server
VirtualBox
virtualLogix
vmware
force.com platform as a service
CITRIX
OpenVZ
KVM
10gen
Microsoft
parascale Powering Cloud Storage
hp
Xen
GIGASPACES
Parallels Optimized Computing
RIGHTSCALE
enomaly
elastra
ORACLE
BUNGEEconnect
PowerVM
virtualiron

The Hype!

- Forrester in 2010 – Cloud computing will go from $40.7 billion in 2010 to $241 billion in 2020.
- Gartner in 2009 - Cloud computing revenue will soar faster than expected and will exceed $150 billion by 2013. It will represent 19% of IT spending by 2015.
- IDC in 2009: “Spending on IT cloud services will triple in the next 5 years, reaching $42 billion.”
- Companies and even Federal/state governments using cloud computing now: fedbizopps.gov

Many Cloud Providers

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

Two Main 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!

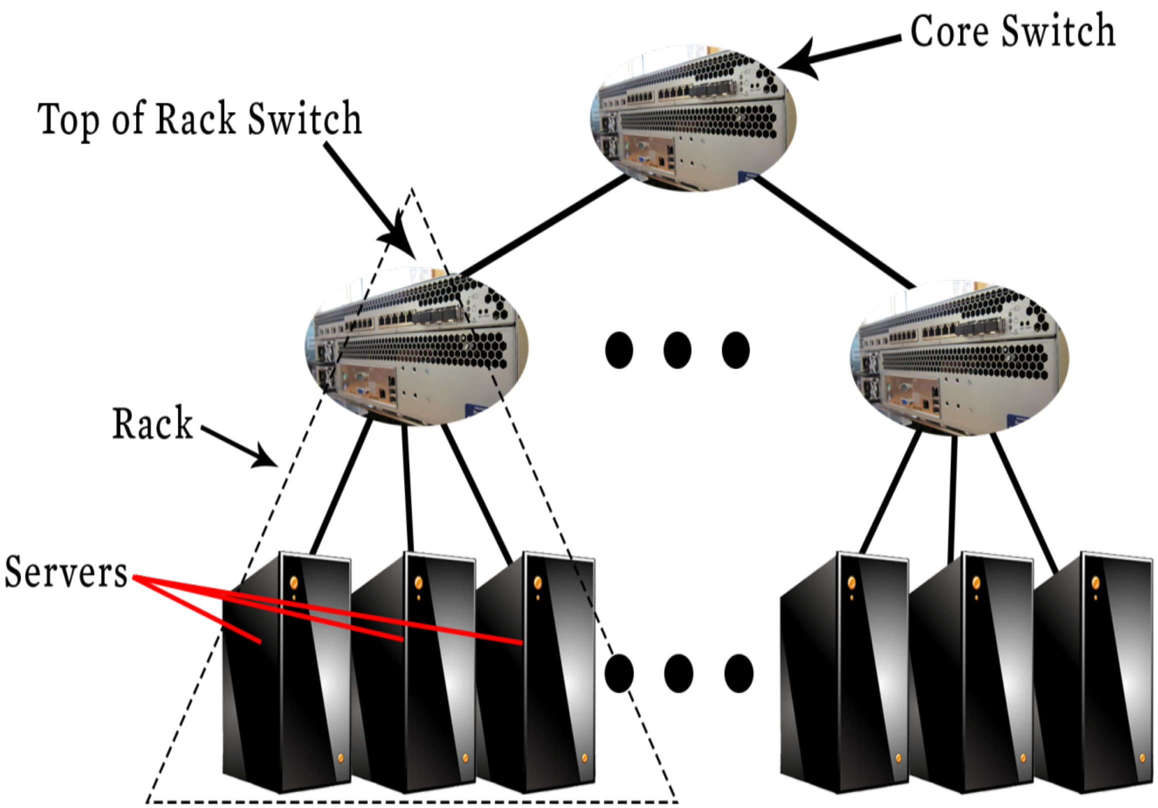
- None of the above
- All of the above

- Cloud = Lots of storage + compute cycles nearby

What is a Cloud?

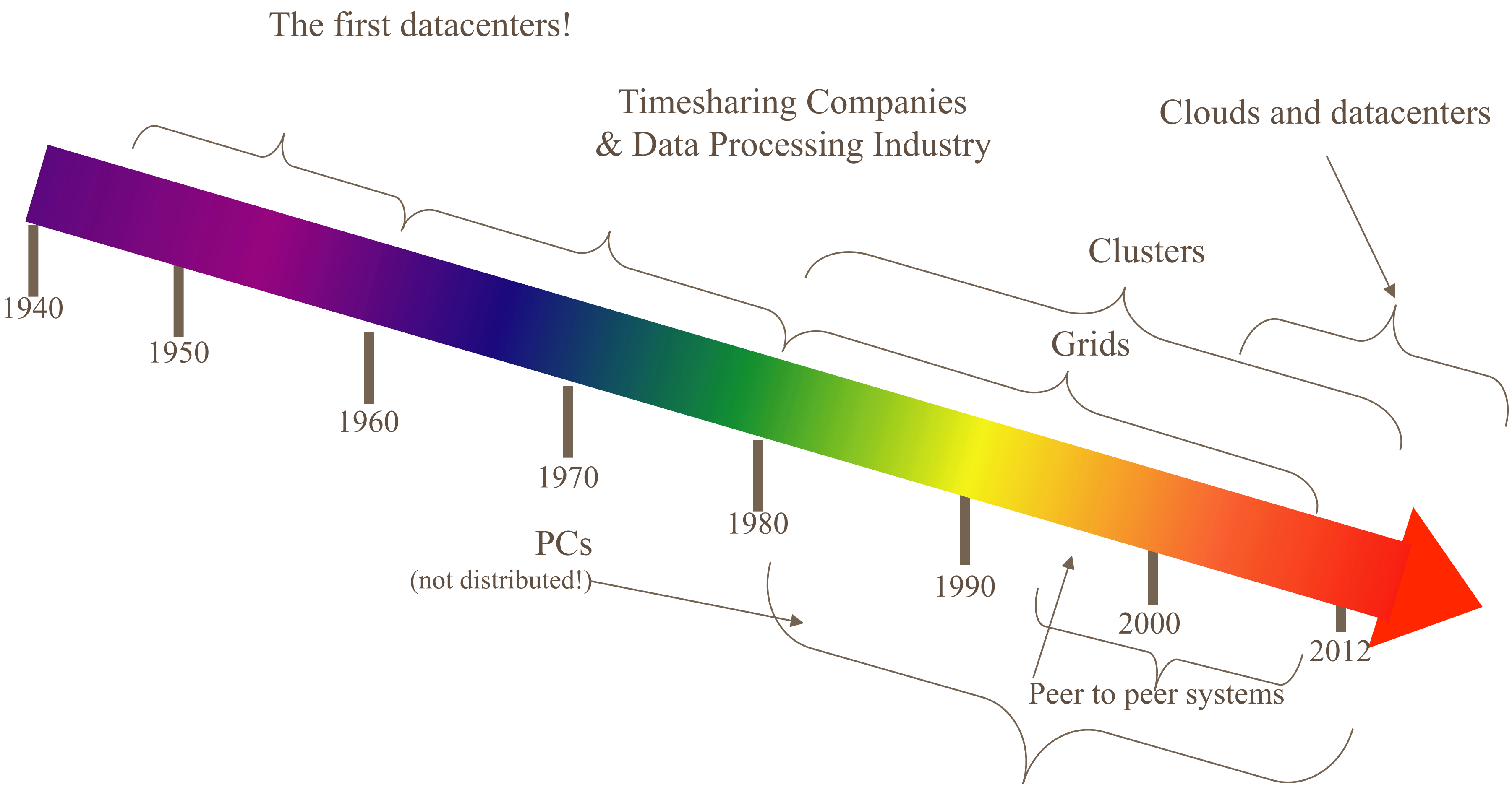
- A single-site cloud (aka "Datacenter") consists of
  - Compute nodes (grouped into racks)
  - Switches, connecting the racks
  - A network topology, e.g., hierarchical
  - Storage (backend) nodes connected to the network
  - Front-end for submitting jobs and receiving client requests
  - (Often called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



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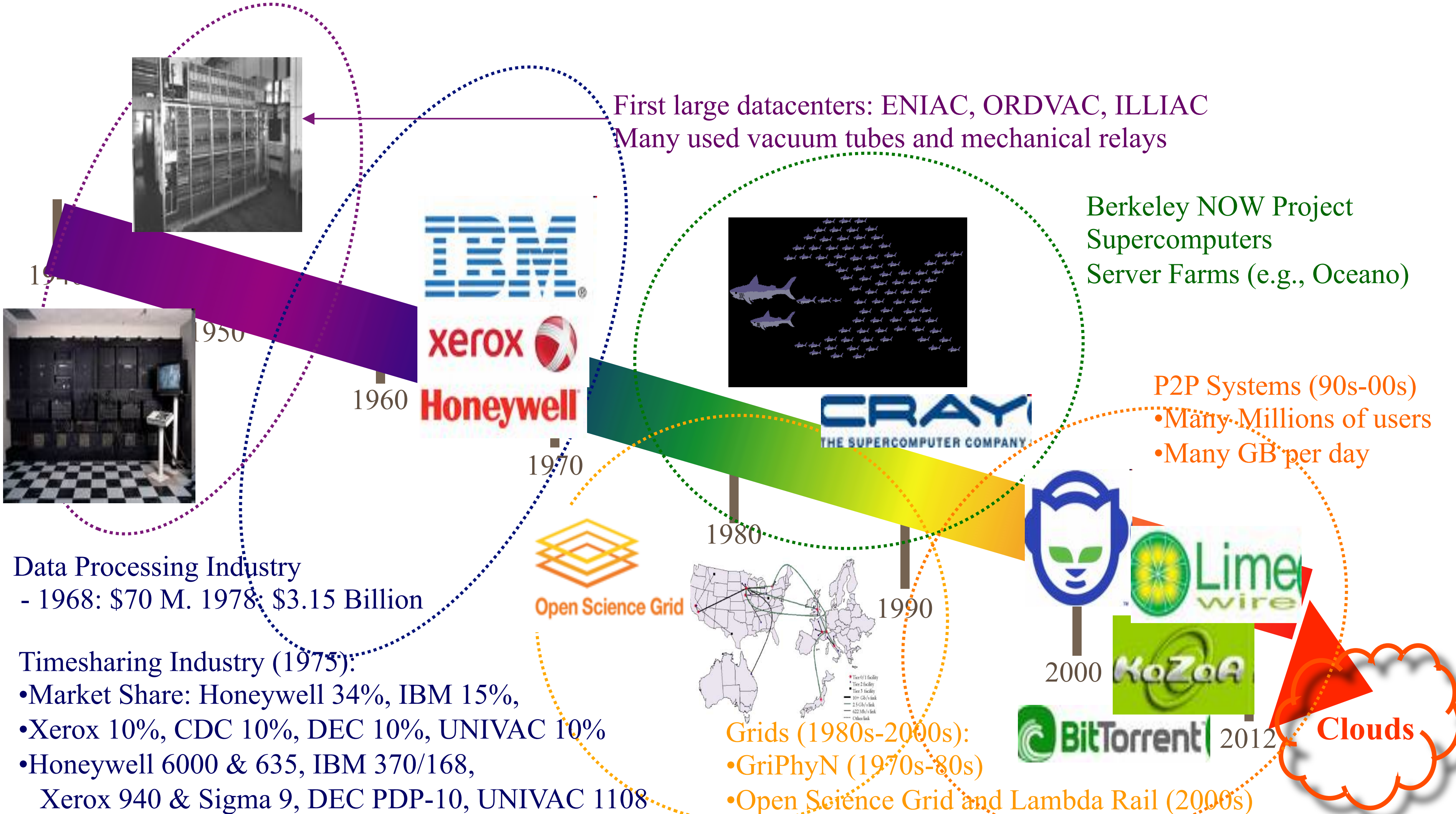


First large datacenters: ENIAC, ORDVAC, ILLIAC
Many used vacuum tubes and mechanical relays

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)

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: http://gigaom.com/cleantech/a-rare-look-inside-facebooks-oregon-data-center-photos-video/

Servers

Front

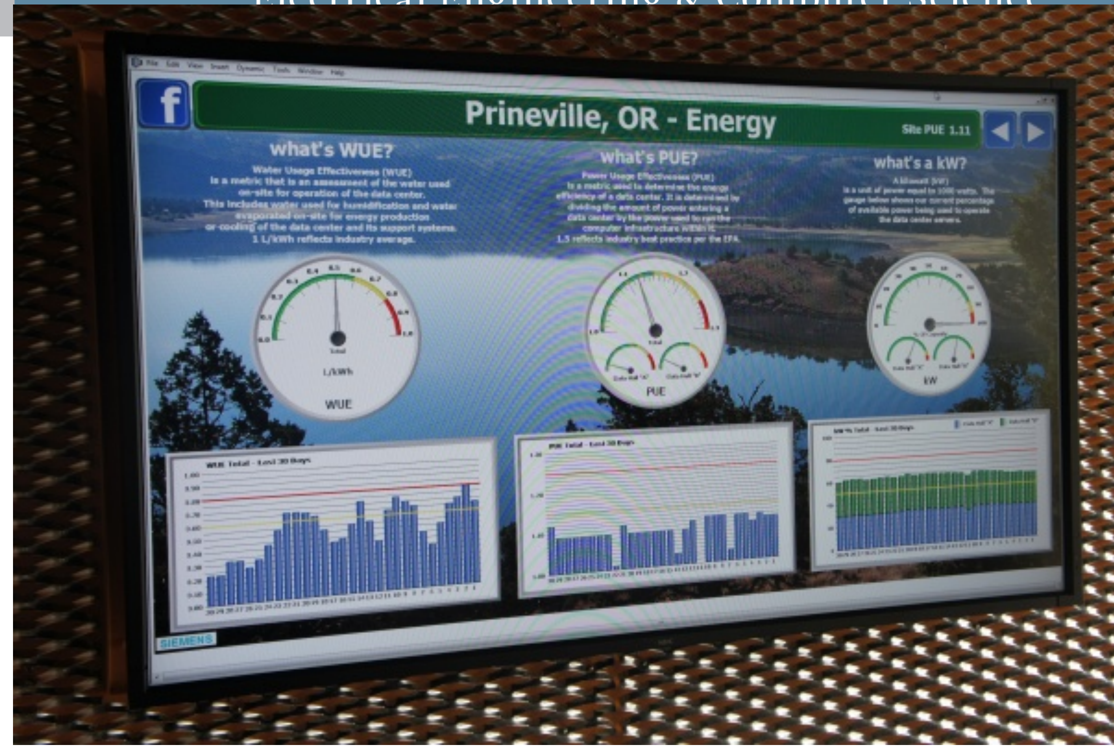
Back

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~1.11)

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=hOxA1l1pQIw

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 to a few $ 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. Often said to subsume HaaS.
  - Ex: Amazon Web Services (AWS: EC2 and S3), Eucalyptus, Rightscale, Microsoft Azure, Google Compute Engine.

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
- 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

emulab
total network testbed

- 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

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.

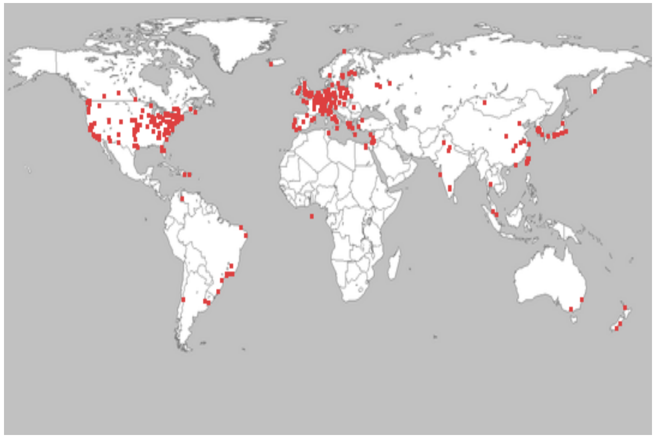
Site: A location, e.g., UIUC, that hosts a number of nodes.

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.



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!