Above the Clouds: 
A Berkeley View of Cloud Computing

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Reliable Adaptive Distributed Systems Lab

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Image: John Curley http://www.flickr.com/photos/jay_que/1834540/
• What is distributed computing?
• What is warehouse-scale computing?
• What is cloud computing?
• Why should you care?
What is distributed computing?
• The first demonstration of how to build really large Internet sites out of *clusters* of computers was done by:

(a) Stanford
(b) Berkeley
(c) Yahoo!
(d) Google
(e) IBM
Big Computers c. 1996

Sun E-10000 “supermini”
- Up to 64 processors @250MHz
- Up to 64 GB RAM
- Up to 20 TB Disk
- Used by eBay, among others

PC
- 200 MHz CPU, 32MB RAM, 4 GB disk
UC Berkeley Networks Of Workstations (1994-1999)
NOW-0

1994

Four HP-735’s
NOW-1

1995

32 Sun SPARC-stations
NOW-2

1997

60 Sun SPARC-2
• A Google datacenter built c.2005 would be designed to house approximately _______ computers.

(a) 1,000
(b) 5,000
(c) 10,000
(d) 50,000
(e) 100,000
Challenge: how do you program a NOW? (or: what is it good for?)
The Killer App for NOWs

• Prof. Eric Brewer, Armando Fox, Steve Gribble, Paul Gauthier, Yatin Chawathe: *Cluster-Based Scalable Network Servers* in Symposium on Operating Systems Principles, 1997

• **Non-goal**: build best/fastest search engine
  – But led to Inktomi, first *truly scalable* search engine that took advantage of NOW ideas

• **Goal**: show general techniques for programming NOW’s for Internet services
Access Is the Killer App!
UC Berkeley, 1994-1999

- Project Daedalus: Profs. Katz & Brewer
- Data, services in infrastructure cloud
  - search, email, personal comms, productivity...
- Mobile access anywhere, anytime
- Many “firsts”:
  - server architecture with auto-scaling
  - cluster-based Internet service: Inktomi
  - mobile Web: TopGun Wingman on Palm

Challenge: deploying the service!
2005: *Datacenter* is new “server”

- “Program” => Web search, email, map/GIS, …
- “Computer” => 1000’s computers, storage, network
- Warehouse-sized facilities and workloads

photos: Sun Microsystems, CNET, & datacenterknowledge.com
RAD Lab 5-year Mission

Enable **1 person** to develop, deploy, operate next-generation Internet application

- Key enabling technology: Statistical machine learning
- Highly interdisciplinary faculty & students
  - 7 faculty across CS, from theory to systems
  - 2 postdocs, ~30 PhD students, ~5 undergrads
Utility Computing Arrives

- Amazon Elastic Compute Cloud (EC2)
- “Compute unit” rental: $0.08-0.80/hr.
  - 1 CU ≈ 1.0-1.2 GHz 2007 AMD Opteron/Xeon core

<table>
<thead>
<tr>
<th>“Instances”</th>
<th>Platform</th>
<th>Cores</th>
<th>Memory</th>
<th>Disk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small - $0.10 / hr</td>
<td>32-bit</td>
<td>1</td>
<td>1.7 GB</td>
<td>160 GB</td>
</tr>
<tr>
<td>Large - $0.40 / hr</td>
<td>64-bit</td>
<td>4</td>
<td>7.5 GB</td>
<td>850 GB – 2 spindles</td>
</tr>
<tr>
<td>XLarge - $0.80 / hr</td>
<td>64-bit</td>
<td>8</td>
<td>15.0 GB</td>
<td>1690 GB – 3 spindles</td>
</tr>
</tbody>
</table>

- No up-front cost, no contract, no minimum
- Billing rounded to nearest hour; pay-as-you-go storage also available
- A new paradigm for deploying services?
But...

What *is* cloud computing, exactly?
“...we’ve redefined Cloud Computing to include everything that we already do... I don’t understand what we would do differently ... other than change the wording of some of our ads.”

– Larry Ellison, CEO, Oracle
(Wall Street Journal, Sept. 26, 2008)
Above the Clouds: A Berkeley View of Cloud Computing

abovetheclouds.cs.berkeley.edu

• 2/09 White paper by RAD Lab PI’s and students
• Goal: stimulate discussion on what’s really new
  – Clarify terminology
  – Comparison with conventional computing
  – Identify challenges & opportunities
• Why can we offer new perspective?
  – Strong engagement with industry
  – Users of cloud computing in our own research and teaching
• Over 60,000 downloads
Above The Clouds Impact

• Research collaborations/hires: Amazon, Google, Microsoft, Twitter, Facebook, Cloudera, Yahoo!...

• Invited presentations/advice
  – Google, Fujitsu, IBM, HP, Microsoft, SAP, Juniper, ...
  – World Economic Forum
  – Nat’l Academy of Engineering
  – OpenCirrus Summit
  – UCB Office of the CIO
  – UC Systemwide Cloud Computing Task Force

UCB is academic leader in cloud computing in both research & education
• Old idea: Software as a Service (SaaS)
  – Software hosted in the infrastructure vs. installed on local servers or desktops; dumb (but brawny) terminals

• New: pay-as-you-go utility computing
  – Illusion of infinite resources on demand
  – Fine-grained billing: release == don’t pay
  – Earlier examples: Sun, Intel Computing Services
    – longer commitment, more $$$/hour, no storage
  – Public (utility) vs. private clouds
• How much data per month, approximately, is processed through Google’s *BigTable* storage system?

(a) 1 TB (1,000 GB)
(b) 100 TB
(c) 1 PB (1,000 TB)
(d) 100 PB
(e) 1 EB (exabyte = 1,000 PB)
Why Now (not then)?

- The Web “Space Race”: Build-out of extremely large datacenters (10,000’s of commodity PCs)
- Driven by growth in demand (more users)
  - Infrastructure software: e.g., Google File System
  - Operational expertise
  - Discovered economy of scale: 5-7x cheaper than provisioning a medium-sized (100’s machines) facility
- More pervasive broadband Internet
- Free & open source software
• Static provisioning for peak - wasteful, but necessary for SLA

“Statically provisioned” data center

“Virtual” data center in the cloud

Unused resources
• Underutilization results if “peak” predictions are too optimistic

Static data center

Unused resources
Risks of Under Provisioning

- Lost revenue
- Lost users

Risks during different time periods (days): 1, 2, 3
What can you do with this?
• 1,000 CPUs for 1 hour same price as 1 CPU for 1,000 hours

• Washington Post converted Hillary Clinton’s travel documents to post on WWW
  – Conversion time: <1 day after released
  – Cost: less than $200

• RAD Lab graduate students demonstrate improved MapReduce scheduling—on 1,000 servers
Risk transfer

• 2001: CNN home page meltdown on 9/11
  – ~10x traffic increase in ~15 minutes
  – result: site had to go offline

• 2008: Animoto
  – traffic doubled every 12 hours for 3 days when released as Facebook plug-in
  – Scaled from 50 to >3500 servers
  – ...then scaled back down
# Indexing the Web

**To be or not to be...**

<table>
<thead>
<tr>
<th>to</th>
<th>A</th>
</tr>
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<tbody>
<tr>
<td>be</td>
<td>A</td>
</tr>
<tr>
<td>or</td>
<td>A</td>
</tr>
<tr>
<td>not</td>
<td>A</td>
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</tbody>
</table>

...or a better fool...

<table>
<thead>
<tr>
<th>or</th>
<th>B</th>
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<tbody>
<tr>
<td>a</td>
<td>B</td>
</tr>
<tr>
<td>better</td>
<td>B</td>
</tr>
<tr>
<td>fool</td>
<td>B</td>
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</table>

...better to love a fool...

<table>
<thead>
<tr>
<th>better</th>
<th>C</th>
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<tbody>
<tr>
<td>to</td>
<td>C</td>
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<tr>
<td>love</td>
<td>C</td>
</tr>
<tr>
<td>a</td>
<td>C</td>
</tr>
<tr>
<td>fool</td>
<td>C</td>
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</table>

**Map & Combine**

<table>
<thead>
<tr>
<th>to</th>
<th>be</th>
<th>or</th>
<th>not</th>
<th>better</th>
<th>love</th>
<th>a</th>
<th>fool</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,C</td>
<td>A</td>
<td>A,B</td>
<td>A</td>
<td>B,C</td>
<td>C</td>
<td>B,C</td>
<td>B,C</td>
</tr>
</tbody>
</table>
MapReduce in Practice

• Example: spam classification
  – training: $10^7$ URLs x 64KB data each = 640GB data
  – One heavy-duty server: ~270 hours
  – 100 servers in cloud: ~3 hours (= ~$255)

• Rapid uptake in other scientific research
  – Large-population genetic risk analysis & simulation (Harvard Medical School)
  – Genome sequencing (UNC Chapel Hill Cancer Ctr)
  – many others... so what’s the downside?
Challenges & Opportunities

- Challenges to adoption, growth, & business/policy models
- Both technical and nontechnical
- Most translate to 1 or more opportunities
- Complete list in paper; I’ll discuss subset
• Challenge: exposing parallelism
  – MapReduce relies on “embarrassing parallelism”
• Programmers must (re)write problems to expose this parallelism, if it’s there to be found
• Tools still primitive, though progressing rapidly
# Challenge: Big Data

<table>
<thead>
<tr>
<th>Application</th>
<th>Data generated per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA Sequencing (Illumina HiSeq machine)</td>
<td>1 TB</td>
</tr>
<tr>
<td>Large Synoptic Survey Telescope</td>
<td>30 TB; 400 Mbps sustained data rate between Chile and NCSA</td>
</tr>
<tr>
<td>Large Hadron Collider</td>
<td>60 TB</td>
</tr>
</tbody>
</table>

- Challenge: Long-haul networking is most expensive cloud resource, and improving most slowly
- Copy 8 TB to Amazon over ~20 Mbps network => ~35 days, ~$800 in transfer fees
- How about shipping 8TB drive to Amazon instead? => 1 day, ~$150 (shipping + transfer fees)

1. Berkeley research culture: integrate leading research into teaching at all levels

2. RAD Lab need for “killer apps” to show off infrastructure

Current efforts (student counts approximate):

• Great Ideas in Computer Architecture (reinvented Fall 2010): 190 students
• Software Engineering for SaaS (in its 4\textsuperscript{th} iteration): 50+50+50+70 students
• Operating Systems: 70 students
• Intro. Data Science (Spring 2010): 30
• Adv. topics in HCI: 20 students
• Natural language processing: 20 students
AWS is a great fit for courses...

• New undergraduate teaching opportunities
  – SaaS: make a database fall over—would need 200 servers for ~20 project teams
  – deploy projects publicly, many continue after course

• Better use of resources
  – Heavy usage right before lab deadlines
Success stories

Notifier is working now. If any newly posted found items' title matches notifiers' keywords, an email will be sent to user's email.

Signed up: Thu Jun 19 07:22:03 -0700 2008 by Chaochin Wang

Image upload
Users can upload up to 4 pictures for each of their last items after creating items.

Hesperian celebrates Clinton global initiative commitment and $2.7 million grant from the Bill and Melinda Gates Foundation

President Bill Clinton recently highlighted Hesperian's commitment to empower communities in combating the death and disease that a lack of safe drinking water and sanitation cause at the Clinton Global Initiative gathering in New York. Hesperian was also delighted to announce that it is the recipient of a $2.7 million grant from the Bill and Melinda Gates Foundation to update and expand one of our most important titles, Where There is No Doctor. 

Hesperian announces our new Spanish language website: http://espagnol.hesperian.org

This user-friendly, easy-to-navigate website offers all of the features of our website in English, current health news, information on issuing publications, and free down-loadable e-publications of most of our titles. Plus a complete translation, all in Spanish, ready to ship anywhere in the world. You can access the Spanish website by clicking on the ESPAÑOL button, located in the top right corner of this page.

Hesperian also works to address the critical need for health education for children who are deaf. And to that end, we have translated a deaf educators guide for the deaf and hard-of-hearing. Visit http://es.hesperian.org to learn more.

CommuterPool
Welcome to CommuterPool, a website designed to help you reduce commute pollution and save money too. If you own a car, you can easily find passengers to share the expenses or if you are looking for a ride, chances are somebody shares the same route.

How does it work?
- Create an account by clicking "Register"
- Enter your starting point and destination
- Browse among users who share the same route
- Choose your ride

Home and Post Ride
Enter either your own details or search the directory for a ride

SCHEDULE
LOGIN
BROWSE
RIDE
Summary

• Cloud computing *democratizes access* to “supercomputer-class” capability
  – All you need is a credit card
• Puts students, academia on more level playing field to have high impact in industry
• The next Google, eBay, Amazon, etc. can come from a small team of entrepreneurs even *without* heavy dose of $$ up front
• **2000**: using medium-sized clusters for Internet services => several PhD’s
• **2010**: CS169 students do it in 6-8 weeks and deploy on cloud computing
• **2020**: ?
Thank you!