To Cloud or Not To.

An exploration of the economics of clouds.

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Feynman Moment

“I have experience only in teaching graduate students [...] and as a result [...] I know that I don't know how to teach.”

please interrupt and engage!
The cloud

“Utility” Computing
- Transparency
- Availability
- Extremely cheap
- Efficient
- On-Demand

Online Services
- Software
- Platforms
- Infrastructure
- Knowledge

government corporations healthcare
consumers
mobile

knowledge
global, massive data centers
storage
e-services
Clouds v. Grids v. ...

+ Control Structure
+ Illusion of “Unlimited”
+ No up-front commitment (“pay as you go”)
+ On-demand
+ (Very) Short-term allocation
+ Close to 100% Transparency
+ Increased Platform Independence
+ It is actually here and happening!
Buzzword Bandwagon

On your marks, get set, GO
Race to results with the powerful Sun Grid Compute environment and our first class catalog of IaaS applications!

On Demand Business

Oracle Database 11g

Oracle 9i

Stony Brook Network Security and Applied Cryptography Laboratory
Flavors

Traditional Outsourcing [(Semi)Private Clouds]
ACME Corp. manages servers for XYZ Financials

Clouds
Amazon EC2, Google Apps, MS Azure

Managed servers

Un-managed hardware
Should I buy it?

costs vs. benefits

costs
- technology costs
- cost of security
- etc.

benefits
- availability
- opportunity
- consolidation
- etc.

the “cloud”

clients
Core costs of computing

+ Storage ($/MByte/year)
+ Computing ($/CPU Cycles)
+ Networking ($/bit)
Reality is way more mundane

**Hardware**

servers, disks, **network**, racks, power, cooling

**Energy**

power, cooling, infrastructure

**People/Service**

maintenance, development

**Space**
Size does matter

Home Users (1-10 CPUs)
“no” rent/cooling/administration

Small Enterprises (up to 1k)
no custom hardware, low utilization

Mid-size Enterprises (up to 20k)
better network service, better utilization

Large/Clouds (50k+)
Clouds

+ Custom hardware
+ Efficient cooling
+ Cross-timezone load shifting
+ High CPU utilization
+ Preferential network deals
+ High Power Usage Efficiency (PUE)
Understand cost of CPU cycle

<table>
<thead>
<tr>
<th>Parameters</th>
<th>H</th>
<th>S</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU utilization</td>
<td>5-8%</td>
<td>10-12%</td>
<td>15-20%</td>
<td>40-56%</td>
</tr>
<tr>
<td>server:admin ratio</td>
<td>N.A.</td>
<td>100-140</td>
<td>140-200</td>
<td>800-1000</td>
</tr>
<tr>
<td>Space (sqft/month)</td>
<td>N.A.</td>
<td>$0.5</td>
<td>$0.5</td>
<td>$0.25</td>
</tr>
<tr>
<td>PUE</td>
<td>N.A.</td>
<td>2-2.5</td>
<td>1.6-2</td>
<td>1.2-1.5</td>
</tr>
</tbody>
</table>

\[
\frac{\lambda_s \cdot N_s}{\tau_s} + (w_p \cdot \mu + w_i \cdot (1 - \mu)) \cdot PUE \cdot \lambda_e + \frac{N_s}{\alpha} \cdot \lambda_p + \lambda_w \cdot N_w/\tau_w + \lambda_f \cdot \left(\frac{w_p \cdot \mu + w_i \cdot (1 - \mu)}{\beta} \right) \cdot PUE
\]

\[
\mu \cdot \nu \cdot N_s
\]
CPU cycle cost (circa 2009)

1 picocent = $10^{-14}$ USD
## Consumer clouds today (cca. 2009)

<table>
<thead>
<tr>
<th>Provider</th>
<th>Picocents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google</td>
<td>0.5 – 2.31</td>
</tr>
<tr>
<td>Microsoft</td>
<td>0.7 – 1.96</td>
</tr>
<tr>
<td>Amazon</td>
<td>0.93 – 2.36</td>
</tr>
<tr>
<td>Rackspace</td>
<td>0.02 – 2.4</td>
</tr>
</tbody>
</table>
Amazon RDS (Q4, 2010)

Price ($/Hour)

- Small
- Large
- Xlarge
- 2Xlarge
- 4Xlarge

Standard
Multi-AZ

June 17, 2012
So: is it worth it?

Mostly yes ...

Why?

1 client cycle
6-27 US picocents

1 cloud cycle
0.58 picocents
What about the tubes?

THE INTERNET
A series of tubes.
We are far!
We are far!

<table>
<thead>
<tr>
<th>provider</th>
<th>monthly</th>
<th>bandwidth (d/u)</th>
<th>picocent/bit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$29.95</td>
<td>15 Mbps / 5 Mbps</td>
<td>77/231</td>
</tr>
<tr>
<td></td>
<td>$44.9</td>
<td>30 Mbps / 5 Mbps</td>
<td>58/346</td>
</tr>
<tr>
<td>$&gt;1000</td>
<td>5-1000 Mbps</td>
<td></td>
<td>5000 (est.)</td>
</tr>
<tr>
<td>$19.99</td>
<td>1 Mbps/384 Kbps</td>
<td></td>
<td>771/2008</td>
</tr>
<tr>
<td>$29.99</td>
<td>3 Mbps/768 Kbps</td>
<td></td>
<td>386/1506</td>
</tr>
<tr>
<td>$42.99</td>
<td>7.1 Mbps/768 Kbps</td>
<td></td>
<td>233/2160</td>
</tr>
<tr>
<td>Mid-size</td>
<td>$95 (est.)</td>
<td>1 Mbps (dedicated)</td>
<td>3665 (est.)</td>
</tr>
<tr>
<td>Large/cloud</td>
<td>$13 (est.)</td>
<td>1 Mbps (dedicated)</td>
<td>500 (est.)</td>
</tr>
</tbody>
</table>
### Additional ammunition?

**Table: Drive Comparison**

<table>
<thead>
<tr>
<th>Disk</th>
<th>cap. (GB)</th>
<th>price (USD)</th>
<th>Adj. MTBF (mil.hrs)</th>
<th>amort. acq. (pc)</th>
<th>power idle (W)</th>
<th>power cost (pc)</th>
<th>total cost (pc)</th>
<th>acq. %</th>
<th>avg. seek time (ms)</th>
<th>avg. seek cost (pc)</th>
<th>avg. seek4 cost (pcents)</th>
<th>power5 read (W)</th>
<th>read cost (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxtor Diamond Max</td>
<td>500</td>
<td>53</td>
<td>0.35</td>
<td>32.89</td>
<td>13.6</td>
<td>8.10</td>
<td>10.85</td>
<td>237.62</td>
<td>12.16</td>
<td>9.00</td>
<td>377542</td>
<td>11.16</td>
<td>0.03</td>
</tr>
<tr>
<td>Hitachi Deskstar 7k500</td>
<td>500</td>
<td>67</td>
<td>0.29</td>
<td>49.89</td>
<td>15</td>
<td>9.60</td>
<td>12.30</td>
<td>269.37</td>
<td>15.63</td>
<td>8.50</td>
<td>407953</td>
<td>27.38</td>
<td>0.02</td>
</tr>
<tr>
<td>Hitachi Ultrastar A7K1000</td>
<td>1024</td>
<td>153</td>
<td>0.35</td>
<td>46.36</td>
<td>14</td>
<td>9.00</td>
<td>11.50</td>
<td>122.97</td>
<td>16.93</td>
<td>8.20</td>
<td>417631</td>
<td>27.38</td>
<td>0.02</td>
</tr>
<tr>
<td>WD Caviar GP Low Power</td>
<td>1024</td>
<td>103</td>
<td>0.29</td>
<td>37.43</td>
<td>7.5</td>
<td>4.00</td>
<td>5.75</td>
<td>61.49</td>
<td>19.99</td>
<td>8.90</td>
<td>271994</td>
<td>7.40</td>
<td>0.02</td>
</tr>
<tr>
<td>Seagate Barracuda 7200.10</td>
<td>750</td>
<td>63</td>
<td>0.35</td>
<td>26.06</td>
<td>12.6</td>
<td>8.30</td>
<td>10.95</td>
<td>158.98</td>
<td>14.02</td>
<td>9.25</td>
<td>369615</td>
<td>13.00</td>
<td>0.06</td>
</tr>
<tr>
<td>WD Caviar SE16</td>
<td>500</td>
<td>62</td>
<td>N/A</td>
<td>8.77</td>
<td>8.40</td>
<td>8.59</td>
<td>188.01</td>
<td>9.90</td>
<td>8.77</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samsung SSD</td>
<td>32</td>
<td>269</td>
<td>0.29</td>
<td>3129.65</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>342.19</td>
<td>1.70</td>
<td>47912</td>
<td>0.5</td>
<td>0.0017</td>
<td></td>
</tr>
<tr>
<td>Intel SSD X18-M</td>
<td>80</td>
<td>389</td>
<td>0.35</td>
<td>1508.59</td>
<td>0.15</td>
<td>0.06</td>
<td>0.11</td>
<td>14.37</td>
<td>0.15</td>
<td>0.0002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intel SSD X25-M</td>
<td>160</td>
<td>765</td>
<td>0.35</td>
<td>1483.38</td>
<td>0.15</td>
<td>0.06</td>
<td>0.11</td>
<td>7.19</td>
<td>0.15</td>
<td>0.0002</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Up to 350 for 3 year lifetime!*
Storage capacity over time

![Graph showing storage capacity over time]

- X-axis: Year
- Y-axis: Capacity (GB)

The graph illustrates the increase in storage capacity from 1980 to 2015, with a significant upward trend.
So: should I buy a piece of sky?

... not always.

**CPU Cycle**
- 6-27 picocents

**1 bit storage/year**
- 6 picocents

**clients**

**1 bit network transfer**
- 800-6000 picocents

**CPU Cycle**
- 0.58 picocents

**1 bit storage/year**
- 5.3-6 picocents
So when is it clearly worth it?

Q: is the application doing enough computation work (cheaper) to offset the distance cost to the cloud?

First Principle of Cloud Viability
It is not worth outsourcing any task of less than 4000 CPU cycles per transferred 32-bit input.
Why should this hold tomorrow?

Ratio of exponentials is exponential 😊
Moore vs. Nielsen
Density (or cycles/$)
Speed

Source: “Gigascale Integration-Challenges and Opportunities”, Shekhar Borkar, Director, Microprocessor Technology, Intel
Networks

“high end connection speed grows 50% per year”
App Owner = Sole Client

Network
very cheap

>5500 picocents/bit (owner expense)

CPU Cycle
6-27 picocents

app owner

clients (internal)

Economics of Clouds

Stony Brook Network Security and Applied Cryptography Laboratory

June 17, 2012
But is this the nominal case?

actual question to ask
what is the overall application profile?
App Owner != Client(s)

Network
>500 picocents/bit (owner expense)

CPU Cycle
0.58 picocents

Network
>5000 picocents/bit (owner expense)
Insight: we had only partial view!

Second Principle of Cloud Viability
“It is almost always worth outsourcing”
Thus

cloud deployment saves
+ >4500 picocents per client-to-app traffic bit
+ tens of picocents per CPU cycle.
But ... it seems sooo expensive!!!

**Computing in cloud**

8c/hour = $1.92/day = $700/yr ≡ $2100/3yr

Instance utilization is still low! (<12%)

**Computing “at home”**

energy = 10c/kWh @ 150W ≡ $394/3yr

acquisition = $500

**Networking in cloud**

5-12c/GB = 582-1397 picocents/bit
Cloud CPU utilization (temp. based)
But wait there's more!
What about other goodies?

<table>
<thead>
<tr>
<th>Primitive</th>
<th>Picocents</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU Cycle</td>
<td>0.58 - 26</td>
</tr>
<tr>
<td>Disk Access /bit</td>
<td>0.02 - 0.06</td>
</tr>
<tr>
<td>Disk Access+DMA /bit</td>
<td>0.023 - 0.11</td>
</tr>
<tr>
<td>Disk Seek</td>
<td>270,000 - 417,000</td>
</tr>
<tr>
<td>Disk Store /bit/hr.</td>
<td>0.011 - 0.036</td>
</tr>
<tr>
<td>Disk am. acq. /bit/hr.</td>
<td>0.003 - 0.0057</td>
</tr>
<tr>
<td>SDRAM am. acq. /bit/hr.</td>
<td>5.96 - 32.96</td>
</tr>
<tr>
<td>SDRAM Access /bit</td>
<td>0.003 - 0.05</td>
</tr>
</tbody>
</table>
Are clouds more or less secure?

+ Yes
+ But what is security?!
Trusting stuff …

“behave in the expected manner for the intended purpose”
Usually the monkey gets you

_____ Voting Machine

online public picture of actual key
Usual suspects

malicious client code
isolation, sandboxing, VM

clients

network security
ID, SSL, firewalls
Secure Outsourcing

proprietary financial models and business logic, sensitive compliance-governed customer/market data
assurances \subseteq \{ \text{query correctness, data confidentiality, access privacy} \}
“while it is possible in principle for computation to be done on encrypted data, [...] current techniques would more than undo the economy gained by the outsourcing and show little sign of becoming practical”.

“Whit” Diffie
So ... do they work?

Unfortunately, not!

Why not?

peanut counting is (too) cheap.

we don’t know how to practically “secure” anything more complex that peanut counting.
Peanut counting

Data Storage
700+ picocents/bit un-amortized extra costs (even in unsecured case!)

PIR (Private Information Retrieval)
2-3 orders of magnitude more expensive

Keyword Searches
4-5 orders of magnitude more expensive

Range Queries
2-3 orders of magnitude costlier even in unsecured case
some crypto (signature aggregation) would add another 2+ orders

Simple Aggregators
using homomorphisms (e.g., VLDB 2007) – would take 12 days/query
e.g., storage + data confidentiality

Decryption cost!

900 picocents per bit

900 picocents per bit

E[kw]

Practical Techniques for Searches on Encrypted Data
D. Song, D. Wagner, and A. Perrig.

Secure Indexes for Searching Efficiently on Encrypted Compressed Data
E.-J. Goh

A few cpu cycles per word

Sequential search

Building index

A few cpu cycles per word
It’s broken

Existing “secure” data outsourcing mechanisms are 2-5 orders of magnitude more expensive than local execution.
Brute-forcing 80 bit key?

Oracle costs ~ 1 picocent/bit.

$$2^{80} \times 80 / 2 = 5 \times 2^{83} \text{ picocents}$$

~ $483.5 \text{ billion}$

for 64 bits ... $5 \text{ million}$ 😊
What can you buy with $1?

500,000 2048-bit DSA sigs
(in the comfort of your home)