A View of Cloud Computing

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Cloud Computing: Computing as a Utility

- Developers of new Internet services no longer require large capital outlays in hardware to deploy their service or the human expense to operate it thus avoiding both over-provisioning and under-provisioning.

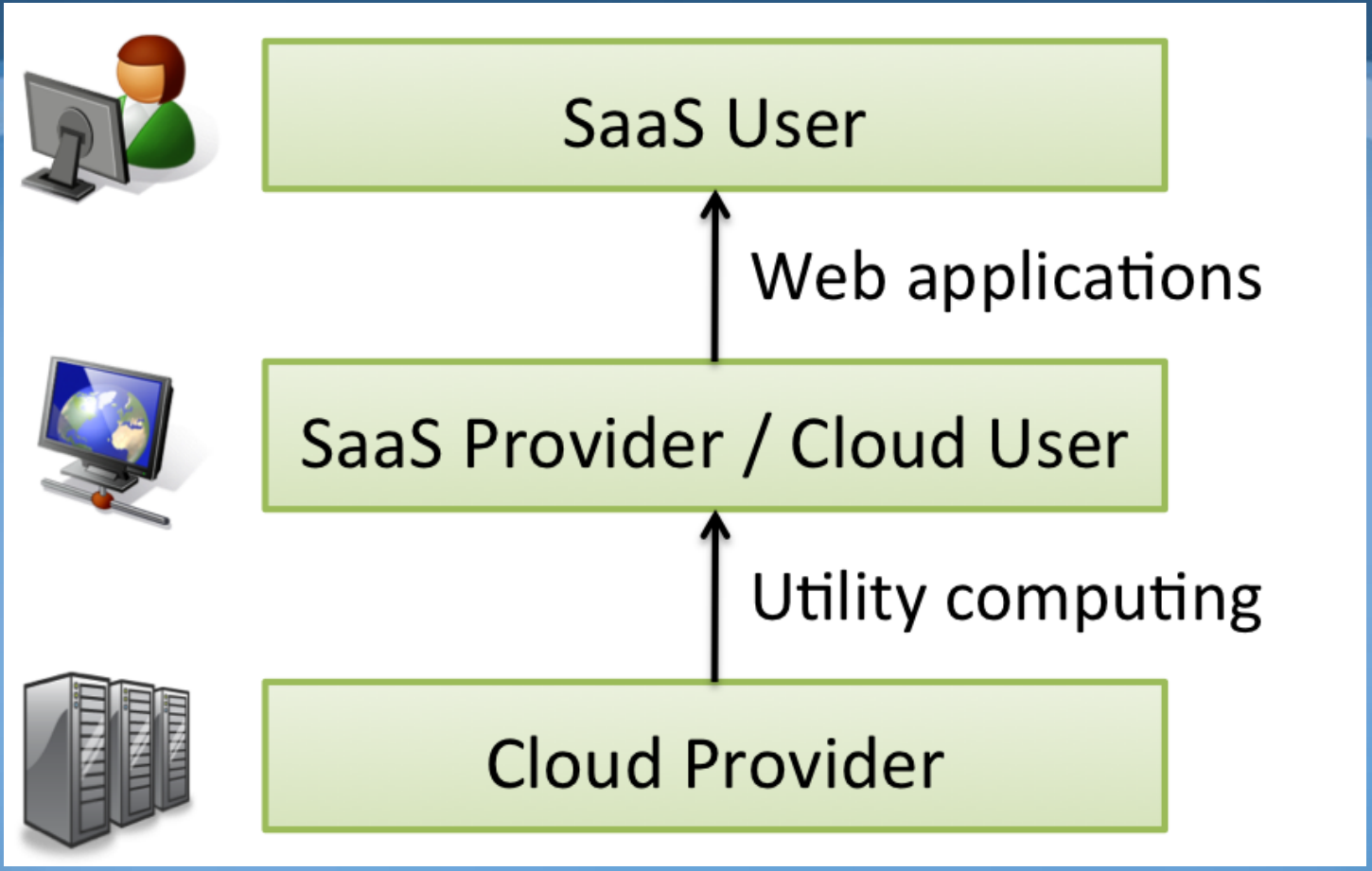
- Cloud Computing refers to both the apps delivered as services over the Internet and the hardware and system software in the datacenter that provide those services. The services themselves are referred to as ***Software-as-a-Service (SaaS)***. The datacenter hardware and system software is what we will call a **Cloud.**

- A cloud that is available in a pay-as-you-go model to the general public is ***Public Cloud***; the service being sold is ***Utility Computing***.

- ***Private Cloud*** refers to internal data centers of a business or other organization not made available to the general public.

- Cloud Computing is the sum of SaaS and Utility Computing.

Users and Providers of Cloud Computing



Users and Providers of Cloud Computing. The top level can be recursive, in that SaaS providers can also be a SaaS users. For example, a provider of rental maps might be a user of the Craigslist and Google maps services.

New Aspects of Cloud Computing from a Hardware Point of View

- **The illusion of infinite computing resources available on demand,** thereby eliminating the need for Cloud Computing users to plan far ahead for provisioning.
- ***The elimination of an up-front commitment by Cloud users,*** thereby allowing companies to start small and increase resources only when there is an increase in their needs.
- ***The ability to pay for use of computing resources on a short-term basis as needed*** (e.g., processors by the hour and storage by the day) and release them as needed, thereby rewarding conservation by letting machines and storage go when they are no longer useful.
  - All three are important to the technical and economic changes made possible by Cloud Computing. Past efforts at utility computing failed, and in each case one or two of these three critical characteristics were missing. For example, Intel Computing Services in 2000-2001 required negotiating a contract and longer-term use than per hour.

Key Enabler of Cloud Computing

- **The construction and operation of extremely large-scale, commodity-computer datacenters at low cost locations was the key necessary enabler of Cloud Computing.**

- This uncovered the factors of 5 to 7 decrease in cost of electricity, network bandwidth, operations, software, and hardware available at these very large economies of scale.

- These factors, combined with statistical multiplexing to increase utilization compared a private cloud, meant that cloud computing could offer services below the costs of a medium-sized datacenter and yet still make a good profit.

Abstraction Levels for Utility of Computing

- Any application needs a model of computation, a model of storage, and a model of communication. The statistical multiplexing necessary to achieve elasticity and the illusion of infinite capacity *requires each of these resources to be virtualized to hide the implementation* of how they are multiplexed and shared.

- Utility computing offerings will be distinguished based on the level of abstraction presented to the programmer and the level of management of the resources..

- Amazon EC2 is at one end of the spectrum. An EC2 instance looks much like physical hardware, and users can control nearly the entire software stack, from the kernel upwards. This low level makes it inherently difficult for Amazon to offer automatic scalability and failover, because the semantics associated with replication and other state management issues are highly application-dependent.

Abstraction Levels for Utility of Computing (contd.)

- At the other extreme of the spectrum are application domain specific platforms such as Google AppEngine. AppEngine is targeted exclusively at traditional web applications, enforcing an application structure of clean separation between a stateless computation tier and a stateful storage tier.

- Applications for Microsoft's Azure are written using the .NET libraries, and compiled to the Common Language Runtime, a language-independent managed environment. Thus, Azure is intermediate between application frameworks like AppEngine and hardware virtual machines like EC2.

When is Utility Computing preferable to running a Private Cloud?

- A first case is when demand for a service varies with time. Provisioning a data center for the peak load it must sustain a few days per month leads to underutilization at other times.
  - Instead, Cloud Computing lets an organization pay by the hour for computing resources, potentially leading to cost savings even if the hourly rate to rent a machine from a cloud provider is higher than the rate to own one.
- A second case is when demand is unknown in advance. For example, a web startup will need to support a spike in demand when it becomes popular, followed potentially by a reduction once some of the visitors turn away.
- Finally, organizations that perform batch analytics can use the “cost associativity” of cloud computing to finish computations faster: using 1000 EC2 machines for 1 hour costs the same as using 1 machine for 1000 hours.

Tradeoff when demand varies with time

- For the first case of a web business with varying demand over time and revenue proportional to user hours, the tradeoff is captured in the equation below.

  UserHourscloud * (revenue - Costcloud) >= UserHoursdatacenter * (revenue - Costdatacenter / Utilization)

- The left-hand side multiplies the net revenue per user-hour by the number of user-hours, giving the expected profit from using Cloud Computing. The right-hand side performs the same calculation for a fixed-capacity datacenter by factoring in the average utilization, including nonpeak workloads, of the datacenter. Whichever side is greater represents the opportunity for higher profit.

Cloud Computing will grow!

- All levels of cloud computing should aim at horizontal scalability of virtual machines over the efficiency on a single VM.
- Applications Software needs to both scale down rapidly as well as scale up, which is a new requirement. Such software also needs a pay-for-use licensing model to match needs of Cloud Computing.
- Infrastructure Software needs to be aware that it is no longer running on bare metal but on VMs. It needs to have billing built in from the beginning.
- Hardware Systems should be designed at the scale of a container (at least a dozen racks), which will be is the minimum purchase size. Cost of operation will match performance and cost of purchase in importance, rewarding energy proportionality such as by putting idle portions of the memory, disk, and network into low power mode.
- Processors should work well with VMs, flash memory should be added to the memory hierarchy, and LAN switches and WAN routers must improve in bandwidth and cost.

Advantages of SaaS

- SaaS service providers enjoy greatly simplified software installation and maintenance and centralized control over versioning.
- End users can access the service “anytime, anywhere”, share data and collaborate more easily, and keep their data stored safely in the infrastructure.
- Cloud Computing does not change these arguments, but it does give more application providers the choice of deploying their product as SaaS, scaling on demand, **without building or provisioning a datacenter**.

A Successful Example

- Elastic Compute Cloud (EC2) from Amazon Web Services (AWS) sells 1.0-GHz x86 ISA “slices” for 10 cents per hour, and a new “slice”, or instance, can be added in 2 to 5 minutes.
- Amazon’s Scalable Storage Service (S3) charges $0.12 to $0.15 per gigabyte-month, with additional bandwidth charges of $0.10 to $0.15 per gigabyte to move data in to and out of AWS over the Internet.
- Amazon’s bet is that by statistically multiplexing multiple instances onto a single physical box, that box can be simultaneously rented to many customers who will not in general interfere with each others’ usage.
- A necessary but not sufficient condition for a company to become a Cloud Computing provider is that it must have existing investments not only in very large datacenters (e.g. Amazon, eBay, Google, Microsoft), but also in large-scale software infrastructure (e.g. MapReduce, the Google File System, BigTable, and Dynamo) and operational expertise required to run them.

Factors Influencing Companies to Become Cloud Computing Providers

- **Make a lot of money.**
  - Although 10 cents per server-hour seems low, very large datacenters (tens of thousands of computers) can purchase hardware, network bandwidth, and power for 1/5 to1/7 the prices offered to a medium-sized (hundreds or thousands of computers) datacenter. Further, the fixed costs of software development and deployment can be amortized over many more machines. Thus, a sufficiently large company could leverage these economies of scale to offer a service well below the costs of a medium-sized company and still make a tidy profit.

- **Leverage existing investment.**
  - Adding Cloud Computing services on top of existing infrastructure provides a new revenue stream at (ideally) low incremental cost, helping to amortize the large investments of datacenters. Indeed, many Amazon Web Services technologies were initially developed for Amazon's internal operations.

- **Defend a franchise.**
  - As conventional server and enterprise applications embrace Cloud Computing, vendors with an established franchise in those applications would be motivated to provide a cloud option of their own. For example, Microsoft Azure provides an immediate path for migrating existing customers of Microsoft enterprise applications to a cloud environment.

Factors Influencing Companies to Become Cloud Computing Providers (contd.)

- **Attack an incumbent.**
  - A company with the requisite datacenter and software resources might want to establish a beachhead in this space before a single “800 pound gorilla” emerges. Example, Google AppEngine provides an alternative path to cloud deployment whose appeal lies in its automation of many of the scalability and load balancing features that developers might otherwise have to build for themselves.
- **Leverage customer relationships.**
  - Example, IT service organizations such as IBM Global Services have extensive customer relationships through their service offerings. Providing a branded Cloud Computing offering gives those customers an anxiety-free migration path that preserves both parties’ investments in the customer relationship.
- **Become a platform.**
  - Example, Facebook’s initiative to enable plug-in applications is a great fit for cloud computing and indeed one infrastructure provider for Facebook plug-in applications is Joyent, a cloud provider. Yet Facebook’s motivation was to make their social-networking application a new development platform.

Some Locales for Cloud Computing

- Several Cloud Computing datacenters are being built in seemingly surprising locations, such as Quincy, Washington (Google, Microsoft, Yahoo!) and San Antonio, Texas (Microsoft, US National Security Agency).
  - The motivation behind choosing these locales is that the costs for electricity, cooling, labor, property purchase costs, and taxes are geographically variable, and of these costs, electricity and cooling alone can account for a third of the costs of the datacenter.
  - Physics tells us it's easier to ship photons than electrons; that is, it's cheaper to ship data over fiber optic cables than to ship electricity over high-voltage transmission lines.

Factors Influencing Companies to Become Cloud Computing Providers

- **Economies of scale in 2006 for medium-sized datacenter (1000 servers) vs. very large datacenter (50,000 servers)**

Technology	Cost in Medium-sized DC	Cost in Very Large DC	Ratio
Network	$95 per Mbit/sec/month	$13 per Mbit/sec/month	7.1
Storage	$2.20 per GByte / month	$0.40 per GByte / month	5.7
Administration	140 Servers / Administrator	>1000 Servers / Administrator	7.1

- **Price of kilowatt-hours of electricity by region**

Price per KWH	Where Possible Reasons	Why
3.6¢	Idaho Hydroelectric power;	not sent long distance
10.0¢	California Electricity	transmitted long distance over the grid; limited transmission lines in Bay Area; no coal fired electricity allowed in California.
18.0¢	Hawaii	Must ship fuel to generate electricity

Clouds: Why now, not then?

- While the construction and operation of extremely large scale commodity-computer datacenters was the key enabler of Cloud Computing, new technology trends and business models also played a key role in making it a reality this time around.

1. **New Technology Trends and Business Models**

   With the emergence of Web 2.0, there was a shift from “high-touch, high-margin, high-commitment” provisioning of service “low-touch, low-margin, low-commitment” self-service.

   Example, in Web 1.0, accepting credit card payments from strangers required a contractual arrangement with a payment processing service such as VeriSign making it onerous for an individual or a very small business to accept credit cards online. With the emergence of PayPal, however, any individual can accept credit card payments with no contract, no long-term commitment, and only modest pay-as-you-go transaction fees (low touch = limited customer support and relationship management)

- AmazonWeb Services capitalized on this insight in 2006 by providing pay-as-you-go computing with no contract: all customers need is a credit card. A second innovation was selling hardware-level virtual machines cycles, allowing customers to choose their own software stack without disrupting each other while sharing the same hardware and thereby lowering costs further.

Clouds: Why now, not then? (contd.)

2. New Application Opportunities

I. Mobile interactive applications

Tim O'Reilly believes that *"the future belongs to services that respond in real time to information provided either by their users or by nonhuman sensors."* Such services will be attracted to the cloud not only because they must be highly available, but also because these services generally rely on large data sets that are most conveniently hosted in large datacenters. This is especially the case for services that combine two or more data sources or other services, e.g., mashups.

II. Parallel Data Processing

Cloud Computing presents a unique opportunity for batch-processing and analytics jobs that analyze terabytes of data and can take hours to finish. If there is enough data parallelism in the application, users can take advantage of the cloud's new "cost associativity": using hundreds of computers for a short time costs the same as using a few computers for a long time.

Programming abstractions such as Google's MapReduce and its open-source counterpart Hadoop allow programmers to express such tasks while hiding the operational complexity of choreographing parallel execution across hundreds of Cloud Computing servers.

The cost/benefit analysis must weigh the cost of moving large datasets into the cloud against the benefit of potential speedup in the data analysis.

Clouds: Why now, not then? (contd.)

III. The rise of analytics

The demand for database transaction processing is leveling off. A growing share of computing resources is now spent on understanding customers, supply chains, buying habits, ranking, and so on. Hence, while online transaction volumes will continue to grow slowly, decision support is growing rapidly, shifting the resource balance in database processing from transactions to business analytics (BI, data mining).

IV. Extension of compute-intensive desktop applications

The latest versions of the mathematics software packages Matlab and Mathematica are capable of using Cloud Computing to perform expensive evaluations. Need to compare the cost of computing in the Cloud plus the cost of moving data in and out of the Cloud to the time savings from using the Cloud. An application that involves a great deal of computing per unit of data is worth investigating for a move to a cloud environment. Examples, offline image rendering, 3D animation.

Applications that are not such good candidates for the cloud ("Earthbound apps")

Some applications that would otherwise be good candidates for the cloud's elasticity and parallelism may be thwarted by data movement costs, the fundamental latency limits of getting into and out of the cloud, or both. For example, while the analytics associated with making long-term financial decisions are appropriate for the Cloud, stock trading that requires microsecond precision is not. Until the cost (and possibly latency) of wide area data transfer decrease, such applications may be less obvious candidates for the cloud.

Classes of Utility Computing

- Different utility computing offerings will be distinguished based on the level of abstraction presented to the programmer and the level of management of the resources.

Amazon EC2

Is at one end of the spectrum. An EC2 instance looks much like physical hardware, and users can control nearly the entire software stack, from the kernel upwards. The API exposed is “thin”: a few dozen API calls to request and configure the virtualized hardware. There is no a priori limit on the kinds of applications that can be hosted; the low level of virtualization—raw CPU cycles, block-device storage, IP-level connectivity- allow developers to code whatever they want. On the other hand, this makes it inherently difficult for Amazon to offer automatic scalability and failover, because the semantics associated with replication and other state management issues are highly application-dependent.

Microsoft’s Azure

Is an intermediate point on this spectrum of flexibility vs. programmer convenience. Azure applications are written using the .NET libraries, and compiled to the Common Language Runtime, a language independent managed environment. The system supports general-purpose computing, rather than a single category of application. Users get a choice of language, but cannot control the underlying operating system or runtime. The libraries provide a degree of automatic network configuration and failover/scalability, but require the developer to declaratively specify some application properties in order to do so. Thus, Azure is intermediate between complete application frameworks like AppEngine on the one hand, and hardware virtual machines like EC2 on the other.

Classes of Utility Computing (contd.)

Google AppEngine

At the other extreme of the spectrum are application domain-specific platforms such as Google AppEngine and Force.com, the SalesForce business software development platform. AppEngine is targeted exclusively at traditional web applications, enforcing an application structure of clean separation between a stateless computation tier and a stateful storage tier.

Furthermore, AppEngine applications are expected to be request-reply based, and as such they are severely rationed in how much CPU time they can use in servicing a particular request. AppEngine's impressive automatic scaling and high-availability mechanisms, and the proprietary MegaStore (based on BigTable) data storage available to AppEngine applications, all rely on these constraints.

Thus, AppEngine is not suitable for general-purpose computing. Similarly, Force.com is designed to support business applications that run against the salesforce.com database, and nothing else.

Will one model beat out the others in the Cloud Computing space?

Different tasks will result in demand for different classes of utility computing. As an analogy, low-level languages such as C and assembly language allow fine control and close communication with the bare metal, but if the developer is writing a Web application, the mechanics of managing sockets, dispatching requests, and so on are cumbersome and tedious to code. high-level frameworks such as Ruby on Rails make these mechanics invisible to the programmer, but are only useful if the application readily fits the request/reply structure and the abstractions provided by Rails.

Classes of Utility Computing (contd.)

Examples of Cloud Computing vendors and how each provides virtualized resources (computation, storage, networking) and ensures scalability and high availability of the resources.

Computation Model (VM)

Amazon EC2

- x86 Instruction Set Architecture (ISA) via Xen VM.
- Computation elasticity allows scalability, but developer must build the machinery, or third party such as RightScale must provide it.

Microsoft's Azure

- Microsoft Common Language Runtime (CLR) VM; common intermediate form executed in managed environment.
- Machines are provisioned based on declarative descriptions (e.g. which "roles" can be replicated); automatic load balancing.

Google AppEngine

- Predefined application structure and framework; programmer-provided "handlers", written in Python, all persistent state stored in MegaStore (outside Python code).
- Automatic scaling up and down of computation and storage; network and server failover; all consistent with 3-tier Web app structure.

Classes of Utility Computing (contd.)

Storage Model

Amazon EC2

- Range of models from block store (EBS) to augmented key/blob store (SimpleDB). Computation elasticity allows scalability, but developer must build the machinery, or third party such as RightScale must provide it.
- Automatic scaling varies from no scaling or sharing (EBS) to fully automatic (SimpleDB, S3), depending on which model used.
- Consistency guarantees vary widely depending on which model used.

Microsoft's Azure

- SQL Data Services (restricted view of SQL Server) .
- Azure storage service

Google AppEngine

- MegaStore/BigTable

Classes of Utility Computing (contd.)

Networking Model

Amazon EC2

- Declarative specification of IP level topology; internal placement details concealed.
- Security Groups enable restricting which nodes may communicate.

Microsoft's Azure

- Automatic based on programmer's declarative descriptions of app components (roles).

Google AppEngine

- Fixed topology to accommodate 3-tier Web app structure.
- Scaling up and down is automatic and programmer invisible.

Cloud Computing Economics

- Economic appeal of Cloud Computing: “converting capital expenses to operating expenses (CapEx to OpEx)” or “pay as you go”. Hours purchased can be distributed non-uniformly in time.

- Even though Amazon’s pay-as-you-go pricing (for example) could be more expensive than buying and depreciating a comparable server over the same period, the cost is outweighed by the extremely important Cloud Computing economic benefits of *elasticity* and transference of risk, especially the risks of over-provisioning (underutilization) and under-provisioning (saturation).

Elasticity: Shifting the Risk

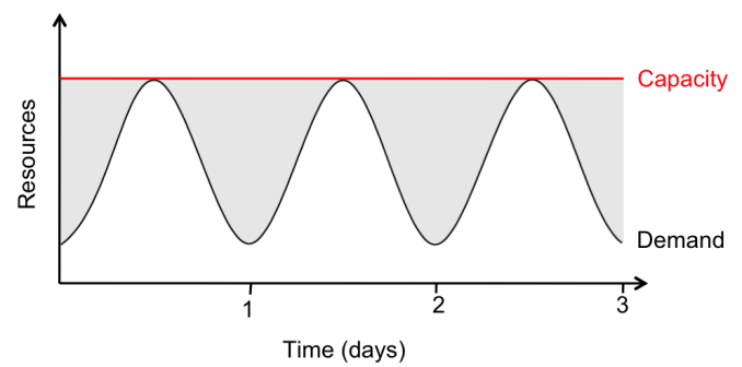
- Cloud Computing's ability to add or remove resources at a fine grain (one server at a time with EC2) and with a lead time of minutes rather than weeks allows matching resources to workload much more closely.
  - Real world estimates of server utilization in datacenters range from 5% to 20%. Users provision for the peak and allow the resources to remain idle at nonpeak times. The more pronounced the variation, the more the waste.
  - Even if peak load can be correctly anticipated, without elasticity we waste resources (shaded area) during nonpeak times.

Elasticity: Shifting the Risk (contd.)

- Example: Elasticity.

Assume our service has a predictable daily demand where the peak requires 500 servers at noon but the trough requires only 100 servers at midnight, as shown in Figure below. As long as the average utilization over a whole day is 300 servers, the actual utilization over the whole day (shaded area under the curve) is 300 * 24 = 7200 server-hours.

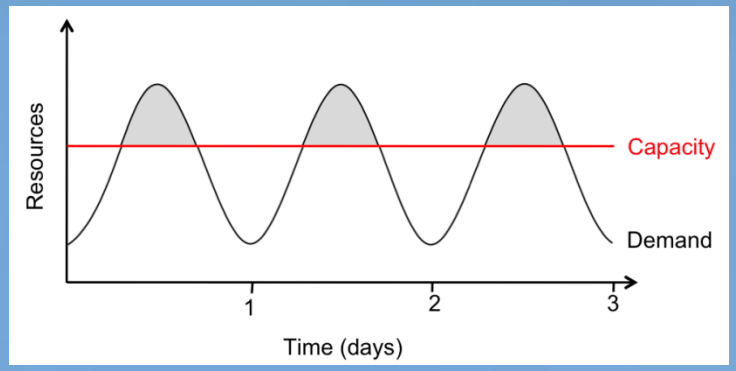
But since we must provision to the peak of 500 servers, we pay for 500 * 24 = 12000 server-hours, a factor of 1.7 more than what is needed. Therefore, as long as the pay-as-you-go cost per server-hour over 3 years is less than 1.7 times the cost of buying the server, we can save money using utility computing.



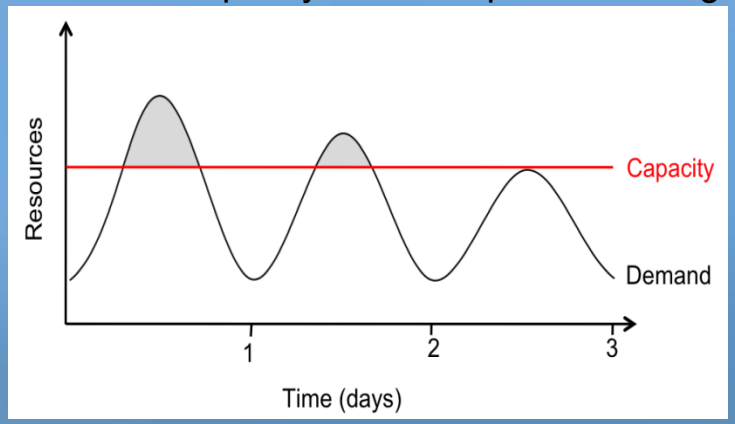
Even if service operators predict the spike sizes correctly, capacity is wasted, and if they overestimate the spike they provision for, it's even worse.

Elasticity: Shifting the Risk (contd.)

- Service operators also underestimate the spike, however, accidentally turning away excess users. While the monetary effects of over-provisioning are easily measured, those of under-provisioning are harder to measure yet potentially equally serious: not only do rejected users generate zero revenue, they may never come back due to poor service.



- Figure 2(c) aims to capture this behavior: users will desert an underprovisioned service until the peak user load equals the datacenter's usable capacity, at which point users again receive acceptable service, but with fewer potential users.



Elasticity: Shifting the Risk (contd.)

- The following equation generalizes all of the cases discussed and assumes that the Cloud Computing vendor employs usage-based pricing, in which customers pay proportionally to the amount of time and the amount of resources they use.

  UserHourscloud * (revenue - Costcloud) >= UserHoursdatacenter * (revenue - Costdatacenter / Utilization)

- The left-hand side multiplies the net revenue per user-hour by the number of user-hours, giving the expected profit from using Cloud Computing. The right-hand side performs the same calculation for a fixed-capacity datacenter by factoring in the average utilization, including nonpeak workloads, of the datacenter. Whichever side is greater represents the opportunity for higher profit.
  - Apparently, if Utilization = 1:0 (the datacenter equipment is 100% utilized), the two sides of the equation look the same. However, basic queuing theory tells us that as utilization approaches 1.0, system response time approaches infinity. In practice, the usable capacity of a datacenter (without compromising service) is typically 0.6 to 0.8.

- The equation makes clear that the common element in all of our examples is the ability to control the cost per user hour of operating the service.

Elasticity: Shifting the Risk (contd.)

- Economic benefits of cloud computing:
- Provides the ability to control the cost per user hour of operating the service.
  - In Example 1, the cost per user-hour without elasticity was high because of resources sitting idle—higher costs but same number of user-hours. The same thing happens when over-estimation of demand results in provisioning for workload that doesn't materialize.
  - In Example 2, the cost per user-hour increased as a result of underestimating a spike and having to turn users away: Since some fraction of those users never return, the fixed costs stay the same but are now amortized over fewer user-hours. This illustrates fundamental limitations of the "buy" model in the face of any nontrivial burstiness in the workload.
- Unexpectedly scaling down (disposing of temporarily underutilized equipment)—for example, due to a business slowdown, or ironically due to improved software efficiency—normally carries a financial penalty. Cloud Computing eliminates this penalty.
  - With 3-year depreciation, a $2,100 server decommissioned after 1 year of operation represents a "penalty" of $1,400. Cloud Computing eliminates this penalty.
- Technology trends suggest that over the useful lifetime of some purchased equipment, hardware costs will fall and new hardware and software technologies will become available. Cloud providers, who already enjoy economy-of-scale buying power, can potentially pass on some of these savings to their customers.
  - Example: Heavy users of AWS saw storage costs fall 20% and networking costs fall 50% over the last 2.5 years, and the addition of nine new services or features to AWS over less than one year. If new technologies or pricing plans become available to a cloud vendor, existing applications and customers can potentially benefit from them immediately, without incurring a capital expense.

Comparing Costs: Should I Move to the Cloud?

- Is it more economical to move an existing datacenter-hosted service to the cloud, or to keep it in a datacenter?
- Table : Gray's costs of computing resources from 2003 to 2008, normalized to what $1 could buy in 2003 vs. 2008, and compared to the cost of paying per use of $1 worth of resources on AWS at 2008 prices.

	WAN bandwidth/mo.	CPU hours (all cores)	disk storage		
Item in 2003	1 Mbps WAN link	2 GHz CPU, 2 GB DRAM	200 GB disk, 50 Mb/s transfer rate		
Cost in 2003	$100/mo.	$2000	$200		
$1 buys in 2003	1 GB	8 CPU hours	1 GB		
Item in 2008	100 Mbps WAN link	2 GHz, 2 sockets, 4 cores/socket, 4 GB DRAM	1 TB disk, 115 MB/s sustained transfer		
Cost in 2008	$3600/mo.	$1000	$100		
$1 buys in 2008	2.7 GB	128 CPU hours	10 GB		
cost/performance improvement	2.7x	16x	16x		
Cost to rent $1 on AWS in 2008	$0.27–$0.40 ($0.10–$0.15/GB * 3 GB)	$2.56 (128 * 2 VM's@$0.10 each)	$1.20–$1.50 ($0.12–$0.15/GB-month * 10 GB)		

Comparing Costs: Should I Move to the Cloud? (contd.)

- To facilitate calculations, Gray calculated what $1 bought in 2003. Table shows his numbers vs. 2008 and compares to EC2/S3 charges. At first glance, it appears that a given dollar will go further if used to purchase hardware in 2008 than to pay for use of that same hardware. However, this simple analysis glosses over several important factors.

1. Pay separately per resource.

   Most applications do not make equal use of computation, storage, and network bandwidth; some are CPU-bound, others network-bound, and so on, and may saturate one resource while underutilizing others. Pay-as-you-go Cloud Computing can charge the application separately for each type of resource, reducing the waste of underutilization.

   – While the exact savings depends on the application, suppose the CPU is only 50% utilized while the network is at capacity; then in a datacenter you are effectively paying for double the number of CPU cycles actually being used. So rather than saying it costs $2.56 to rent only $1 worth of CPU, it would be more accurate to say it costs $2.56 to rent $2 worth of CPU.

Comparing Costs: Should I Move to the Cloud? (contd.)

2. Power, cooling and physical plant costs.

- The costs of power, cooling, and the amortized cost of the building are missing from our simple analyses so far. Hamilton estimates that the costs of CPU, storage and bandwidth roughly double when those costs are amortized over the building's lifetime.
  - Using this estimate, buying 128 hours of CPU in 2008 really costs $2 rather than $1, compared to $2.56 on EC2. Similarly, 10 GB of disk space costs $2 rather than $1, compared to $1.20–$1.50 per month on S3. Lastly, S3 actually replicates the data at least 3 times for durability and performance, and will replicate it further for performance if there is high demand for the data. That means the costs are $6.00 when purchasing vs. $1.20 to $1.50 per month on S3.

3. Operations costs.

- Today, hardware operations costs are very low—rebooting servers is easy and minimally trained staff can replace broken components at the rack or server level. On one hand, since Utility Computing uses virtual machines instead of physical machines from the cloud user's point of view these tasks are shifted to the cloud provider. On the other hand, depending on the level of virtualization, much of the software management costs may remain—upgrades, applying patches, and so on.

- Example: Moving to the cloud. Suppose a biology lab creates 500 GB of new data for every wet lab experiment. A computer the speed of one EC2 instance takes 2 hours per GB to process the new data. The lab has the equivalent 20 instances locally, so the time to evaluate the experiment is 500*2/20 or 50 hours. They could process it in a single hour on 1000 instances at AWS. The cost to process one experiment would be just 1000*$0.10 or $100 in computation and another 500*$0.10 or $50 in network transfer fees. So far, so good. They measure the transfer rate from the lab to AWS at 20 Mbits/second. The transfer time is (500GB *1000MB/GB *8bits/Byte) / 20Mbits/sec = 4,000,000/20 = 200,000 seconds or more than 55 hours. Thus, it takes 50 hours locally vs. 55 + 1 or 56 hours on AWS, so they don't move to the cloud.

Obstacles and Opportunities for Cloud Computing (contd.)

1. Availability of a Service

- Organizations worry about whether Utility Computing services will have adequate availability, and this makes some wary of Cloud Computing. Ironically, existing SaaS products have set a high standard in this regard.
  - Despite the negative publicity due to these outages, few enterprise IT infrastructures are as good.

Outages in AWS, AppEngine, and Gmail

Service and Outage	Duration	Date
S3 outage: authentication service overload leading to unavailability	2 hours	2/15/08
S3 outage: Single bit error leading to gossip protocol blowup.	6-8 hours	7/20/08
AppEngine partial outage: programming error	5 hours	6/17/08
Gmail: site unavailable due to outage in contacts system	1.5 hours	8/11/08

- The only plausible solution to very high availability is multiple Cloud Computing providers.

Obstacles and Opportunities for Cloud Computing

1. Availability of a Service (contd.)

   Another availability obstacle is Distributed Denial of Service (DDoS) attacks. Criminals threaten to cut off the incomes of SaaS providers by making their service unavailable, extorting $10,000 to $50,000 payments to prevent the launch of a DDoS attack. Such attacks typically use large “botnets” that rent bots on the black market for $0.03 per bot (simulated bogus user) per week.

- Utility Computing offers SaaS providers the opportunity to defend against DDoS attacks by using quick scale-up.

- Example:

  Suppose an EC2 instance can handle 500 bots, and an attack is launched that generates an extra 1 GB/second of bogus network bandwidth and 500,000 bots. At $0.03 per bot, such an attack would cost the attacker $15,000 invested up front. At AWS’s current prices, the attack would cost the victim an extra $360 per hour in network bandwidth and an extra $100 per hour (1,000 instances) of computation. The attack would therefore have to last 32 hours in order to cost the potential victim more than it would the blackmailer. A botnet attack this long may be difficult to sustain, since the longer an attack lasts the easier it is to uncover and defend against, and the attacking bots could not be immediately re-used for other attacks on the same provider.

- As with elasticity, Cloud Computing shifts the attack target from the SaaS provider to the Utility Computing provider, who can more readily absorb it and is also likely to have already DDoS protection as a core competency.

Obstacles and Opportunities for Cloud Computing (contd.)

2. Data Lock-In

- APIs for Cloud Computing itself are still essentially proprietary, or have not been the subject of active standardization. Thus, customers cannot easily extract their data and programs from one site to run on another. Concern about the difficult of extracting data from the cloud is preventing some organizations from adopting Cloud Computing.
  - Customer lock-in may be attractive to Cloud Computing providers, but Cloud Computing users are vulnerable to price increases (as Stallman warned), to reliability problems, or even to providers going out of business.
- The obvious solution is to standardize the APIs so that a SaaS developer could deploy services and data across multiple Cloud Computing providers so that the failure of a single company would not take all copies of customer data with it.
- The obvious fear is that this would lead to a “race-to-the-bottom” of cloud pricing and flatten the profits of Cloud Computing providers. However, the quality of a service matters as well as the price, so customers will not necessarily jump to the lowest cost service. In addition, standardization of APIs enables a new usage model in which the same software infrastructure can be used in a Private Cloud and in a Public Cloud.

Obstacles and Opportunities for Cloud Computing (contd.)

3. Data Confidentiality and Auditability

- "My sensitive corporate data will never be in the cloud." Anecdotally we have heard this repeated multiple times. Current cloud offerings are essentially public networks, exposing the system to more attacks.

- There are also requirements for auditability, in the sense of Sarbanes-Oxley and Health Insurance Portability and Accountability Act (HIPAA) regulations that must be provided for corporate data to be moved to the cloud. Utility Computing offers SaaS providers the opportunity to defend against DDoS attacks by using quick scale-up.

- There are no fundamental obstacles to making a cloud-computing environment as secure as in-house IT environments, and that many of the obstacles can be overcome immediately with well understood technologies such as encrypted storage, Virtual Local Area Networks, and network middle boxes (e.g. firewalls). For example, encrypting data before placing it in a Cloud may be even more secure than unencrypted data in a local data center.

- Auditability could be added as an additional layer beyond the reach of the virtualized guest OS, providing facilities arguably more secure than those built into the applications themselves and centralizing the software responsibilities related to confidentiality and auditability into a single logical layer. Such a new feature reinforces the Cloud Computing perspective of changing our focus from specific hardware to the virtualized capabilities being provided.

- Cloud Computing gives SaaS providers and SaaS users greater freedom to place their storage. For example, Amazon provides S3 services located physically in the United States and in Europe, allowing providers to keep data in whichever they choose.

Obstacles and Opportunities for Cloud Computing (contd.)

4. Data Transfer Bottlenecks

- Applications continue to become more data-intensive. If we assume applications may be “pulled apart” across the boundaries of clouds, this may complicate data placement and transport. At $100 to $150 per terabyte transferred, these costs can quickly add up, making data transfer costs an important issue. Cloud users and cloud providers have to think about the implications of placement and traffic at every level of the system if they want to minimize costs.

- One opportunity to overcome the high cost of Internet transfers is to ship disks. The cheapest way to send a lot of data is to physically send disks or even whole computers via overnight delivery services.

- Example: Assume that we want to ship 10 TB from U.C. Berkeley to Amazon in Seattle, Washington. Suppose we get 20 Mbit/sec over a WAN link. It would take:

  10*10^12 Bytes / (20*10^6 bits/second) = (8*10^13) / (2*10^7) seconds = 4,000,000 seconds,

  which is more than 45 days. Amazon would also charge you $1000 in network transfer fees when it received the data.

  If we instead sent ten 1 TB disks via overnight shipping, it would take less than a day to transfer 10 TB and the cost would be roughly $400, an effective bandwidth of about 1500 Mbit/sec. So we could halve costs of bulk transfers into the cloud but more importantly reduce latency by a factor of 45.

- A second opportunity is to find other reasons to make it attractive to keep data in the cloud, for once data is in the cloud for any reason it may no longer be a bottleneck and may enable new services that could drive the purchase of Cloud Computing cycles. Amazon recently began hosting large public datasets (e.g. US Census data) for free on S3; since there is no charge to transfer data between S3 and EC2, these datasets might “attract” EC2 cycles.

Obstacles and Opportunities for Cloud Computing (contd.)

4. Data Transfer Bottlenecks (contd.)

- A third, more radical opportunity is to try to reduce the cost of WAN bandwidth more quickly. One estimate is that two-thirds of the cost of WAN bandwidth is the cost of the high-end routers, whereas only one-third is the fiber cost. Researchers are exploring simpler routers built from commodity components as a low-cost alternative to the high-end routers.

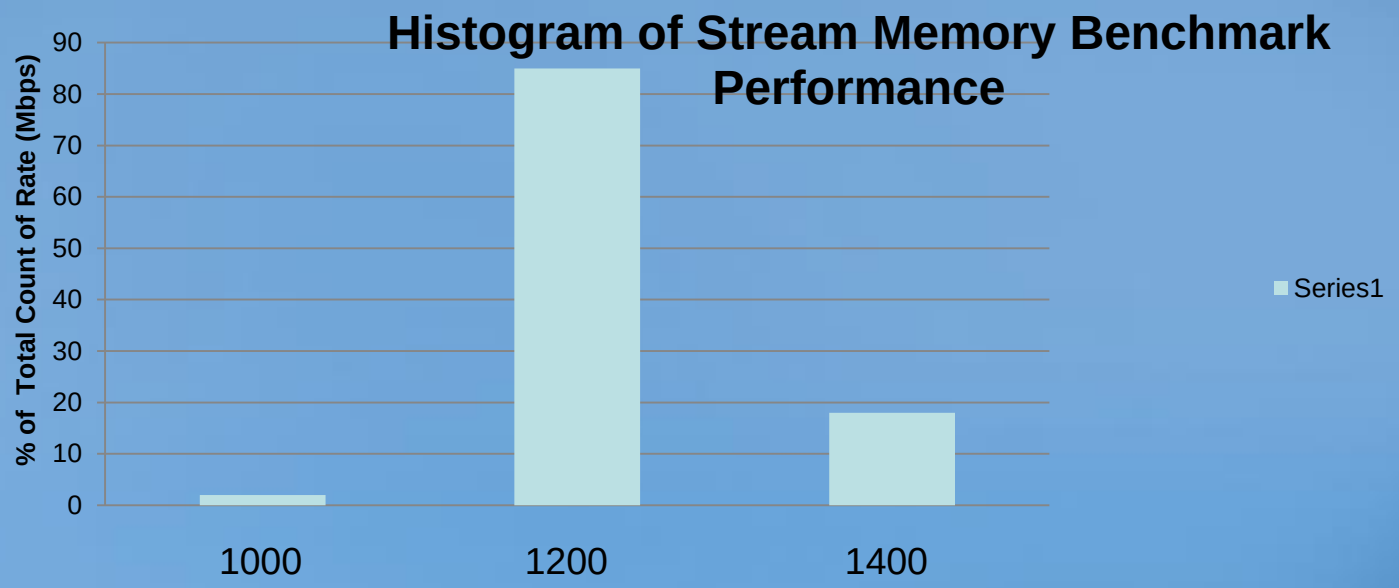
- In addition to WAN bandwidth being a bottleneck, intra-cloud networking technology may be a performance bottleneck as well. Today inside the datacenter, typically 20-80 processing nodes within a rack are connected via a top-of-rack switch to a second level aggregation switch. These in turn are connected via routers to storage area networks and wide-area connectivity, such as the Internet or inter-datacenter WANs. Inexpensive 1 Gigabit Ethernet (1GbE) is universally deployed at the lower levels of aggregation. This bandwidth can represent a performance bottleneck and is one reason few scientists using Cloud Computing.

- Need 10 GbE at the first level and 40 GbE or 100 GbE at the second level of aggregation.

Obstacles and Opportunities for Cloud Computing (contd.)

5. Performance Unpredictability

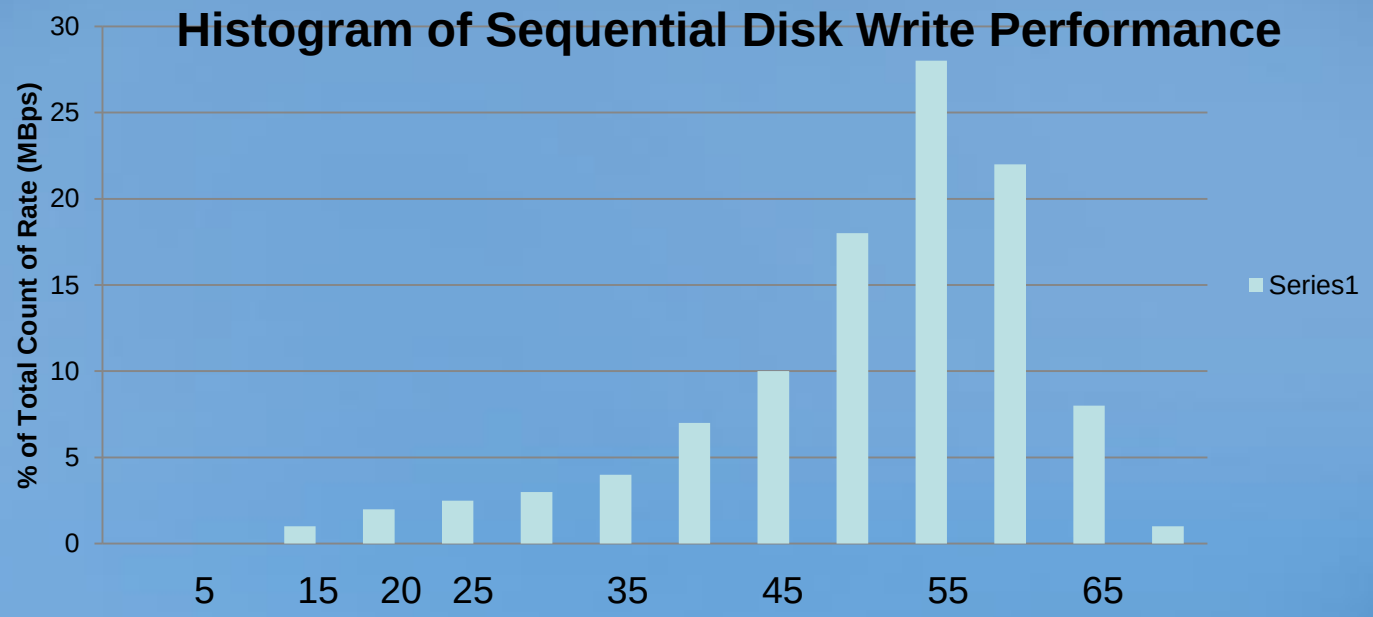
- Multiple Virtual Machines can share CPUs and main memory surprisingly well in Cloud Computing, but I/O sharing is more problematic. The figure below shows the average memory bandwidth for 75 EC2 instances running the STREAM memory benchmark. The mean bandwidth is 1355 MBytes per second, with a standard deviation of just 52 MBytes/sec, less than 4% of the mean.



Obstacles and Opportunities for Cloud Computing (contd.)

5. Performance Unpredictability

Figure below shows the average disk bandwidth for 75 EC2 instances each writing 1 GB files to local disk. The mean disk write bandwidth is nearly 55 MBytes per second with a standard deviation of a little over 9 MBytes/sec, more than 16% of the mean. This demonstrates the problem of I/O interference between virtual machines.



One opportunity is to improve architectures and operating systems to efficiently virtualize interrupts and I/O channels. Technologies such as PCIexpress are difficult to virtualize, but they are critical to the cloud.

Obstacles and Opportunities for Cloud Computing (contd.)

5. Performance Unpredictability (contd.)

- Another possibility is that flash memory will decrease I/O interference. Flash is semiconductor memory that preserves information when powered off like mechanical hard disks, but since it has no moving parts, it is much faster to access (microseconds vs. milliseconds) and uses less energy.

- Flash memory can sustain many more I/Os per second per gigabyte of storage than disks, so multiple virtual machines with conflicting random I/O workloads could coexist better on the same physical computer without the interference we see with mechanical disks.

- The lack of interference that we see with semiconductor main memory (seen in the 1st figure in this section) might extend to semiconductor storage as well, thereby increasing the number of applications that can run well on VMs and thus share a single computer. This advance could lower costs to Cloud Computing providers, and eventually to Cloud Computing consumers.

- Another unpredictability obstacle concerns the scheduling of virtual machines for some classes of batch processing programs, specifically for high performance computing. Cost associativity means that there is no cost penalty for using 20 times as much computing for 1/20th the time. Potential applications that could benefit include those with very high potential financial returns—financial analysis, petroleum exploration, movie animation—and could easily justify paying a modest premium for a 20x speedup. One estimate is that a third of today's server market is high-performance computing.

- The obstacle to attracting HPC is that many HPC applications need to ensure that all the threads of a program are running simultaneously, and today's virtual machines and operating systems do not provide a programmer-visible way to ensure this.

Obstacles and Opportunities for Cloud Computing (contd.)

6. Scalable Storage

- We identified three properties whose combination gives Cloud Computing its appeal: short-term usage (which implies scaling down as well as up when resources are no longer needed), no up-front cost, and infinite capacity on-demand. While it's straightforward what this means when applied to computation, it's less obvious how to apply it to persistent storage.

- There have been many attempts to answer this question, varying in the richness of the query and storage API's, the performance guarantees offered, and the complexity of data structures that are directly supported by the storage system (e.g., schema-less blobs vs. column-oriented storage). The opportunity, which is still an open research problem, is to create a storage system that would not only meet these needs but combine them with the cloud advantages of scaling arbitrarily up and down on-demand, as well as meeting programmer expectations in regard to resource management for scalability, data durability, and high availability.

Obstacles and Opportunities for Cloud Computing (contd.)

7. Bugs in Large-Scale Distributed Systems

- One of the difficult challenges in Cloud Computing is removing errors in these very large scale distributed systems. A common occurrence is that these bugs cannot be reproduced in smaller configurations, so the debugging must occur at scale in the production datacenters.

- One opportunity may be the reliance on virtual machines in Cloud Computing. Many traditional SaaS providers developed their infrastructure without using VMs, either because they preceded the recent popularity of VMs or because they felt they could not afford the performance hit of VMs. Since VMs are de rigueur in Utility Computing, that level of virtualization may make it possible to capture valuable information in ways that are implausible without VMs.

8. Scaling Quickly

- Pay-as-you-go certainly applies to storage and to network bandwidth, both of which count bytes used. Computation is slightly different, depending on the virtualization level. Google AppEngine automatically scales in response to load increases and decreases, and users are charged by the cycles used. AWS charges by the hour for the number of instances you occupy, even if your machine is idle.

- Another reason for scaling is to conserve resources as well as money. Since an idle computer uses about two-thirds of the power of a busy computer, careful use of resources could reduce the impact of datacenters on the environment. By imposing per-hour and per-byte costs, utility computing encourages programmers to pay attention to efficiency (i.e., releasing and acquiring resources only when necessary), and allows more direct measurement of operational and development inefficiencies.

Obstacles and Opportunities for Cloud Computing (contd.)

9. Reputation Fate Sharing

- One customer's bad behavior can affect the reputation of the cloud as a whole. Cloud Computing providers would want legal liability to remain with the customer and not be transferred to them (e.g., the company sending spam through an app hosted in the cloud should be held liable, not Amazon).

10. Software Licensing

- Current software licenses commonly restrict the computers on which the software can run. Users pay for the software and then pay an annual maintenance fee. E.g. SAP announced that it would increase its annual maintenance fee to at least 22% of the purchase price of the software, which is comparable to Oracle's pricing. Hence, many cloud computing providers originally relied on open source software in part because the licensing model for commercial software is not a good match to Utility Computing.

- The primary opportunity is either for open source to remain popular or simply for commercial software companies to change their licensing structure to better fit Cloud Computing. For example, Microsoft and Amazon now offer pay-as-you-go software licensing for Windows Server and Windows SQL Server on EC2.

- A related obstacle is encouraging sales forces of software companies to sell products into Cloud Computing. The opportunity for cloud providers is simply to offer prepaid plans for bulk use that can be sold at discount. For example, Oracle sales people might sell 100,000 instance hours using Oracle that can be used over the next two years at a cost less than if the customer were to purchase 100,000 hours on their own.

Conclusions and Implications for Clouds of Tomorrow

- The long dreamed vision of computing as a utility is finally emerging. The elasticity of a utility matches the need of businesses providing services directly to customers over the Internet, as workloads can grow (and shrink) far faster than 20 years ago.

- From the **cloud provider's view**, the construction of very large datacenters at low cost sites using commodity computing, storage, and networking uncovered the possibility of selling those resources on a pay-as-you-go model below the costs of many medium-sized datacenters, while making a profit by statistically multiplexing among a large group of customers.

- From the **cloud user's view**, it would be as startling for a new software startup to build its own datacenter. In addition to startups, many other established organizations take advantage of the elasticity of Cloud Computing regularly, including newspapers like the Washington Post and movie companies like Pixar.

- Developers would be wise to design their next generation of systems to be deployed into Cloud Computing. In general, the emphasis should be horizontal scalability to hundreds or thousands of virtual machines over the efficiency of the system on a single virtual machine (i.e. horizontal scaling as opposed to vertical scaling).

- When asked to identify the top benefit of deploying applications in a public cloud the most cited by developers were: freedom from maintaining hardware (19.9%), cost savings (19.4%), and scalability (16.4%). Source: http://www.hpcinthecloud.com/features/Cloud-Developments-for-Developers-An-Analyst-View-99840204.html

Conclusions and Implications for Clouds of Tomorrow (contd.)

- There are specific implications as well:

1. **Applications Software** of the future will likely have a piece that runs on clients and a piece that runs in the Cloud. The cloud piece needs to both scale down rapidly as well as scale up, which is a new requirement for software systems. Such software also needs a pay-for-use licensing model to match needs of Cloud Computing.

2. **Infrastructure Software** of the future needs to be cognizant that it is no longer running on bare metal but on virtual machines. Moreover, it needs to have billing built in from the beginning, as it is very difficult to retrofit an accounting system.

3. **Hardware Systems** of the future need to be designed at the scale of a container (at least a dozen racks) rather than at the scale of a single box or single rack, as that is the minimum level at which it will be purchased.

4. **Cost of operation** will match performance and cost of purchase in importance in the acquisition decision. Hence, they need to strive for energy proportionality by making it possible to put into low power mode the idle portions of the memory, storage, and networking, which already happens inside a microprocessor today.

5. **Hardware** should also be designed assuming that the lowest level software will be virtual machines rather than a single native operating system, and it will need to facilitate flash as a new level of the memory hierarchy between DRAM and disk. Finally, we need improvements in bandwidth and costs for both datacenter switches and WAN routers.

Looking into the Crystal Ball: What Will Cloud Computing Look Like in 5 years?

- Change In Technology and Prices Over Time:

  Clearly, the number of cores per chip will increase over time, doubling every two to four years. Flash memory has the potential of adding another relatively fast layer to the classic memory hierarchy; what will be its billing unit? Will technology or business innovations accelerate network bandwidth pricing, which is currently the most slowly-improving technology?

- Virtualization Level:

- Will Cloud Computing be dominated by low-level hardware virtual machines like Amazon EC2, intermediate language offerings like Microsoft Azure, or high-level frameworks like Google AppEngine? Or will we have many virtualization levels that match different applications?

- Will value-added services by independent companies like RightScale, Heroku, or EngineYard survive in Utility Computing, or will the successful services be entirely co-opted by the Cloud providers?

- If they do consolidate to a single virtualization layer, will multiple companies embrace a common standard? Will this lead to a race to the bottom in pricing so that it’s unattractive to become a Cloud Computing provider, or will they differentiate in services or quality to maintain margins?