UNIT-1

Introduction to Cloud Computing

Cloud computing is a virtualization-based technology that allows us to create, configure, and customize applications via an internet connection. The cloud technology includes a development platform, hard disk, software application, and database.

What is Cloud Computing?

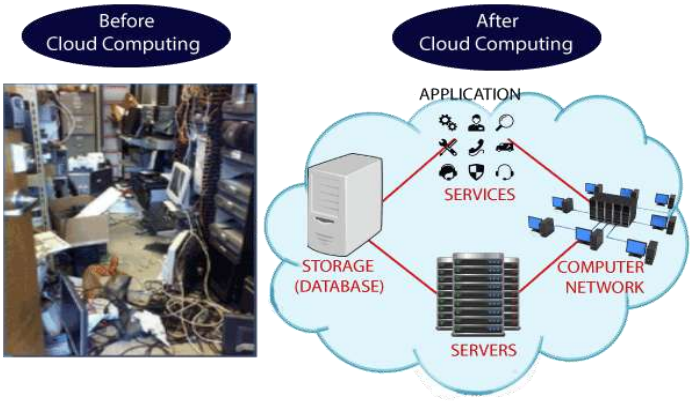
The term cloud refers to a network or the internet. It is a technology that uses remote servers on the internet to store, manage, and access data online rather than local drives. The data can be anything such as files, images, documents, audio, video, and more.

There are the following operations that we can do using cloud computing:

- Developing new applications and services
- Storage, back up, and recovery of data
- Hosting blogs and websites
- Delivery of software on demand
- Analysis of data
- Streaming videos and audios

Why Cloud Computing?

Small as well as large IT companies, follow the traditional methods to provide the IT infrastructure. That means **for any IT company, we need a Server Room that is the basic need of IT companies**.



In that server room, there should be a database server, mail server, networking, firewalls, routers, modem, switches, QPS (Query Per Second means how much queries or load will be handled by the server), configurable system, high net speed, and the maintenance engineers.

To establish such IT infrastructure, we need to spend lots of money. To overcome all these problems and to reduce the IT infrastructure cost, Cloud Computing comes into existence.

Characteristics of Cloud Computing

The characteristics of cloud computing are given below:

1) Agility

The cloud **works in a distributed computing environment**. It shares resources among users and works very fast.

2) High availability and reliability

The availability of servers is high and more reliable because the **chances of infrastructure failure are minimum**.

3) High Scalability

Cloud offers **"on-demand" provisioning of resources on a large scale**, without having engineers for peak loads.

4) Multi-Sharing

With the help of cloud computing, **multiple users and applications can work more efficiently** with cost reductions by sharing common infrastructure.

5) Device and Location Independence

Cloud computing enables the users to access systems using a web browser regardless of their location or what device they use e.g. PC, mobile phone, etc. **As infrastructure is off-site** (typically provided by a third-party) **and accessed via the Internet, users can connect from anywhere**.

6) Maintenance

Maintenance of cloud computing applications is easier, since they **do not need to be installed on each user's computer and can be accessed from different places**. So, it reduces the cost also.

7) Low Cost

By using cloud computing, the cost will be reduced because to take the services of cloud computing, **IT Company need not to set its own infrastructure** and pay-as-per usage of resources.

8) Services in the pay-per-use mode

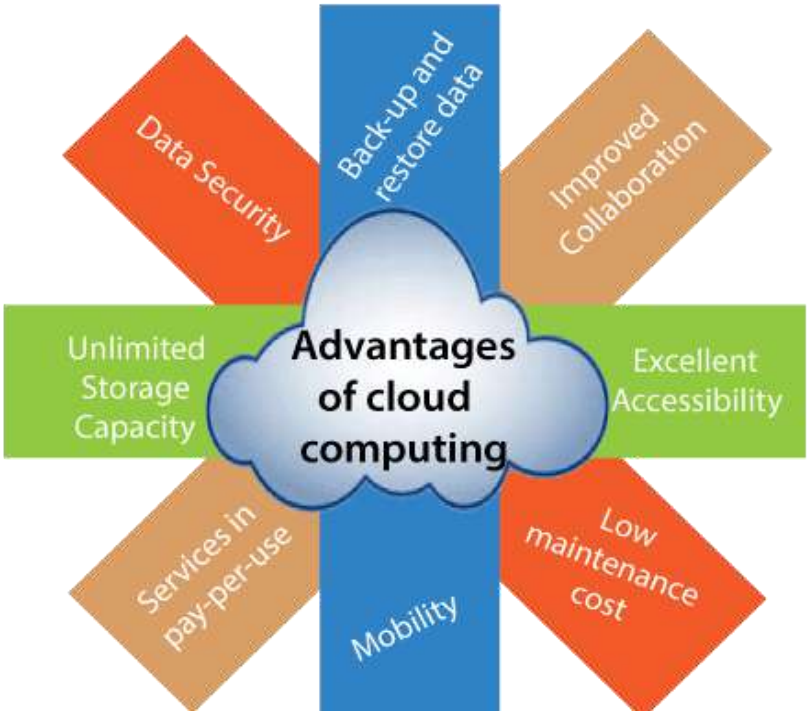
Application Programming Interfaces **(APIs) are provided to the users so that they can access services on the cloud** by using these APIs **and pay the charges as per the usage of services**.

Advantages and Disadvantages of Cloud Computing

Advantages of Cloud Computing

As we all know that Cloud computing is trending technology. Almost every company switched their services on the cloud to rise the company growth.

Here, we are going to discuss some important advantages of Cloud Computing-



1) Back-up and restore data

Once the data is stored in the cloud, it is easier to get back-up and restore that data using the cloud.

2) Improved collaboration

Cloud applications improve collaboration by allowing groups of people to quickly and easily share information in the cloud via shared storage.

2) Vendor lock-in

Vendor lock-in is the biggest disadvantage of cloud computing. Organizations may face problems when transferring their services from one vendor to another. As different vendors provide different platforms, that can cause difficulty moving from one cloud to another.

3) Limited Control

As we know, cloud infrastructure is completely owned, managed, and monitored by the service provider, so the cloud users have less control over the function and execution of services within a cloud infrastructure.

4) Security

Although cloud service providers implement the best security standards to store important information. But, before adopting cloud technology, you should be aware that you will be sending all your organization's sensitive information to a third party, i.e., a cloud computing service provider. While sending the data on the cloud, there may be a chance that your organization's information is hacked by Hackers.

Disadvantages:

- It requires good internet connection.
- User have limited control on the data.

Cloud Computing	Grid Computing
Cloud Computing follows client-server computing architecture.	Grid computing follows a distributed computing architecture.
Scalability is high.	Scalability is normal.
Cloud Computing is more flexible than grid computing.	Grid Computing is less flexible than cloud computing.
Cloud operates as a centralized management system.	Grid operates as a decentralized management system.
In cloud computing, cloud servers are owned by infrastructure providers.	In Grid computing, grids are owned and managed by the organization.
Cloud computing uses services like IaaS, PaaS, and SaaS.	Grid computing uses systems like distributed computing, distributed information, and distributed pervasive.
Cloud Computing is Service-oriented.	Grid Computing is Application-oriented.
It is accessible through standard web protocols.	It is accessible through grid middleware.

1. Overview

This section provides an overview of introductory cloud computing topics. It begins with a brief history of cloud computing along with short descriptions of its business and technology drivers. This is followed by definitions of basic concepts and terminology, in addition to explanations of the primary benefits and challenges of cloud computing adoption.

This section covers the following topics:

- A Brief History
- Business Drivers
- Technology Innovations

1.1 A Brief History

The idea of computing in a "cloud" traces back to the origins of utility computing, a concept that computer scientist John McCarthy publicly proposed in 1961:

"If computers of the kind I have advocated become the computers of the future, then computing may someday be organized as a public utility just as the telephone system is a public utility… The computer utility could become the basis of a new and important industry."

In 1969, Leonard Kleinrock, a chief scientist of the Advanced Research Projects Agency Network or ARPANET project that seeded the Internet, stated:

"As of now, computer networks are still in their infancy, but as they grow up and become sophisticated, we will probably see the spread of 'computer utilities' …".

The general public has been leveraging forms of Internet-based computer utilities since the mid-1990s through various incarnations of search engines (Yahoo!, Google), e-mail services (Hotmail, Gmail), open publishing platforms (MySpace, Facebook, YouTube), and other types of social media (Twitter, LinkedIn). Though consumer-centric, these services popularized and validated core concepts that form the basis of modern-day cloud computing.

In the late 1990s, Salesforce.com pioneered the notion of bringing remotely provisioned services into the enterprise. In 2002, Amazon.com launched the Amazon Web Services (AWS) platform, a suite of enterprise-oriented services that provide remotely provisioned storage, computing resources, and business functionality.

A slightly different evocation of the term "Network Cloud" or "Cloud" was introduced in the early 1990s throughout the networking industry. It referred to an abstraction layer derived in the delivery methods of data across heterogeneous public and semi-public networks that were primarily packet-switched, although cellular networks used the "Cloud" term as well. The networking method at this point supported the transmission of data from one end-point (local network) to the "Cloud" (wide area network) and then further decomposed to another intended end-point. This is relevant, as the networking industry still references the use of this term, and is considered an early adopter of the concepts that underlie utility computing.

It wasn't until 2006 that the term "cloud computing" emerged in the commercial arena. It was during this time that Amazon launched its Elastic Compute Cloud (EC2) services that enabled organizations to "lease" computing capacity and processing power to run their enterprise applications. Google Apps also began providing browser-based enterprise applications in the same year, and three years later, the Google App Engine became another historic milestone.

Definitions

A Gartner report listing cloud computing at the top of its strategic technology areas further reaffirmed its prominence as an industry trend by announcing its formal definition as:

"...a style of computing in which scalable and elastic IT-enabled capabilities are delivered as a service to external customers using Internet technologies."

This is a slight revision of Gartner's original definition from 2008, in which "massively scalable" was used instead of "scalable and elastic." This acknowledges the importance of scalability in relation to the ability to scale vertically and not just to enormous proportions.

Forrester Research provided its own definition of cloud computing as:

"...a standardized IT capability (services, software, or infrastructure) delivered via Internet technologies in a pay-per-use, self-service way."

The definition that received industry-wide acceptance was composed by the National Institute of Standards and Technology (NIST). NIST published its original definition back in 2009, followed by a revised version after further review and industry input that was published in September of 2011:

"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models."

This book provides a more concise definition:

"Cloud computing is a specialized form of distributed computing that introduces utilization models for remotely provisioning scalable and measured resources."

This simplified definition is in line with all of the preceding definition variations that were put forth by other organizations within the cloud computing industry. The characteristics, service models, and deployment models referenced in the NIST definition are further covered.

1.2 Business Drivers

Before delving into the layers of technologies that underlie clouds, the motivations that led to their creation by industry leaders must first be understood. Several of the primary business drivers that fostered modern cloud-based technology are presented in this section.

The origins and inspirations of many of the characteristics, models, and mechanisms covered throughout subsequent chapters can be traced back to the upcoming business drivers. It is important to note that these influences shaped clouds and the overall cloud computing market from both ends. They have motivated organizations to adopt cloud computing in support of their business automation requirements. They have correspondingly motivated other organizations to become providers of cloud environments and cloud technology vendors in order to create and meet the demand to fulfill consumer needs.

1.2.1 Capacity Planning

Capacity planning is the process of determining and fulfilling future demands of an organization's IT resources, products, and services. Within this context, capacity represents the maximum amount of work that an IT resource is capable of delivering in a given period of time. A discrepancy between the capacity of an IT resource and its demand can result in a

system becoming either inefficient (over-provisioning) or unable to fulfill user needs (under-provisioning). Capacity planning is focused on minimizing this discrepancy to achieve predictable efficiency and performance.

Different capacity planning strategies exist:

- *Lead Strategy* – adding capacity to an IT resource in anticipation of demand
- *Lag Strategy* – adding capacity when the IT resource reaches its full capacity
- *Match Strategy* – adding IT resource capacity in small increments, as demand increases

Planning for capacity can be challenging because it requires estimating usage load fluctuations. There is a constant need to balance peak usage requirements without unnecessary over-expenditure on infrastructure. An example is outfitting IT infrastructure to accommodate maximum usage loads which can impose unreasonable financial investments. In such cases, moderating investments can result in under-provisioning, leading to transaction losses and other usage limitations from lowered usage thresholds.

1.2.2 Cost Reduction

A direct alignment between IT costs and business performance can be difficult to maintain. The growth of IT environments often corresponds to the assessment of their maximum usage requirements. This can make the support of new and expanded business automations an ever-increasing investment. Much of this required investment is funneled into infrastructure expansion because the usage potential of a given automation solution will always be limited by the processing power of its underlying infrastructure.

Two costs need to be accounted for: the cost of acquiring new infrastructure, and the cost of its ongoing ownership. Operational overhead represents a considerable share of IT budgets, often exceeding up-front investment costs.

Common forms of infrastructure-related operating overhead include the following:

- technical personnel required to keep the environment operational
- upgrades and patches that introduce additional testing and deployment cycles
- utility bills and capital expense investments for power and cooling
- security and access control measures that need to be maintained and enforced to protect infrastructure resources
- administrative and accounts staff that may be required to keep track of licenses and support arrangements

The on-going ownership of internal technology infrastructure can encompass burdensome responsibilities that impose compound impacts on corporate budgets. An IT department can consequently become a significant-and at times overwhelming-drain on the business, potentially inhibiting its responsiveness, profitability, and overall evolution.

Organizational Agility

Businesses need the ability to adapt and evolve to successfully face change caused by both internal and external factors. Organizational agility is the measure of an organization's responsiveness to change.

An IT enterprise often needs to respond to business change by scaling its IT resources beyond the scope of what was previously predicted or planned for. For example, infrastructure may be

subject to limitations that prevent the organization from responding to usage fluctuations-even when anticipated-if previous capacity planning efforts were restricted by inadequate budgets.

In other cases, changing business needs and priorities may require IT resources to be more available and reliable than before. Even if sufficient infrastructure is in place for an organization to support anticipated usage volumes, the nature of the usage may generate runtime exceptions that bring down hosting servers. Due to a lack of reliability controls within the infrastructure, responsiveness to consumer or customer requirements may be reduced to a point whereby a business' overall continuity is threatened.

On a broader scale, the up-front investments and infrastructure ownership costs that are required to enable new or expanded business automation solutions may themselves be prohibitive enough for a business to settle for IT infrastructure of less-than-ideal quality, thereby decreasing its ability to meet real-world requirements.

Worse yet, the business may decide against proceeding with an automation solution altogether upon review of its infrastructure budget, because it simply cannot afford to. This form of inability to respond can inhibit an organization from keeping up with market demands, competitive pressures, and its own strategic business goals.

1.3 Technology Innovations

Established technologies are often used as inspiration and, at times, the actual foundations upon which new technology innovations are derived and built. This section briefly describes the pre-existing technologies considered primary influences on cloud computing.

Clustering

A cluster is a group of independent IT resources that are interconnected and work as a single system. System failure rates are reduced while availability and reliability are increased, since redundancy and failover features are inherent to the cluster.

A general prerequisite of hardware clustering is that its component systems have reasonably identical hardware and operating systems to provide similar performance levels when one failed component is to be replaced by another. Component devices that form a cluster are kept in synchronization through dedicated, high-speed communication links.

The basic concept of built-in redundancy and failover is core to cloud platforms. Clustering technology is explored further in Chapter 8 as part of the Resource Cluster mechanism description.

Grid Computing

A computing grid (or "computational grid") provides a platform in which computing resources are organized into one or more logical pools. These pools are collectively coordinated to provide a high performance distributed grid, sometimes referred to as a "super virtual computer." Grid computing differs from clustering in that grid systems are much more loosely coupled and distributed. As a result, grid computing systems can involve computing resources that are heterogeneous and geographically dispersed, which is generally not possible with cluster computing-based systems.

Grid computing has been an on-going research area in computing science since the early 1990s. The technological advancements achieved by grid computing projects have influenced various aspects of cloud computing platforms and mechanisms, specifically in relation to common feature-sets such as networked access, resource pooling, and scalability and

resiliency. These types of features can be established by both grid computing and cloud computing, in their own distinctive approaches.

For example, grid computing is based on a middleware layer that is deployed on computing resources. These IT resources participate in a grid pool that implements a series of workload distribution and coordination functions. This middle tier can contain load balancing logic, failover controls, and autonomic configuration management, each having previously inspired similar-and several more sophisticated-cloud computing technologies. It is for this reason that some classify cloud computing as a descendant of earlier grid computing initiatives.

1.3.1 Virtualization

Virtualization represents a technology platform used for the creation of virtual instances of IT resources. A layer of virtualization software allows physical IT resources to provide multiple virtual images of themselves so that their underlying processing capabilities can be shared by multiple users.

Prior to the advent of virtualization technologies, software was limited to residing on and being coupled with static hardware environments. The virtualization process severs this software-hardware dependency, as hardware requirements can be simulated by emulation software running in virtualized environments.

Established virtualization technologies can be traced to several cloud characteristics and cloud computing mechanisms, having inspired many of their core features. As cloud computing evolved, a generation of *modern* virtualization technologies emerged to overcome the performance, reliability, and scalability limitations of traditional virtualization platforms.

As a foundation of contemporary cloud technology, modern virtualization provides a variety of virtualization types and technology layers.

1.3.2 Technology Innovations vs. Enabling Technologies

It is essential to highlight several other areas of technology that continue to contribute to modern-day cloud-based platforms. These are distinguished as *cloud-enabling technologies*

- Broadband Networks and Internet Architecture
- Data Center Technology
- (Modern) Virtualization Technology
- Web Technology
- Multitenant Technology
- Service Technology

Each of these cloud-enabling technologies existed in some form prior to the formal advent of cloud computing. Some were refined further, and on occasion even redefined, as a result of the subsequent evolution of cloud computing.

1.4 Basic Concepts and Terminology

This section establishes a set of basic terms that represent the fundamental concepts and aspects pertaining to the notion of a cloud and its most primitive artifacts.

This section covers the following topics:

- Cloud
- IT Resource
- On-Premise
- Scaling
- Cloud Service
- Cloud Service Consumer

Cloud

A *cloud* refers to a distinct IT environment that is designed for the purpose of remotely provisioning scalable and measured IT resources. The term originated as a metaphor for the Internet which is, in essence, a network of networks providing remote access to a set of decentralized IT resources. Prior to cloud computing becoming its own formalized IT industry segment, the symbol of a cloud was commonly used to represent the Internet in a variety of specifications and mainstream documentation of Web-based architectures. This same symbol is now used to specifically represent the boundary of a cloud environment, as shown in Figure 1.

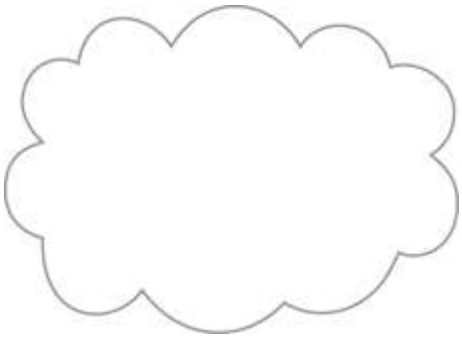


Figure 1 – The symbol used to denote the boundary of a cloud environment.

It is important to distinguish the term "cloud" and the cloud symbol from the Internet. As a specific environment used to remotely provision IT resources, a cloud has a finite boundary. There are many individual clouds that are accessible via the Internet.

Whereas the Internet provides open access to many Web-based IT resources, a cloud is typically privately owned and offers access to IT resources that is metered.

Much of the Internet is dedicated to the access of content-based IT resources published via the World Wide Web. IT resources provided by cloud environments, on the other hand, are dedicated to supplying back-end processing capabilities and user-based access to these capabilities. Another key distinction is that it is not necessary for clouds to be Web-based even if they are commonly based on Internet protocols and technologies. Protocols refer to standards and methods that allow computers to communicate with each other in a pre-defined and structured manner. A cloud can be based on the use of any protocols that allow for the remote access to its IT resources.

IT Resource

An *IT resource* is a physical or virtual IT-related artifact that can be either software based, such as a virtual server or a custom software program, or hardware-based, such as a physical server or a network device (Figure 1).

Figure 1 – Examples of common IT resources and their corresponding symbols.

Figure 2 illustrates how the cloud symbol can be used to define a boundary for a cloud-based environment that hosts and provisions a set of IT resources. The displayed IT resources are consequently considered to be cloud-based IT resources.

Technology architectures and various interaction scenarios involving IT resources are illustrated in diagrams like the one shown in Figure 2. It is important to note the following points when studying and working with these diagrams:

- The IT resources shown within the boundary of a given cloud symbol usually do not represent all of the available IT resources hosted by that cloud. Subsets of IT resources are generally highlighted to demonstrate a particular topic.
- Focusing on the relevant aspects of a topic requires many of these diagrams to intentionally provide abstracted views of the underlying technology architectures. This means that only a portion of the actual technical details are shown.

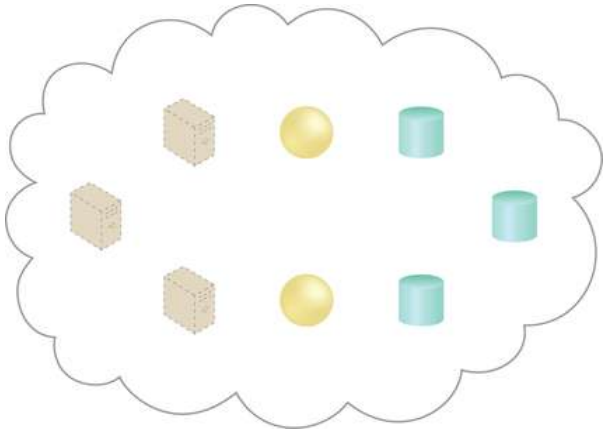


Figure 2 – A cloud is hosting eight IT resources: three virtual servers, two cloud services, and three storage devices.

Furthermore, some diagrams will display IT resources outside of the cloud symbol. This convention is used to indicate IT resources that are not cloud-based.

On-Premise

As a distinct and remotely accessible environment, a cloud represents an option for the deployment of IT resources. An IT resource that is hosted in a conventional IT enterprise within an organizational boundary (that does not specifically represent a cloud) is considered to be located on the premises of the IT enterprise, or *on-premise* for short. In other words, the term "on-premise" is another way of stating "on the premises of a controlled IT environment that is not cloud-based." This term is used to qualify an IT resource as an alternative to "cloud-based." An IT resource that is on-premise cannot be cloud-based, and vice-versa.

Scaling

Scaling, from an IT resource perspective, represents the ability of the IT resource to handle increased or decreased usage demands.

The following are types of scaling:

- *Horizontal Scaling* – scaling out and scaling in
- *Vertical Scaling* – scaling up and scaling down

Horizontal Scaling

The allocating or releasing of IT resources that are of the same type is referred to as *horizontal scaling* (Figure 1). The horizontal allocation of resources is referred to as *scaling* out and the horizontal releasing of resources is referred to as *scaling in*. Horizontal scaling is a common form of scaling within cloud environments.

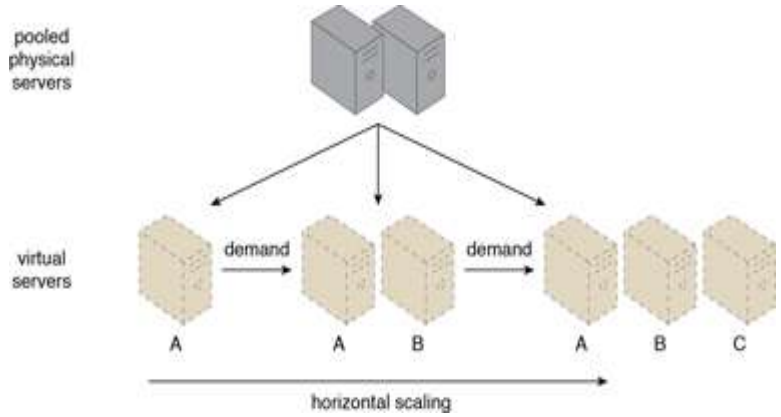


Figure 1 – An IT resource (Virtual Server A) is scaled out by adding more of the same IT resources (Virtual Servers B and C).

Vertical Scaling

When an existing IT resource is upgraded or replaced by another with higher or lower capacity, *vertical scaling* is considered to have occurred (Figure 2). Specifically, the upgrading or replacing of an IT resource with another that has a higher capacity is referred to as *scaling up* and the downgrading or replacing an IT resource with another that has a lower capacity is considered *scaling down*. Vertical scaling is less common in cloud environments due to the downtime that may be required to scale up or down.

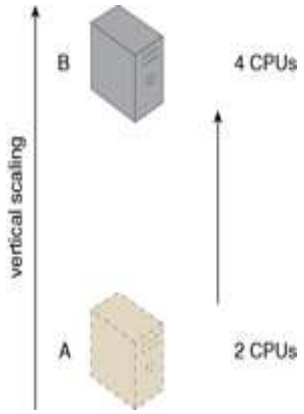


Figure 2 – In this example, an IT resource (a virtual server with two CPUs) is scaled up by replacing it with a more powerful IT resource with increased capacity for data storage (a physical server with four CPUs).

Table 1 provides a brief overview of common pros and cons associated with horizontal and vertical scaling.

HORIZONTAL SCALING	VERTICAL SCALING
less expensive (through commodity hardware components)	more expensive (specialized servers)
IT resources instantly available	IT resources normally instantly available
resource replication and automated scaling	additional setup is normally needed
additional IT resources needed	no additional IT resources needed
not limited by hardware capacity	limited by maximum hardware capacity

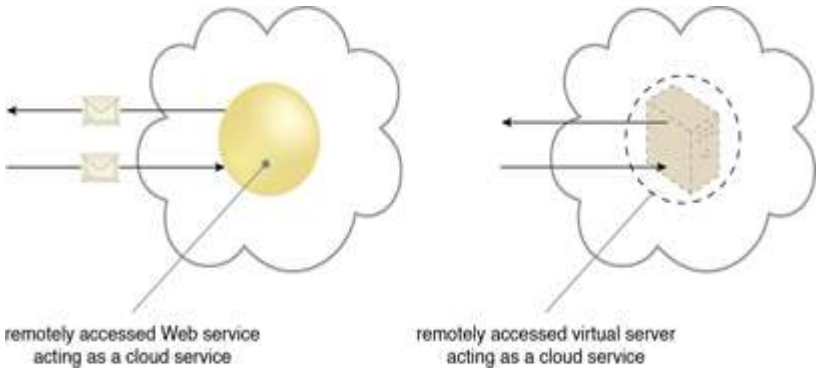
Table 1 – A comparison of horizontal and vertical scaling.

Cloud Service

Although a cloud is a remotely accessible environment, not all IT resources residing within a cloud can be made available for remote access. For example, a database or a physical server deployed within a cloud may only be accessible by other IT resources that are within the same cloud. A software program with a published API may be deployed specifically to enable access by remote clients.

A *cloud service* is any IT resource that is made remotely accessible via a cloud. Unlike other IT fields that fall under the service technology umbrella – such as service-oriented architecture – the term "service" within the context of cloud computing is especially broad. A cloud service can exist as a simple Web-based software program with a technical interface invoked via the use of a messaging protocol, or as a remote access point for administrative tools or larger environments and other IT resources.

In Figure 1, the yellow circle symbol is used to represent the cloud service as a simple Web-based software program. A different IT resource symbol may be used in the latter case, depending on the nature of the access that is provided by the cloud service.



Figures 1 – A cloud service with a published technical interface is being accessed by a consumer outside of the cloud (left). A cloud service that exists as a virtual server is also being accessed from outside of the cloud's boundary (right). The cloud service on the left is likely being invoked by a consumer program that was designed to access the cloud service's published technical interface. The cloud service on the right may be accessed by a human user that has remotely logged on to the virtual server.

The driving motivation behind cloud computing is to provide IT resources as services that encapsulate other IT resources, while offering functions for clients to use and leverage remotely. A multitude of

models for generic types of cloud services have emerged, most of which are labeled with the "as-a-service" suffix.

Cloud Service Consumer

The *cloud service consumer* is a temporary runtime role assumed by a software program when it accesses a cloud service.

As shown in Figure 1, common types of cloud service consumers can include software programs and services capable of remotely accessing cloud services with published service contracts, as well as workstations, laptops and mobile devices running software capable of remotely accessing other IT resources positioned as cloud services.

Figures 1 – Examples of cloud service consumers. Depending on the nature of a given diagram, an artifact labeled as a cloud service consumer may be a software program or a hardware device (in which case it is implied that it is running a software program capable of acting as a cloud service consumer).

Goals and Benefits

The common benefits associated with adopting cloud computing are explained in this section.

The following sections make reference to the terms "public cloud" and "private cloud." These terms are described in the *Cloud Deployment Models* section.

- Reduced Investments and Proportional Costs
- Increased Scalability
- Increased Availability and Reliability

Reduced Investments and Proportional Costs

Similar to a product wholesaler that purchases goods in bulk for lower price points, public cloud providers base their business model on the mass-acquisition of IT resources that are then made available to cloud consumers via attractively priced leasing packages. This opens the door for organizations to gain access to powerful infrastructure without having to purchase it themselves.

The most common economic rationale for investing in cloud-based IT resources is in the reduction or outright elimination of up-front IT investments, namely hardware and software purchases and ownership costs. A cloud's Measured Usage characteristic represents a feature-set that allows measured operational expenditures (directly related to business performance) to replace anticipated capital expenditures. This is also referred to as *proportional costs*.

This elimination or minimization of up-front financial commitments allows enterprises to start small and accordingly increase IT resource allocation as required. Moreover, the reduction of up-front capital expenses allows for the capital to be redirected to the core business investment. In its most basic form, opportunities to decrease costs are derived from the deployment and operation of large-scale data centers by major cloud providers. Such data centers are commonly located in destinations where real estate, IT professionals, and network bandwidth can be obtained at lower costs, resulting in both capital and operational savings.

The same rationale applies to operating systems, middleware or platform software, and application software. Pooled IT resources are made available to and shared by multiple cloud consumers, resulting in increased or even maximum possible utilization. Operational costs and inefficiencies can be further reduced by applying proven practices and patterns for optimizing cloud architectures, their management and governance.

Common measurable benefits to cloud consumers include:

- On-demand access to pay-as-you-go computing resources on a short-term basis (such as processors by the hour), and the ability to release these computing resources when they are no longer needed.
- The perception of having unlimited computing resources that are available on demand, thereby reducing the need to prepare for provisioning.
- The ability to add or remove IT resources at a fine-grained level, such as modifying available storage disk space by single gigabyte increments.
- Abstraction of the infrastructure so applications are not locked into devices or locations and can be easily moved if needed.

For example, a company with sizable batch-centric tasks can complete them as quickly as their application software can scale. Using 100 servers for one hour costs the same as using one server for 100 hours. This "elasticity" of IT resources, achieved without requiring steep initial investments to create a large-scale computing infrastructure, can be extremely compelling.

Despite the ease with which many identify the financial benefits of cloud computing, the actual economics can be complex to calculate and assess. The decision to proceed with a cloud computing adoption strategy will involve much more than a simple comparison between the cost of leasing and the cost of purchasing. For example, the financial benefits of dynamic scaling and the risk transference of both over-provisioning (under-utilization) and under-provisioning (over-utilization) must also be accounted for.

Increased Scalability

By providing pools of IT resources, along with tools and technologies designed to leverage them collectively, clouds can instantly and dynamically allocate IT resources to cloud consumers, on-demand or via the cloud consumer's direct configuration. This empowers cloud consumers to scale their cloud-based IT resources to accommodate processing fluctuations and peaks automatically or manually. Similarly, cloud-based IT resources can be released (automatically or manually) as processing demands decrease.

A simple example of usage demand fluctuations throughout a 24 hour period is provided in Figure 1

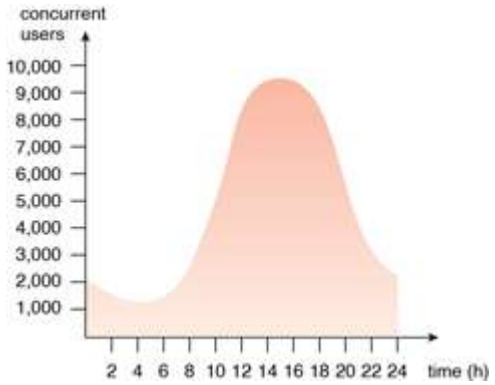


Figure 1 – An example of an organization's changing demand for an IT resource over the course of a day.

The inherent, built-in feature of clouds to provide flexible levels of scalability to IT resources is directly related to the aforementioned proportional costs benefit. Besides the evident financial gain to the automated reduction of scaling, the ability of IT resources to always meet and fulfill unpredictable usage demands avoids potential loss of business that can occur when usage thresholds are met.

Increased Availability and Reliability

The availability and reliability of IT resources are directly associated with tangible business benefits. Outages limit the time an IT resource can be "open for business" for its customers, thereby limiting its usage and revenue generating potential. Runtime failures that are not immediately corrected can have a more significant impact during high-volume usage periods. Not only is the IT resource unable to respond to customer requests, its unexpected failure can decrease overall customer confidence.

A hallmark of the typical cloud environment is its intrinsic ability to provide extensive support for increasing the availability of a cloud-based IT resource to minimize or even eliminate outages, and for increasing its reliability so as to minimize the impact of runtime failure conditions.

Specifically:

- An IT resource with increased availability is accessible for longer periods of time (for example, 22 hours out of a 24 hour day). Cloud providers generally offer "resilient" IT resources for which they are able to guarantee high levels of availability.
- An IT resource with increased reliability is able to better avoid and recover from exception conditions. The modular architecture of cloud environments provides extensive failover support that increases reliability.

It is important that organizations carefully examine the SLAs offered by cloud providers when considering the leasing of cloud-based services and IT resources. Although many cloud environments are capable of offering remarkably high levels of availability and reliability, it comes down to the guarantees made in the SLA that typically represent their actual contractual obligations.

Risks and Challenges

Several of the most critical cloud computing challenges pertaining mostly to cloud consumers that use IT resources located in public clouds are presented and examined.

This section covers the following topics:

- Increased Security Vulnerabilities
- Reduced Operational Governance Control
- Limited Portability Between Cloud Providers
- Multi-Regional Regulatory and Legal Issues

Increased Security Vulnerabilities

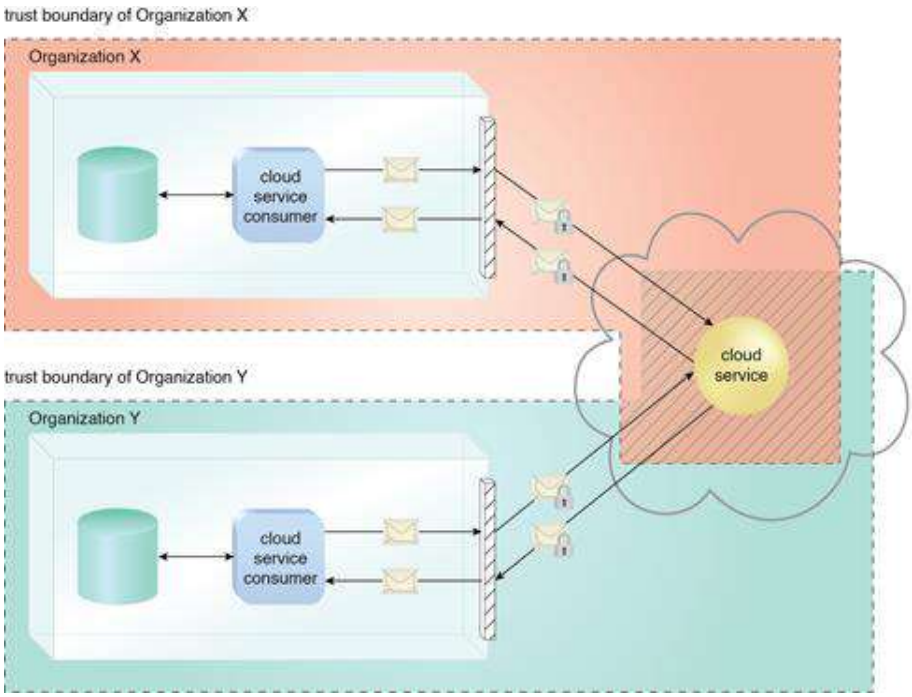
The moving of business data to the cloud means that the responsibility over data security becomes shared with the cloud provider. The remote usage of IT resources requires an expansion of trust boundaries by the cloud consumer to include the external cloud. It can be difficult to establish a security architecture that spans such a trust boundary without introducing vulnerabilities, unless cloud consumers and cloud providers happen to support the same or compatible security frameworks—which is unlikely with public clouds.

Another consequence of overlapping trust boundaries relates to the cloud provider's privileged access to cloud consumer data. The extent to which the data is secure is now limited to the security controls and policies applied by both the cloud consumer and cloud provider. Furthermore, there can be overlapping trust boundaries from different cloud consumers due to the fact that cloud-based IT resources are commonly shared.

The overlapping of trust boundaries and the increased exposure of data can provide malicious cloud consumers (human and automated) with greater opportunities to attack IT resources and steal or damage business data. Figure 1 illustrates a scenario whereby two organizations accessing the same cloud service are required to extend their respective trust boundaries to the cloud, resulting in overlapping trust boundaries. It can be challenging for the cloud provider to offer security mechanisms that accommodate the security requirements of both cloud service consumers.

Reduced Operational Governance Control

Cloud consumers are usually allotted a level of governance control that is lower than that over on-premise IT resources. This reduced level of governance control can introduce risks associated with how the cloud provider operates its cloud, as well as the external connections that are required for communicate between the cloud and the cloud consumer.



Figures 1 – The shaded area with diagonal lines indicates the overlap of two organizations' trust boundaries.

Consider the following examples:

- An unreliable cloud provider may not maintain the guarantees it makes in the SLAs that were published for its cloud services. This can jeopardize the quality of the cloud consumer solutions that rely on these cloud services.
- Longer geographic distances between the cloud consumer and cloud provider can require additional network hops that introduce fluctuating latency and potential bandwidth constraints.

The latter scenario is illustrated in Figure 2.

Legal contracts, when combined with SLAs, technology inspections, and monitoring, can mitigate governance risks and issues. A cloud governance system is established through SLAs, given the "as-a-service" nature of cloud computing. A cloud consumer must keep track of the actual service level being offered and the other warranties that are made by the cloud provider. Note that different cloud delivery models offer varying degrees of operational control granted to cloud consumers.

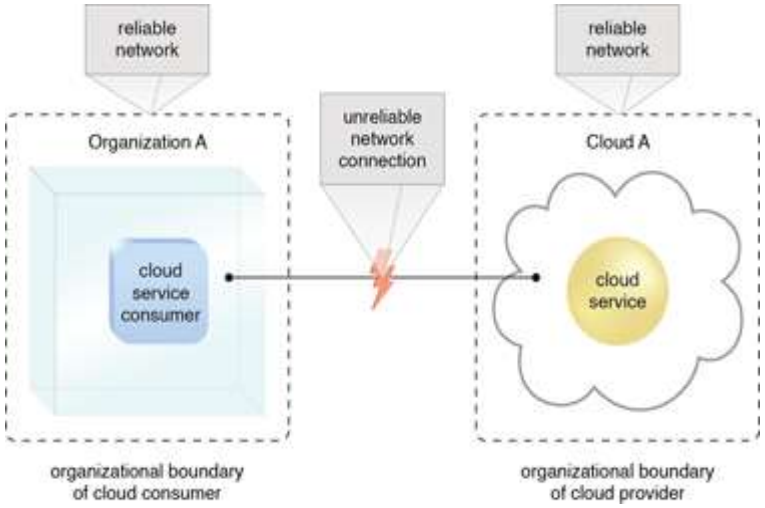


Figure 2 – An unreliable network connection compromises the quality of communication between cloud consumer and cloud provider environments.

Limited Portability between Cloud Providers

Due to a lack of established industry standards within the cloud computing industry, public clouds are commonly proprietary to various extents. For cloud consumers that have custom-built solutions with dependencies on these proprietary environments, it can be challenging to move from one cloud provider to another.

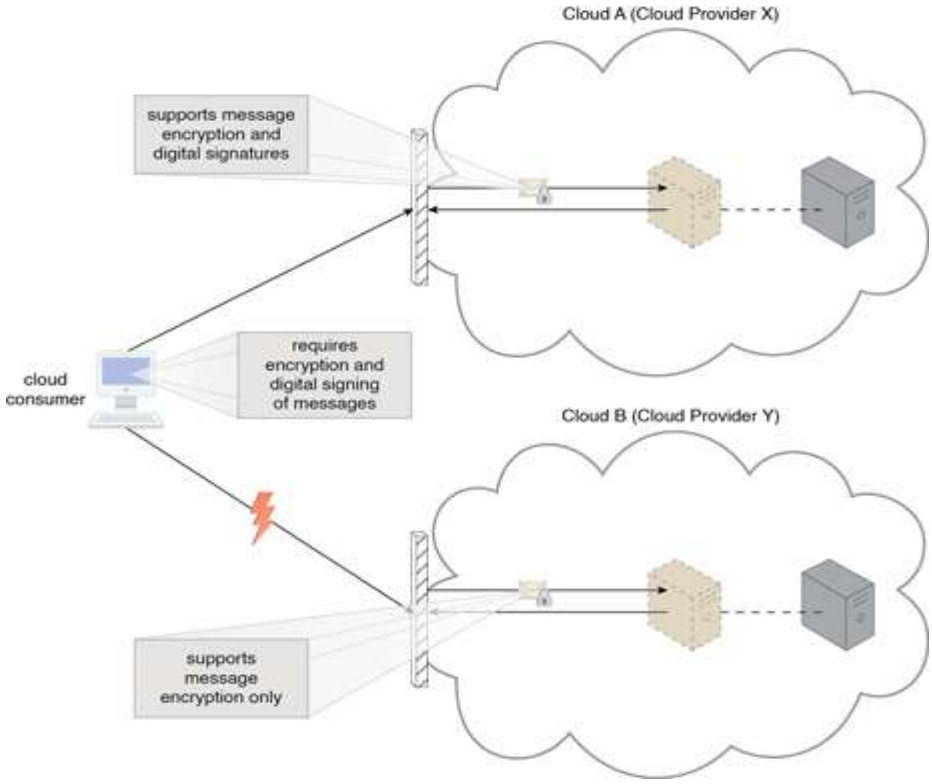


Figure 3 – A cloud consumer's application has a decreased level of portability when assessing a potential migration from Cloud A to Cloud B, because the cloud provider of Cloud B does not support the same security technologies as Cloud A.

Portability is a measure used to determine the impact of moving cloud consumer IT resources and data between clouds (Figure 3).

Multi-Regional Regulatory and Legal Issues

Third-party cloud providers will frequently establish data centers in affordable or convenient geographical locations. Cloud consumers will often not be aware of the physical location of their IT resources and data when hosted by public clouds. For some organizations, this can pose serious legal concerns pertaining to industry or government regulations that specify data privacy and storage policies. For example, some UK laws require personal data belonging to UK citizens to be kept within the United Kingdom.

Another potential legal issue pertains to the accessibility and disclosure of data. Countries have laws that require some types of data to be disclosed to certain government agencies or to the subject of the data. For example, a European cloud consumer's data that is located in the U.S. can be more easily accessed by government agencies (due to the U.S. Patriot Act) when compared to data located in many European Union countries.

Most regulatory frameworks recognize that cloud consumer organizations are ultimately responsible for the security, integrity, and storage of their own data, even when it is held by an external cloud provider.

FUNDAMENTAL CONCEPTS and MODELS

1. Roles and Boundaries

The fundamental models used to categorize and define clouds and their most common service offerings, along with definitions of organizational roles and the specific set of characteristics that collectively distinguish a cloud.

Organizations and humans can assume different types of pre-defined roles depending on how they relate to and/or interact with a cloud and its hosted IT resources. Each of the upcoming roles participates and carries out responsibilities in relation to cloud-based activity. The following sections define these roles and identify their main interactions.

This section covers the following topics:

- Cloud Provider
- Cloud Consumer
- Cloud Service Owner
- Cloud Resource Administrator
- Additional Resources
- Organizational Boundaries
- Trust Boundaries

Cloud Provider

The organization that provides cloud-based IT resources is the *cloud provider*. When assuming the role of cloud provider, an organization is responsible for making cloud services available to cloud consumers, as per agreed upon SLA guarantees. The cloud provider is further tasked with any required management and administrative duties to ensure the on-going operation of the overall cloud infrastructure.

Cloud providers normally own the IT resources that are made available for lease by cloud consumers; however, some cloud providers also "resell" IT resources leased from other cloud providers.

Cloud Consumer

A *cloud consumer* is an organization (or a human) that has a formal contract or arrangement with a cloud provider to use IT resources made available by the cloud provider. Specifically, the cloud consumer uses a cloud service consumer to access a cloud service (Figure 1).

The figures in this book do not always explicitly label symbols as "cloud consumers." Instead, it is generally implied that organizations or humans shown remotely accessing cloud-based IT resources are considered cloud consumers.

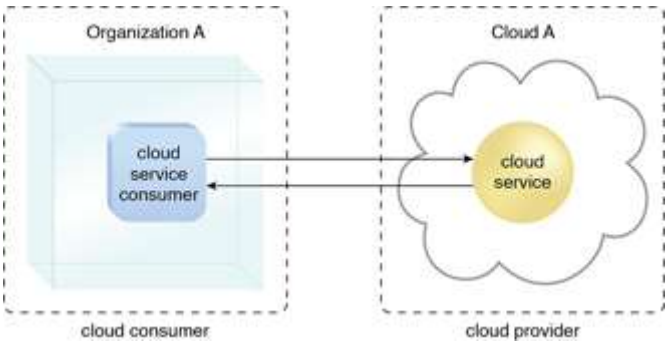


Figure 1 – A cloud consumer (Organization A) interacts with a cloud service from a cloud provider (that owns Cloud A). Within Organization A, the cloud service consumer is being used to access the cloud service.

Cloud Service Owner

The person or organization that legally owns a cloud service is called a *cloud service owner*. The cloud service owner can be the cloud consumer, or the cloud provider that owns the cloud within which the cloud service resides.

For example, either the cloud consumer of Cloud X or the cloud provider of Cloud X could own Cloud Service A (Figures 1 and 2).

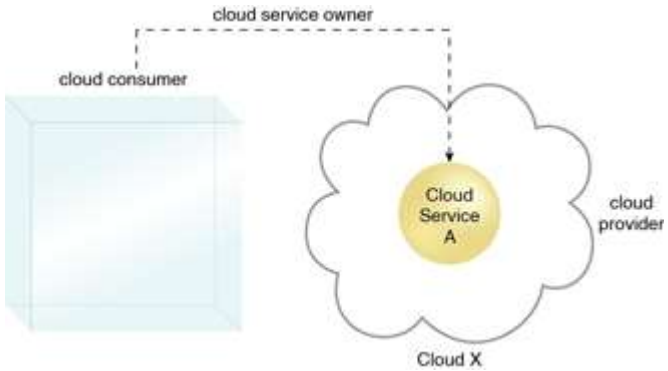


Figure 1 – A cloud consumer can be a cloud service owner when it deploys its own service in a cloud.

Note that a cloud consumer that owns a cloud service hosted by a third-party cloud does not necessarily need to be the user (or consumer) of the cloud service. Several cloud consumer organizations develop and deploy cloud services in clouds owned by other parties for the purpose of making the cloud services available to the general public.

The reason a cloud service owner is not called a cloud resource owner is because the cloud service owner role only applies to cloud services .

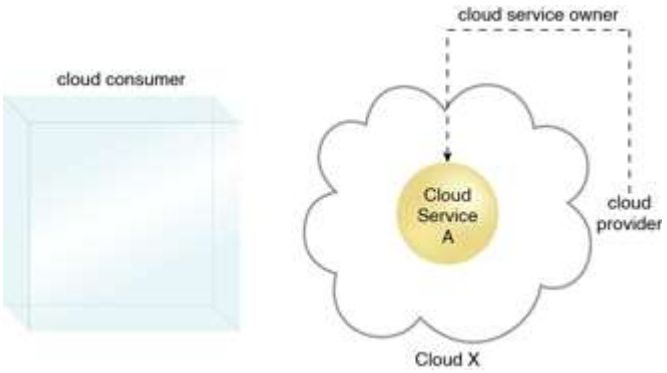


Figure 2 – A cloud provider becomes a cloud service owner if it deploys its own cloud service, typically for other cloud consumers to use.

Cloud Resource Administrator

A *cloud resource administrator* is the person or organization responsible for administering a cloud-based IT resource (including cloud services). The cloud resource administrator can be (or belong to) the cloud consumer or cloud provider of the cloud within which the cloud service resides. Alternatively, it can be (or belong to) a third-party organization contracted to administer the cloud-based IT resource.

For example, a cloud service owner can contract a cloud resource administrator to administer a cloud service (Figures 1 and 2).

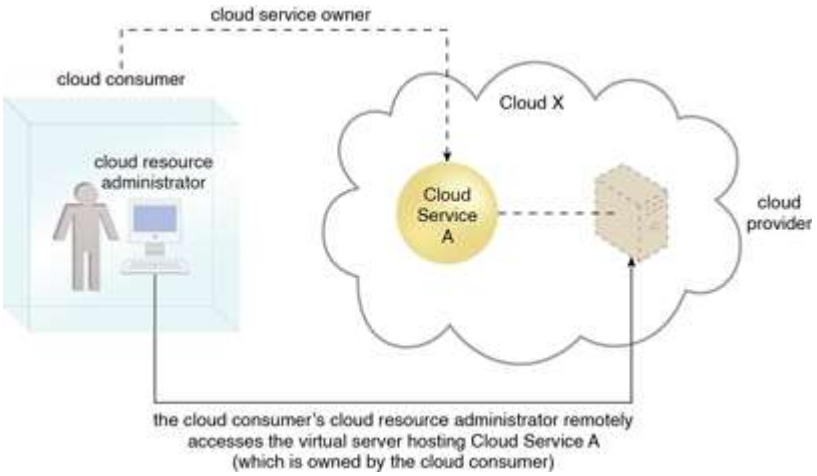


Figure 1 – A cloud resource administrator can be with a cloud consumer organization and administer remotely accessible IT resources that belong to the cloud consumer.

The reason a cloud resource administrator is not referred to as a “cloud service administrator” is because this role may be responsible for administering cloud-based IT resources that don’t exist as cloud services. For example, if the cloud resource administrator belongs to (or is contracted by) the cloud provider, IT resources not made remotely accessible may be administered by this role (and these types of IT resources are not classified as cloud services).

Additional Roles

The NIST(National Institute of Standards and Technology) Cloud Computing Reference Architecture defines the following supplementary roles:

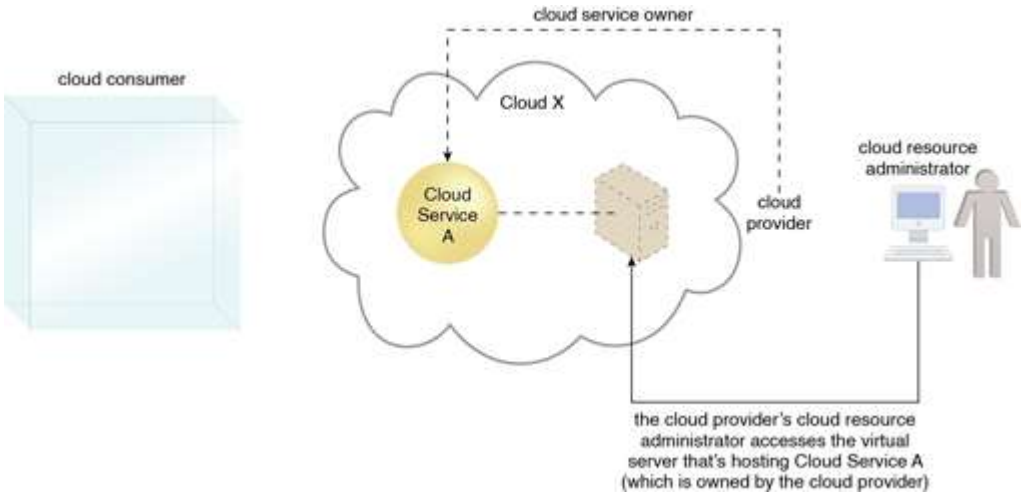


Figure 2 – A cloud resource administrator can be with a cloud provider organization for which it can administer the cloud provider's internally and externally available IT resources.

- *Cloud Auditor* – A third-party (often accredited) that conducts independent assessments of cloud environments assumes the role of the *cloud auditor*. The typical responsibilities associated with this role include the evaluation of security controls, privacy impacts, and performance. The main purpose of the cloud auditor role is to provide an unbiased assessment (and possible endorsement) of a cloud environment to help strengthen the trust relationship between cloud consumers and cloud providers.
- *Cloud Broker* – This role is assumed by a party that assumes the responsibility of managing and negotiating the usage of cloud services between cloud consumers and cloud providers. Mediation services provided by *cloud brokers* include service intermediation, aggregation, and arbitrage.
- *Cloud Carrier* – The party responsible for providing the wire-level connectivity between cloud consumers and cloud providers assumes the role of the *cloud carrier*. This role is often assumed by network and telecommunication providers.

Organizational Boundary

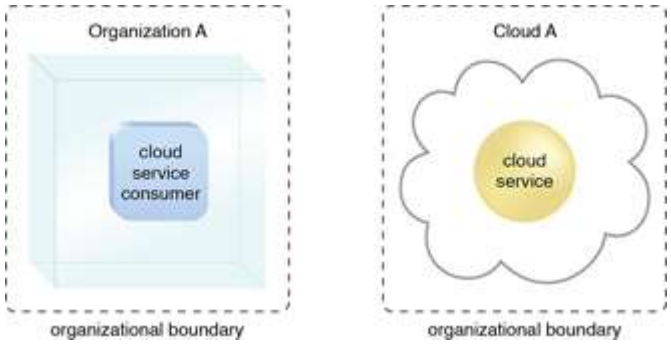


Figure 1 – Organizational boundaries of a cloud consumer (left), and a cloud provider (right), represented by a broken line notation.

An *organizational boundary* represents the physical perimeter that surrounds a set of IT resources that are owned and governed by an organization. The organizational boundary does not represent the boundary of an actual organization, only an organizational set of IT assets and IT resources. Similarly, clouds have an organizational boundary (Figure 1).

Trust Boundary

When an organization assumes the role of cloud consumer to access cloud-based IT resources, it needs to extend its trust beyond the physical boundary of the organization to include parts of the cloud environment.

A *trust boundary* is a logical perimeter that typically spans beyond physical boundaries to represent the extent to which IT resources are trusted (Figure 4.7). When analyzing cloud environments, the trust boundary is most frequently associated with the trust issued by the organization acting as the cloud consumer.

Cloud Characteristics

An IT environment requires a specific set of characteristics to enable the remote provisioning of scalable and measured IT resources in an effective manner. These characteristics need to exist to a meaningful extent for the IT environment to be considered an effective cloud.

The following six specific characteristics are common to the majority of cloud environments:

- On-Demand Usage
- Ubiquitous Access
- Multi-tenancy (Resourcing Pooling)
- Elasticity (and Scalability)
- Measured Usage
- Resiliency

Cloud providers and cloud consumers can assess these characteristics individually and collectively to measure the value offering of a given cloud platform. Although cloud-based services and IT resources will inherit and exhibit individual characteristics to varying extents, usually the greater the degree to which they are supported and utilized, the greater the resulting value proposition.

Note: The NIST definition of cloud computing defines only five characteristics; resiliency is excluded. Resiliency has emerged as an aspect of significant importance and its common level of support constitutes its necessary inclusion as a common cloud characteristic.

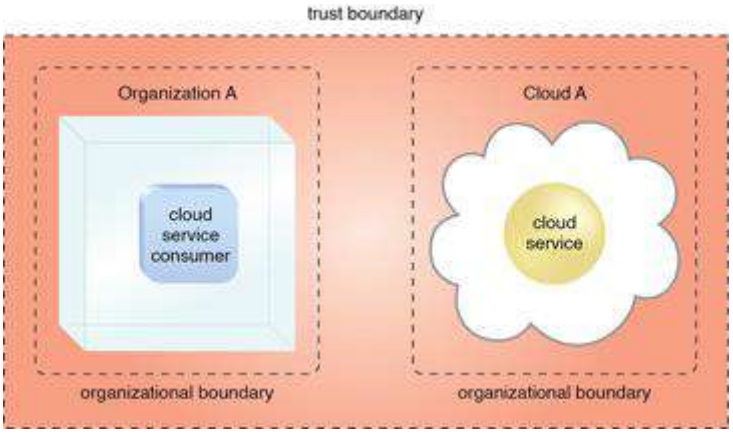


Figure 1 – An extended trust boundary encompasses the organizational boundaries of the cloud provider and the cloud consumer.

Note: Another type of boundary relevant to cloud environments is the logical network perimeter. This type of boundary is classified as a cloud computing mechanism.

On-Demand Usage

A cloud consumer can unilaterally access cloud-based IT resources giving the cloud consumer the freedom to self-provision these IT resources. Once configured, usage of the self-provisioned IT resources can be automated, requiring no further human involvement by the cloud consumer or cloud provider. This results in an *on-demand usage* environment. Also known as "on-demand self-service usage," this characteristic enables the service-based and usage-driven features found in mainstream clouds.

Ubiquitous Access

Ubiquitous Access represents the ability for a cloud service to be widely accessible. Establishing ubiquitous access for a cloud service can require support for a range of devices, transport protocols, interfaces, and security technologies. To enable this level of access generally requires that the cloud service architecture be tailored to the particular needs of different cloud service consumers.

Multitenancy (and Resource Pooling)

The characteristic of a software program that enables an instance of the program to serve different consumers (tenants) whereby each is isolated from the other, is referred to as *multitenancy*. A cloud provider pools its IT resources to serve multiple cloud service consumers by using multitenancy models that frequently rely on the use of virtualization technologies. Through the use of multitenancy technology, IT resources can be dynamically assigned and reassigned, according to cloud service consumer demands.

Resource pooling allows cloud providers to pool large-scale IT resources to serve multiple cloud consumers. Different physical and virtual IT resources are dynamically assigned and reassigned according to cloud consumer demand, typically followed by execution through statistical multiplexing. Resource pooling is commonly achieved through multitenancy technology, and therefore encompassed by this multitenancy characteristic.

Figures 1 and 2 illustrate the difference between single-tenant and multitenant environments.

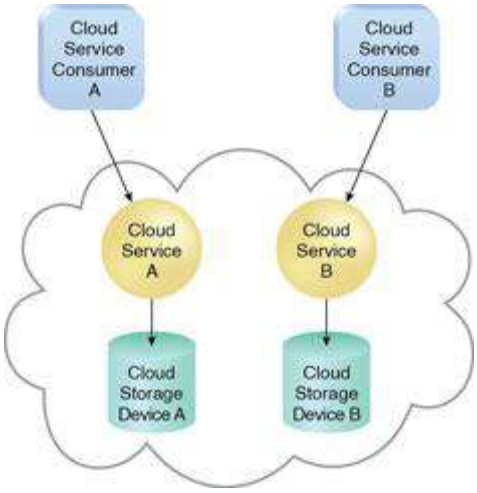


Figure 1 – In a single-tenant environment, each cloud consumer has a separate IT resource instance.

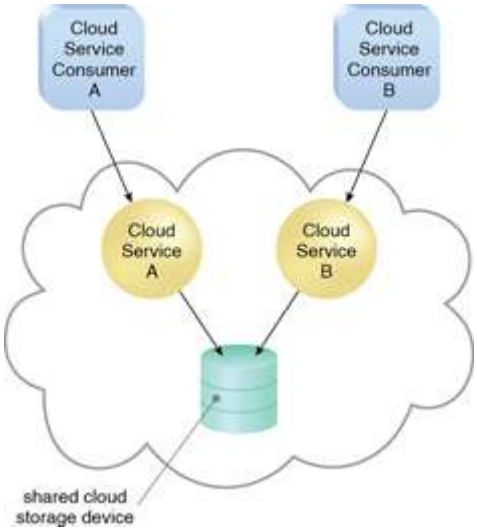


Figure 2 – In a multitenant environment, a single instance of an IT resource, such as a cloud storage device, serves multiple consumers.

As illustrated in Figure 1, multitenancy allows several cloud consumers to use the same IT resource or its instance while each remains unaware that it may be used by others.

Elasticity

Elasticity is the automated ability of a cloud to transparently scale IT resources, as required in response to runtime conditions or as pre-determined by the cloud consumer or cloud provider. Elasticity is often considered a core justification for the adoption of cloud computing, primarily due to the fact that it is closely associated with the Reduced Investment and Proportional Costs benefit. Cloud providers with vast IT resources can offer the greatest range of elasticity.

Measured Usage

The *measured usage* characteristic represents the ability of a cloud platform to keep track of the usage of its IT resources, primarily by cloud consumers. Based on what is measured, the cloud provider can charge a cloud consumer only for the IT resources actually used and/or for the timeframe during which access to the IT resources was granted. In this context, measured usage is closely related to the on-demand characteristic.

Measured usage is not limited to tracking statistics for billing purposes. It also encompasses the general monitoring of IT resources and related usage reporting (for both cloud provider

and cloud consumers). Therefore, measured usage is also relevant to clouds that do not charge for usage (which may be applicable to the private cloud deployment model described in the upcoming *Cloud Deployment Models* section).

Resiliency

Resilient computing is a form of failover that distributes redundant implementations of IT resources across physical locations. IT resources can be pre-configured so that if one becomes deficient, processing is automatically handed over to another redundant implementation.

Within cloud computing, the characteristic of resiliency can refer to redundant IT resources within the same cloud (but in different physical locations) or across multiple clouds. Cloud consumers can increase both the reliability and availability of their applications by leveraging the resiliency of cloud-based IT resources (Figure 1).

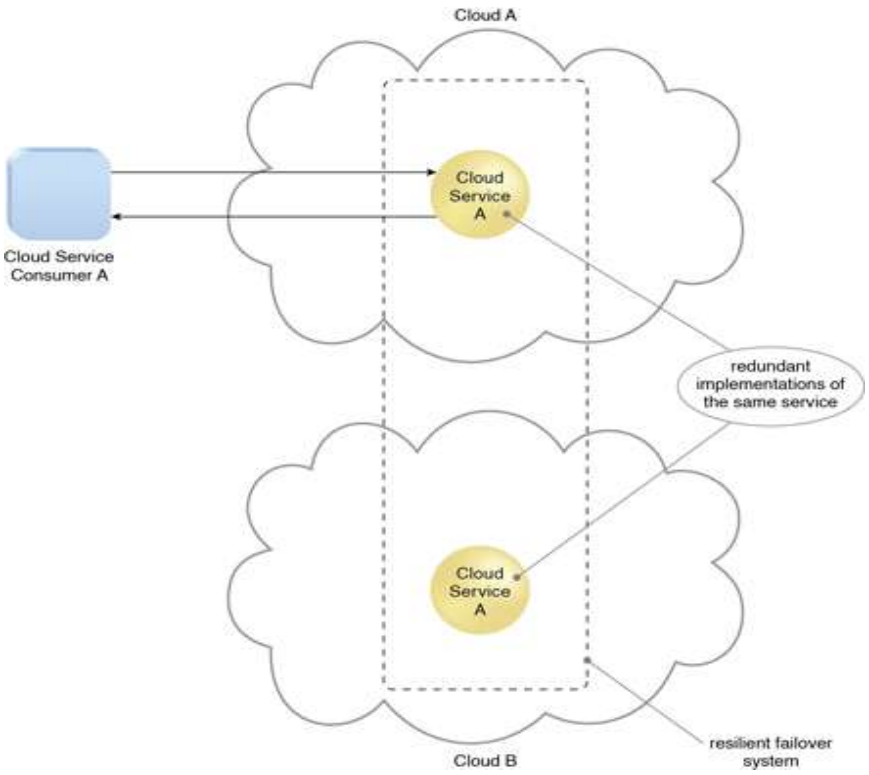


Figure 1 – A resilient system in which Cloud B hosts a redundant implementation of Cloud Service A to provide failover in case Cloud Service A on Cloud A becomes unavailable.

Cloud Delivery Models

A *cloud delivery model* represents a specific, pre-packaged combination of IT resources offered by a cloud provider. Three common cloud delivery models have become widely established and formalized:

- Infrastructure-as-a-Service (IaaS)
- Platform-as-a-Service (PaaS)
- Software-as-a-Service (SaaS)

These three models are interrelated in how the scope of one can encompass that of another, as explored in the *Combining Cloud Delivery Models* section later in this chapter.

Note

Many specialized variations of the three base cloud delivery models have emerged, each comprised of a distinct combination of IT resources. Some examples include:

- Storage-as-a-Service
- Database-as-a-Service
- Security-as-a-Service
- Communication-as-a-Service
- Integration-as-a-Service
- Testing-as-a-Service
- Process-as-a-Service

A cloud delivery model can be referred to as a cloud service delivery model because each model is classified as a different type of cloud service offering.

This section covers the following topics:

Infrastructure-as-a-Service (IaaS)

The IaaS delivery model represents a self-contained IT environment comprised of infrastructure-centric IT resources that can be accessed and managed via cloud service-based interfaces and tools. This environment can include hardware, network, connectivity, operating systems, and other “raw” IT resources. In contrast to traditional hosting or outsourcing environments, with IaaS, IT resources are typically virtualized and packaged into bundles that simplify up-front runtime scaling and customization of the infrastructure.

The general purpose of an IaaS environment is to provide cloud consumers with a high level of control and responsibility over its configuration and utilization. The IT resources provided by IaaS are generally not pre-configured, placing the administrative responsibility directly upon the cloud consumer. This model is therefore used by cloud consumers that require a high level of control over the cloud-based environment they intend to create.

Sometimes cloud providers will contract IaaS offerings from other cloud providers in order to scale their own cloud environments. The types and brands of the IT resources provided by IaaS products offered by different cloud providers can vary. IT resources available through IaaS environments are generally offered as freshly initialized virtual instances. A central and primary IT resource within a typical IaaS environment is the virtual server. Virtual servers are leased by specifying server hardware requirements, such as processor capacity, memory, and local storage space, as shown in Figure 1.

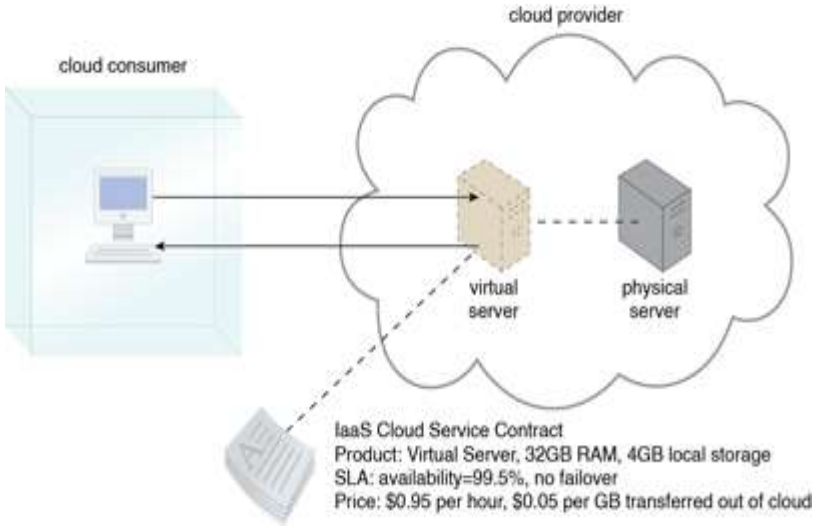


Figure 1 – A cloud consumer is using a virtual server within an IaaS environment. Cloud consumers are provided with a range of contractual guarantees by the cloud provider, pertaining to characteristics such as capacity, performance, and availability.

Platform-as-a-Service (PaaS)

The PaaS delivery model represents a pre-defined "ready-to-use" environment typically comprised of already deployed and configured IT resources. Specifically, PaaS relies on (and is primarily defined by) the usage of a ready-made environment that establishes a set of pre-packaged products and tools used to support the entire delivery lifecycle of custom applications.

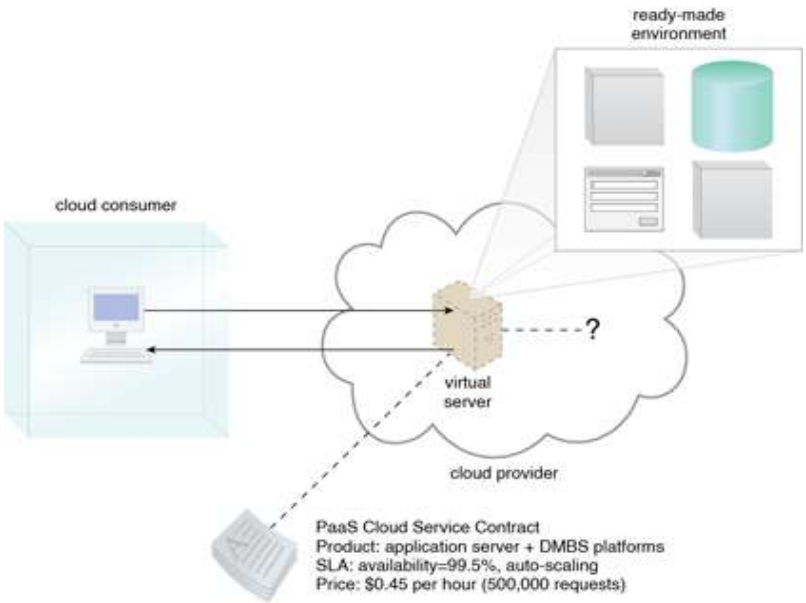


Figure 1 – A cloud consumer is accessing a ready-made PaaS environment. The question mark indicates that the cloud consumer is intentionally shielded from the implementation details of the platform.

Common reasons a cloud consumer would use and invest in a PaaS environment include:

- The cloud consumer wants to extend on-premise environments into the cloud for scalability and economic purposes.
- The cloud consumer uses the ready-made environment to entirely substitute an on-premise environment.

- The cloud consumer wants to become a cloud provider and deploys its own cloud services to be made available to other external cloud consumers.

By working within a ready-made platform, the cloud consumer is spared the administrative burden of setting up and maintaining the bare infrastructure IT resources provided via the IaaS model. Conversely, the cloud consumer is granted a lower level of control over the underlying IT resources that host and provision the platform (Figure 1).

PaaS products are available with different development stacks. For example, Microsoft Azure provides a .NET-based environment, while Google App Engine offers a Java and Python-based environment.

PaaS products are available with different development stacks. For example, Google App Engine offers a Java and Python-based environment.

Software-as-a-Service (SaaS)

A software program positioned as a shared cloud service and made available as a "product" or generic utility represents the typical profile of a SaaS offering. The SaaS delivery model is typically used to make a reusable cloud service widely available (often commercially) to a range of cloud consumers. An entire marketplace exists around SaaS products that can be leased and used for different purposes and via different terms (Figure 1).

A cloud consumer is generally granted very limited administrative control over a SaaS implementation. It is most often provisioned by the cloud provider, but it can be legally owned by whichever entity assumes the cloud service owner role. For example, an organization acting as a cloud consumer while using and working with a PaaS environment can build a cloud service that it decides to deploy in that same environment as a SaaS offering. The same organization then effectively assumes the cloud provider role as the SaaS-based cloud service is made available to other organizations that act as cloud consumers when using that cloud service.

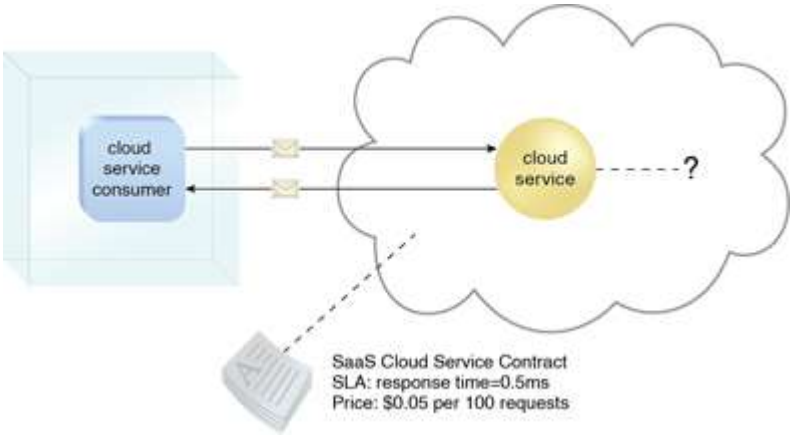


Figure 1 – The cloud service consumer is given access the cloud service contract, but not to any underlying IT resources or implementation details.

Combining Cloud Delivery Models

The three base cloud delivery models comprise a natural provisioning hierarchy, allowing for opportunities for the combined application of the models to be explored. The upcoming sections briefly highlight considerations pertaining to two common combinations.

IaaS + PaaS

A PaaS environment will be built upon an underlying infrastructure comparable to the physical and virtual servers and other IT resources provided in an IaaS environment.

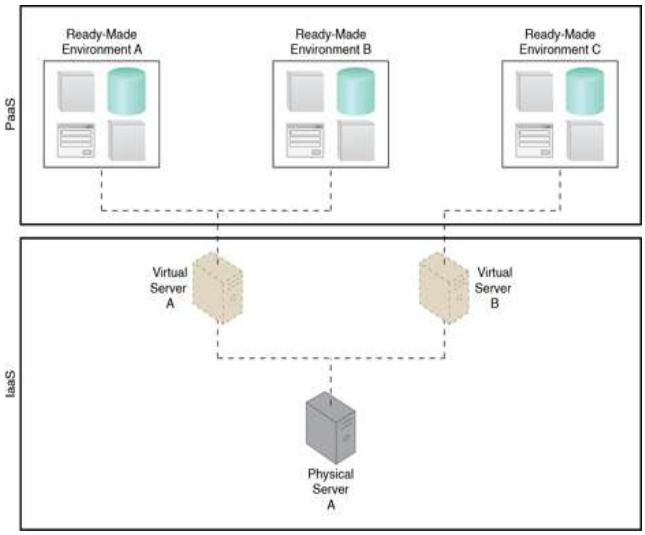


Figure 1 – A PaaS environment based on the IT resources provided by an underlying IaaS environment.

Figure 1 shows how these two models can conceptually be combined into a simple layered architecture.

A cloud provider would not normally need to provision an IaaS environment from its own cloud in order to make a PaaS environment available to cloud consumers. So how would the architectural view provided by Figure 1 be useful or applicable? Let's say that the cloud provider offering the PaaS environment chose to lease an IaaS environment from a *different* cloud provider.

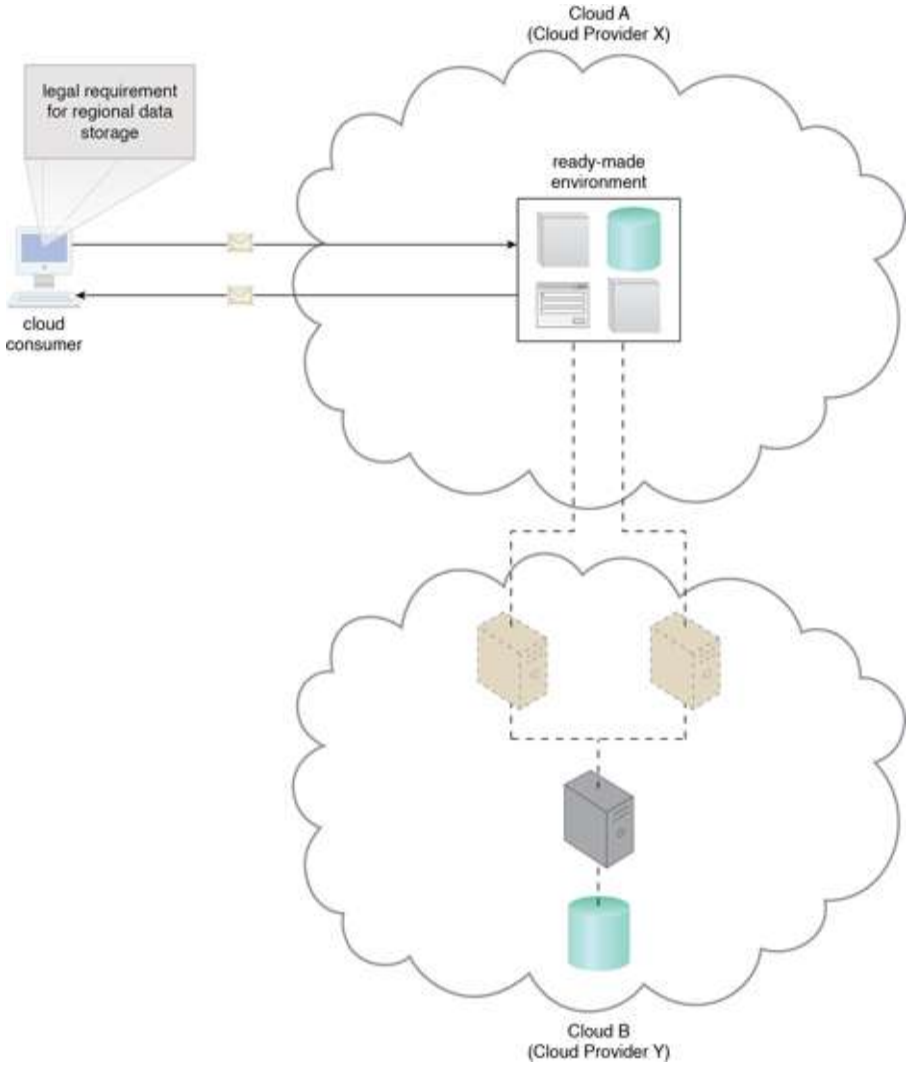


Figure 2 – An example of a contract between Cloud Providers X and Y, in which services offered by Cloud Provider X are physically hosted on virtual servers belonging to Cloud Provider Y. Sensitive data that is legally required to stay in a specific region is physically kept in Cloud B, which is physically located in that region.

The motivation for such an arrangement may be influenced by economics or maybe because the first cloud provider is close to exceeding its existing capacity by serving other cloud consumers. Or, perhaps a particular cloud consumer imposes a legal requirement for data to be physically stored in a specific region (different from where the first cloud provider's cloud resides), as illustrated in Figure 2.

IaaS + PaaS + SaaS

All three cloud delivery models can be combined to establish layers of IT resources that build upon each other. For example, by adding on to the preceding layered architecture shown in Figure 4.15, the ready-made environment provided by the PaaS environment can be used by the cloud consumer organization to develop and deploy its own SaaS cloud services that it can then make available as commercial products (Figure 3).

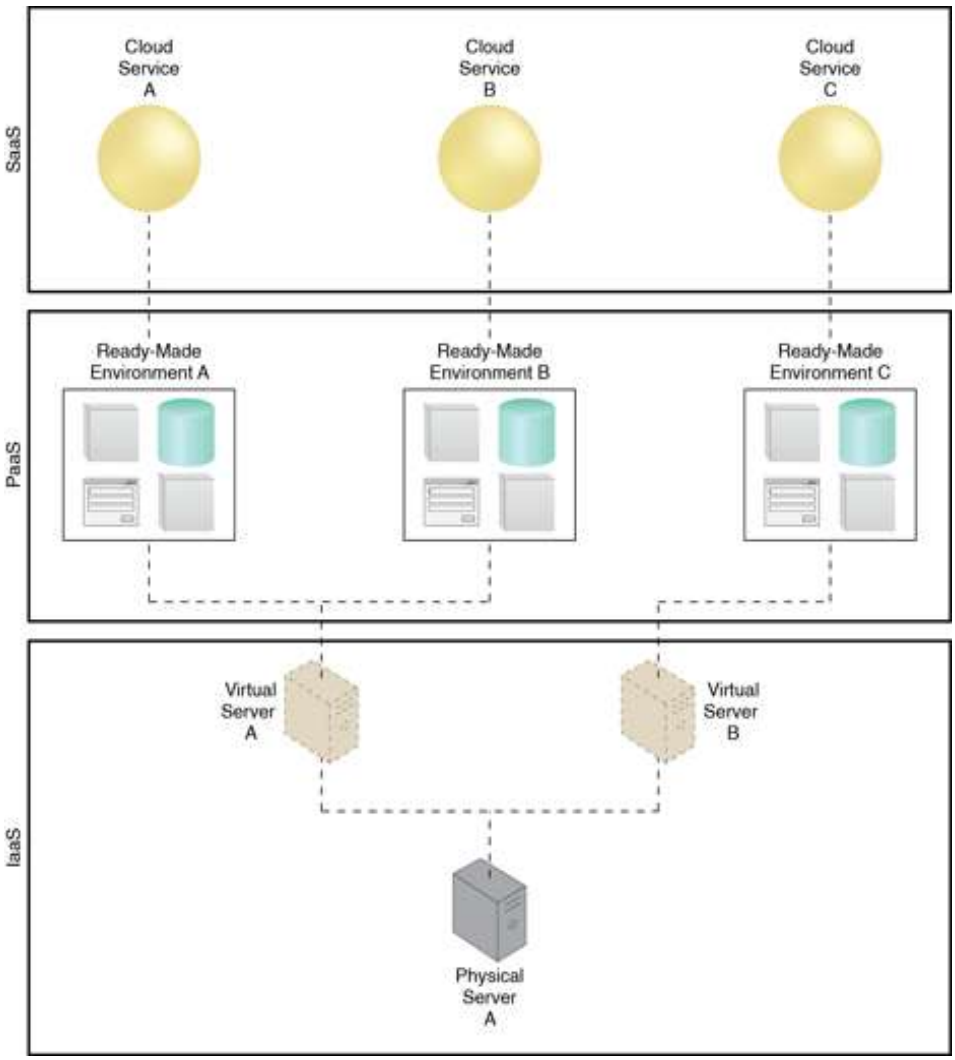


Figure 3 – A simple layered view of an architecture comprised of IaaS and PaaS environments hosting three SaaS cloud service implementations

Cloud Deployment Models

A cloud deployment model represents a specific type of cloud environment, primarily distinguished by ownership, size, and access.

There are four common cloud deployment models:

- Public Clouds
- Community Clouds
- Private Clouds
- Hybrid Clouds
- Other Deployment Models

The following sections describe each.

Public Clouds

A *public cloud* is a publicly accessible cloud environment owned by a third-party cloud provider. The IT resources on public clouds are usually provisioned via the previously

described cloud delivery models and are generally offered to cloud consumers at a cost or are commercialized via other avenues (such as advertisement).

The cloud provider is responsible for the creation and on-going maintenance of the public cloud and its IT resources. Many of the scenarios and architectures explored in upcoming chapters involve public clouds and the relationship between the providers and consumers of IT resources via public clouds.

Figure 1 shows a partial view of the public cloud landscape, highlighting some of the primary vendors in the marketplace.

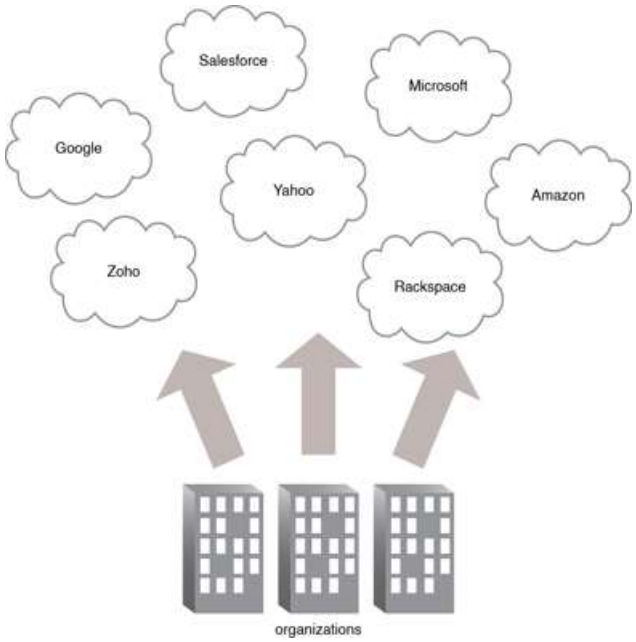


Figure 1 – Organizations act as cloud consumers when accessing cloud services and IT resources made available by different cloud providers.

Community Clouds

A community cloud is similar to a public cloud except that its access is limited to a specific community of cloud consumers. The community cloud may be jointly owned by the community members or by a third-party cloud provider that provisions a public cloud with limited access. The member cloud consumers of the community typically share the responsibility for defining and evolving the community cloud (Figure 1).

Membership in the community does not necessarily guarantee access to or control of all the cloud's IT resources. Parties outside the community are generally not granted access unless allowed by the community.

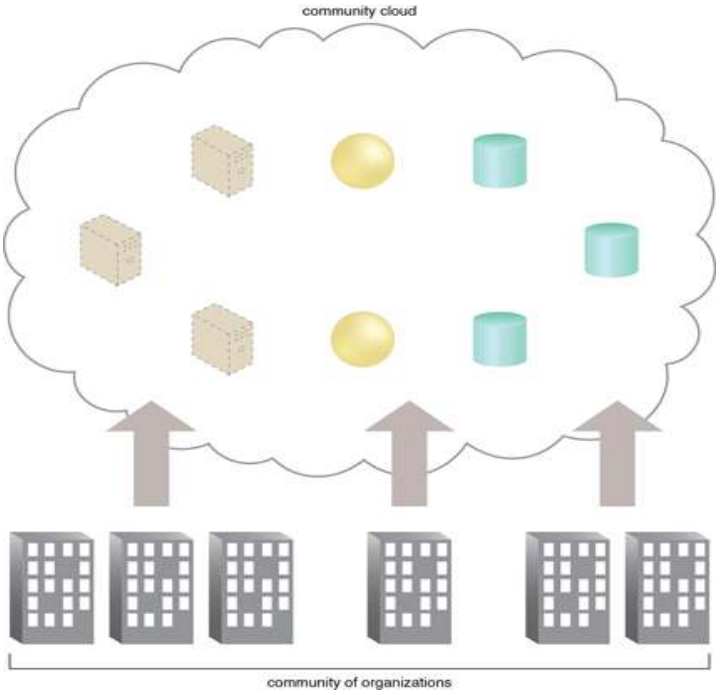


Figure 1 – An example of a "community" of organizations accessing IT resources from a community cloud.

Private Clouds

A private cloud is owned by a single organization. Private clouds enable an organization to use cloud computing technology as a means of centralizing access to IT resources by different parts, locations, or departments of the organization. When a private cloud exists as a controlled environment, the problems described in the Risks and Challenges section do not tend to apply.

The use of a private cloud can change how organizational and trust boundaries are defined and applied. The actual administration of a private cloud environment may be carried out by internal or outsourced staff.

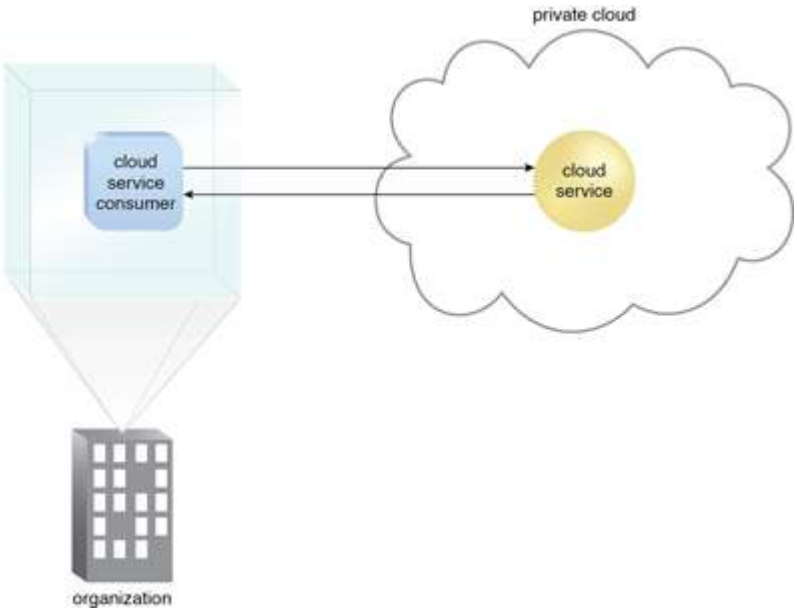


Figure 1 – A cloud service consumer in the organization's on-premise environment accesses a cloud service hosted on the same organization's private cloud via a virtual private network.

With a private cloud, the same organization is technically both the cloud consumer and cloud provider (Figure 1). In order to differentiate these roles:

- a separate organizational department typically assumes the responsibility for provisioning the cloud (and therefore assumes the cloud provider role)
- departments requiring access to the private cloud assume the cloud consumer role

It is important to use the terms "on-premise" and "cloud-based" correctly within the context of a private cloud. Even though the private cloud may physically reside on the organization's premises, IT resources it hosts are still considered "cloud-based" as long as they are made remotely accessible to cloud consumers. IT resources hosted outside of the private cloud by the departments acting as cloud consumers are therefore considered "on-premise" in relation to the private cloud-based IT resources.

Hybrid Clouds

A hybrid cloud is a cloud environment comprised of two or more different cloud deployment models. For example, a cloud consumer may choose to deploy cloud services processing sensitive data to a private cloud and other, less sensitive cloud services to a public cloud. The result of this combination is a hybrid deployment model (Figure 1).

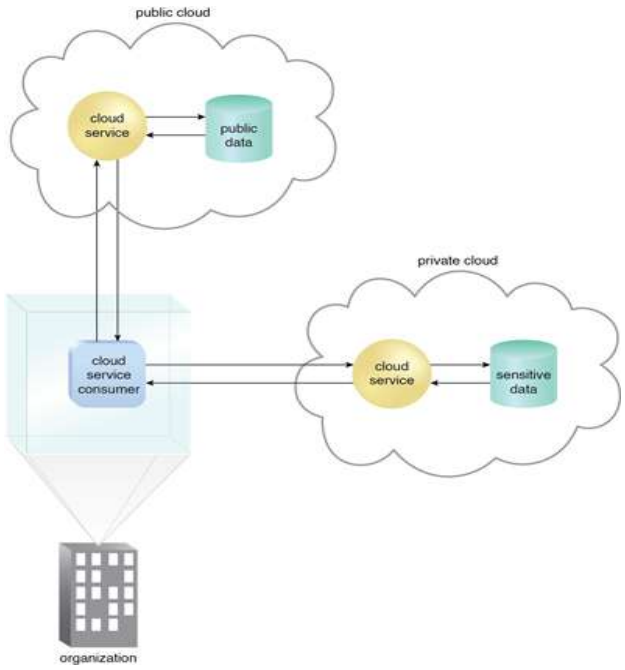


Figure 1 – An organization using a hybrid cloud architecture that utilizes both a private and public cloud.

Hybrid deployment architectures can be complex and challenging to create and maintain due to the potential disparity in cloud environments and the fact that management responsibilities are typically split between the private cloud provider organization and the public cloud provider.

Other Deployment Models

Additional variations of the four base cloud deployment models can exist. Examples include:

- *Virtual Private Cloud* – Also known as a "dedicated cloud" or "hosted cloud," this model results in a self-contained cloud environment hosted and managed by a public cloud provider, and made available to a cloud consumer.
- *Inter-Cloud* – This model is based on an architecture comprised of two or more inter-connected clouds.