

Part I

CONCEPTUAL ASPECTS ON CLOUD AND APPLICATIONS OF MACHINE LEARNING

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Hybrid Cloud: A New Paradigm in Cloud Computing

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Abstract

Hybrid cloud computing is basically a combination of cloud computing with on-premise resources to provide work portability, load distribution, and security. Hybrid cloud may include one public and one private cloud, or it may contain two or more private clouds or may have two or more public clouds depending on the requirement. Public clouds are generally provided by third party vendors like Amazon, Google, and Microsoft. These clouds traditionally ran off premise and provide services through internet. Whereas private clouds also offer computing services to selected user either over the internet or within a private internal network and conventionally ran on-premise. But this scenario is changing nowadays. Earlier distinction between private and public clouds can be done on the location and ownership information, but currently, public clouds are running in on-premise data centers of customer and private clouds are constructed on off premise rented, vendor-owned data centers as well. So, the architecture is becoming complex. Hybrid cloud reduces the potential exposure of sensitive or crucial data from the public while keeping non-sensitive data into the cloud. Thus, secure access to data while enjoying attractive services of the public cloud is the key factor in hybrid cloud. Here, we have done a survey on hybrid cloud as it is one of the most promising areas in cloud computing, discuss all insight details. Security issues and measures in hybrid cloud are also discussed along with the use of artificial intelligence. We do not intend to propose any new findings rather we will figure out some of future research directions.

Keywords: PaaS, SaaS, IaaS, SLA, agility, encryption, middleware, AI

1.1 Introduction

Cloud computing is catering computing services such as storage, networking, servers, analytics, intelligence, and software through the internet on demand basis. We typically have to pay for only for the services we use. IT is a growing industry and catering its service requirement is challenging. On-premise resources are not sufficient always, so leveraging attractive facilities provided by cloud service providers is often required. Typical services

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provided by cloud computing are Platform as a service (PaaS), Software as a service (SaaS), and Infrastructure as a service (IaaS). But all the clouds are not same and no one particular cloud can satisfy all the customer. As a result, various types of services are emerging to cater the need of any organization. The following are the facilities cater by cloud computing.

- **Scalability:** IT services are not restricted to offline resources anymore, online cloud services can do a wonder. Any business can be extended based on the market need through the use of cloud computing services. A client needs almost nothing but a computer with internet connection, rest of the services can be borrowed from cloud vendors. Business can grow according to the requirement. Scalability is the key factor in adoption of any new paradigm. An organization meant for 100 people can be easily scaled up to 1,000 (ideally any number) people with the help of the cloud computing services.
- **Cost:** Since cloud provides services pay as you use basis, cost of setting up a business has reduced manifolds. Capital expense in buying server, software, and experts for managing infrastructure is not mandatory anymore; vendors can provide all these services. Cost saving is one of the most lucrative features of cloud computing. Any startup company can afford the cost of the setup price required for the orchestration of public cloud; thus, they can engage their selves exclusively for the development of their business.
- **Speed:** Cloud computing helps to speed up the overall functioning of any organization. Several lucrative easy-to-use options are just one click away, so designers and programmers can freely think about their innovations, and as a result, the speed and performance can be enhanced. Moreover, since most of the background hazards are handled by the cloud service providers as a result implementation of any advanced thinking can be made possible quickly and effortlessly.
- **Reliability:** Reliability is a key factor where huge data need to handle all the time. Periodic data backup and use of disaster recovery methods helps to increase the data reliability in cloud computing. Also, since space is not a constraint anymore, clients can keep mirrored data. A reliable system often leads to a secure system. Any organizations need to handle huge user centric sensitive data as well as business related data. Maintaining the reliability in the data need several rules and regulations to be enforced.
- **Performance:** Improved operation, better customer support, and flexible workplace aid companies to perform better than conventional on-premise system. Amazon helps Car company Toyota to build cloud-based data centers. The company is going to use the behavioral data of the user of the car, and based on that, they will send service and insurance related data [1]. User can also use Facebook or Twitter in their car dashboard. This is only an example; there is lot more. Adaptation of advanced technology excels the performance of existing system as cloud plays a crucial role here.

- **Security:** Cloud service providers use many security mechanisms like encryption, authentication of user, authorization, and use of some Artificial Intelligence (AI)-based method to secure their app, data, and infrastructure from possible threats.

A combination of secure open source technologies along with integrated network may be used for secure hybrid cloud deployment like it does in HCDM [16]. But, before deployment, the customer need to determine what type of cloud computing architecture is best suitable. There are three different ways to organize cloud: private, public, and hybrid. Here, we will discuss about hybrid cloud, its benefits, and security aspects.

Thus, motivation of this review is to provide a broad details of hybrid cloud computing, why it is gaining popularity, how business is going to be affected through the use of cloud adaption in near future, what security aspects need to dealt by vendors, and how AI can help in this regard. The following sections deal with all this topics.

1.2 Hybrid Cloud

If we go by the definition of National Institute of Standards and Technology [3], hybrid cloud is a “composition of two or more different types of cloud infrastructure that are bind together with the help of proprietary and standardized technology for the purpose of data and application portability. So, Simple amalgamation of cloud and on-premise data should not misinterpret as hybrid cloud. It should also provide the following facilities [2]:

- Workload distribution by portability.
- Networking between system and devices, by the use of LAN, WAN, or VPN.
- Use of a comprehensive unified automation tool.
- A complex powerful middleware for abstracting the background details.
- Incorporating availability and scalability of resources.
- Integrating disaster management and recovery strategies.

Thus, it enables the customer to extend their business by leveraging the attractive services provided by public cloud as well as securing the delicate data through the use of private cloud. When the demand of a business fluctuates that may be sudden peak in the business come or sudden fall down, in those scenarios, hybrid cloud is the best possible option as it has that flexibility [8]. Organizations can seamlessly use public cloud amenities without directly giving access to their data centers which are part of their on-premise servers. So, business critical data and applications can be kept safe behind, while computing power of the public cloud can be used for doing complex tasks. Organizations will only have to pay for the services it is using without considering the capital expenditure involve in purchasing, programming and maintaining new resources which can be used for a short span of time and may remain idle for long. Private cloud on the other hand is more like public cloud, but generally installed on clients datacenter and mainly focus on self-servicing, scalable structure. Single tone service nature, service-level agreement (SLA), and similar association make the relationship between client and cloud stronger and less demanding [33, 34].

1.2.1 Architecture

There may be any combination of cloud services when to deploy a hybrid cloud. It may the client has its own on-premise private cloud as IaaS and leverage public cloud as SaaS. Private cloud may be on premise or sometimes off premise on a dedicated server [10]. There is no fixed fits for all architecture. Private clouds can be made individually, whereas public cloud can be hired from vendors like Amazon, Microsoft, Alibaba, Google, and IBM. Next, a middleware is required to combine public and private cloud mostly provided by the cloud vendors as a part of their package. Figure 1.1 gives general diagram of a hybrid cloud.

In case of hybrid cloud architecture, the following is a list of properties that must to be kept in mind [4]:

- Multiple devices need to be connected via LAN, WAN, or VPN with a common middleware that provides an API for user services. Rather than using a vast network of API, a single operating system must be used throughout the network and APIs can be built on top of that.
- Resources are made available to all the connected devices via virtualization and it can be scaled up to any limit.
- The middleware does all the coordination between devices and resources are made available on demand basis with proper authentication.

1.2.2 Why Hybrid Cloud is Required?

Hybrid cloud means different service to different people [5]. Need of an organization depends on diverse aspects of IT. As the perspective of application designer, business developer, and infrastructure support personnel is different from one another, their expectation from the system also varies.

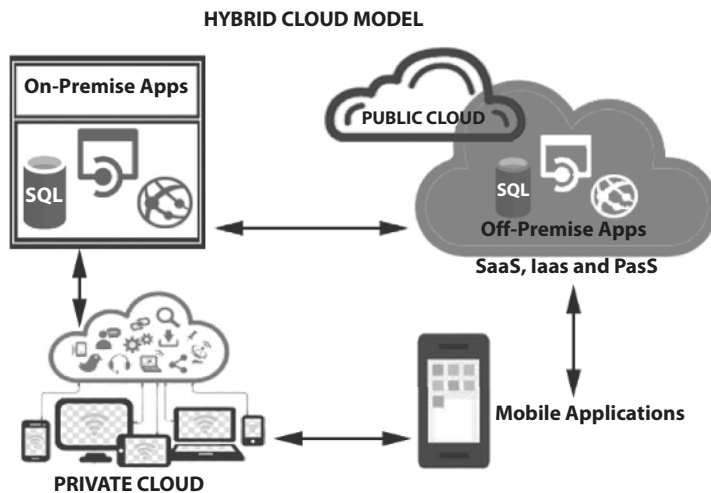


Figure 1.1 General architecture of hybrid cloud.

- ***Application programmer always requires support for edge technologies.*** Availability of high-end resources and cutting edge technology support is the primary concern of a developer. Off premise support for such is essential. Flexibility in deployment of changing technology services, speedy availability of the new resources required by the solution, peak support for on-premise system, and seamless and continuous integration of system services are key issues need to be dealt in hybrid cloud. Disaster management is also an integral part of it.
- ***On the contrary, infrastructure support personnel always look for a steady build in support for smooth execution of overall activities of the organization.*** Off premise support for virtualized computing resources is often necessary in IT. In this scenario, the role of infrastructure support team is very crucial. Visibility of all the resources wherever it is, monitoring them in federated way following SLA, management of deployed setup for auditing and security management, accessibility of all resources, and control provisioning are key consideration in case of hybrid cloud.
- ***Business developer, on the other hand, focuses on consumer marketing in cost-effective manner*** [6]. The need of IT business has manifolds. Support for newly growing technology like mobile or web-based application requires agile and easy to extend network, and at the same time, consistent system and stable process management services cannot be replaced. So, business developers have to look into all these aspects, and at the same time, they have to focus on the cost. The maintenance and management cost should not exceed the overall financial budget. Looking at the SLAs and software license exposure, they need to design financial plans that can fulfill the whole organization's prerequisites.

No matter how well we plan the future, it still remains uncertain and hybrid cloud provides the facility to use cloud services as and when it is required. It is also quite unlikely that workload of an organization remains same throughout the whole year. Suppose an organization is working on big data analytics, it can take help of public cloud computing resources for high complex computations but that too is not needed for long run, may be require for few months. Here, public cloud resources can be borrowed for few months only. In the same way, startup companies can start with some trivial private resources and take cloud services for rest of the processing. Then, based on the performance, they can plan to expand the business with the help of public cloud. All these are possible only in case of hybrid cloud as it has ***agility, scalability, data reliability, speedy recovery, and improved connectivity and security.***

1.2.3 Business and Hybrid Cloud

According to Hybrid Cloud Market report, in 2018, hybrid cloud market was USD 44.6 billion and expected to grow to USD 97.6 billion by the end of 2023 with Compound Annual Growth Rate (CAGR) of 17.0% [9]. IaaS is expected to hold a large market in the forecast period as it facilitates to migrate workload from on premise to off premise in high peak hours. Hybrid web hosting also hold a big market as it provides management of all

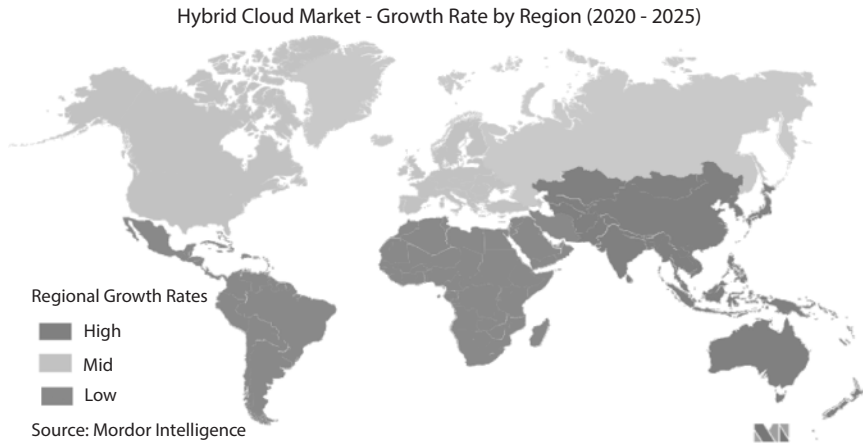


Figure 1.2 Market trend of hybrid cloud [14].

hosting services in just single point of contact. North America was the most promising hybrid cloud market place in 2018 and Asia Pacific areas shows the highest CAGR. So, hybrid cloud is a promising area in business. Major sectors using hybrid cloud computing are healthcare, retail, government, or public sectors, banking, entertainment media, insurance, finance, communication media, etc. [14]. According to a report published by Mordor Intelligence, North America, Middle East, Africa, Europe, and Asia Pacific are top growing regions worldwide. Figure 1.2 shows the hybrid cloud market. Green portions represent highly growing market. Hybrid cloud management software solution is the main reason of this popularity. Starting from deployment to quota management, customization of service library, costing, performance management, and governance, everything is taken care of, like the software management tool. Mostly, the services provided by public providers are restricted to some architecture or technology and vendor specific. But the management tool provided by hybrid providers helps to amalgamate different services provided by various vendors. Amazon and Microsoft, the giants in this field, are working hard in the up gradation of their management software by including advanced infrastructure templates, libraries, API, and apps. In India, IBM is also approaching toward hybrid cloud and AI [15]. IBM invested \$1 billion into a cloud ecosystem project in the month of August. They are expected to invest more in the coming time. In India, 17% of organizations are planning to spend investment from 42% to 49% on hybrid cloud by 2023 according to a study by IBM IBV. Since India is heading toward a digital transformation and self-reliant camping, so the opportunity of new technology adaptation also increasing.

1.2.4 Things to Remember When Deploying Hybrid Cloud

Having an understanding what hybrid cloud is and how it facilitates the activities of any organization, now, we need to understand some factors that have to be considered before the deployment of hybrid cloud.

- **Selection of best suitable platform for cloud:** As discussed, the need of every organization is not same. Before deployment of the hybrid cloud, organizations need to have a plan for the services; it will borrow from the public

cloud. If it is going to use only SaaS, then it is not a problem but it is going to use IaaS or PaaS and then it is very important to take the correct decision from the commencement of the service as building a hybrid structure that would not be able to handle additional workload generates severe problem.

- ***Whether to use unified OS or not:*** In true hybrid cloud, a unified OS is installed in the middleware that basically governs the overall functionalities. But in some cases, on-premise system may be operated by its own OS then just with the help of internet they can connect to public cloud. The performance of this architecture will be vast different from unified OS. OpenStack, VMWare cloud, Nutanix, and Kubernetes are some example of cloud OS framework. These frameworks are sufficient building the middleware and it provides OS and all supporting application for the smooth execution of all activities in hybrid cloud.
- ***How to manage different activity:*** Huge amount of data need to be handled in case of hybrid cloud. A hybrid system should look into smooth accessibility of data, and at the same time, security of data needs to be guaranteed. Anyone cannot host any data onto the public cloud. Proper personnel with adequate experience need to be engaged for the management of dedicated applications.
- ***How security of data will be guaranteed:*** Since data is moving in between public and private cloud, it needs to be secured. Through security mechanisms of public cloud, it has developed much from its early date but still it is not 100% secure. There are always threats of data breach. Migration of sensitive need special care as sight alteration in business sensitive data might cause severe problem in the business.
- ***How to integrate public cloud with existing on-premise system:*** Amalgamation of public cloud onto an existing on-premise system often needs several alterations in the working of the existing on-premise system. Overall performance of the system should always improve with the addition of the public cloud, and it should not degrade.
- ***How to manage common backup and disaster recovery:*** Data need to be backed up to ensure reliability and availability. Backing up of all the data both in private and public cloud need to be done. At the same time, the system should be able to handle catastrophic failure or disaster. How to maintain a common routine for all the operational data to accommodate those situations is key to the success of hybrid cloud deployment.

Building a hybrid cloud is a complex procedure but successful implementation will provide scalability, flexibility, security, and cost saving. More and more organizations approaching toward hybrid cloud for the current benefit and future growth.

1.3 Comparison Among Different Hybrid Cloud Providers

The major famous leading cloud computing vendors are Google Cloud, AWS, and Microsoft Azure. They have their some advantages and disadvantages. These three leading

cloud providers have important role in the PaaS and IaaS markets. Synergy Research Group reported that the growth of Amazon is very significantly high in overall growth of market. It possesses a share of 33% of cloud market throughout the world. In second position, there is Microsoft. Microsoft is very fast growing and in the last four quarters, and its share has been increased by 3% and it reaches at 18%. Nowadays, cloud computing is become much matured. It is becoming hybrid cloud, and it also becomes more enhanced as market share. New trends have come to improve cloud computing system in 2020 than that of 2017, 2018, and 2019 [17].

Hybrid cloud [17] provides strategy for enterprises that involve operational part of varieties of job in varieties infrastructure, whether on private cloud and public cloud with a proprietary different layers at the top level. Multi-cloud concept is similar kind of but not to involve any private cloud. Hybrid cloud is the most popular strategy among enterprises; 58% of respondents stated that it is their choice able approach while 10% for a single public cloud provider and 17% for multiple public clouds.

- **Microsoft Azure Stack:** Microsoft is a popular vendor that provides hybrid cloud. Because it has huge on-premises legacy. The services of MS Azure are developed on Windows Server. The .Net framework and the Visual Studio provide better features of on apps for their smoother services [17].
- **AWS Outposts:** Amazon's Amazon Web Services (AWS) is a one of the best product. It is one of the most popular in market and its share is next to the Microsoft leading competitor. This company has variety of services and largest data center that continues to provide facilities to billions of customers. AWS is very well-known public cloud that offers many services to connect for installations to the cloud. It also serves everything like disaster recovery and burst capacity [17].
- **Google Cloud Anthos:** The Google Cloud Platform is another one popular in hybrid cloud. It is a competitor of Microsoft AWS and IBM. Google primarily made pure cloud system, but later, they changed policy and started to work with on-premise systems for disaster recovery, elastic infrastructure, Big Data, and DevOps. It also provides a huge number of cloud-based services. The services are based on AI efforts based on AI processor and TensorFlow. No one can buy TensorFlow system but can run AI and machine learning apps on Google Cloud [17, 18].
- **Oracle Cloud at Customer:** This is another one popular hybrid cloud service provider. It provides mostly on-demand service, in its own cloud system. Unlike Azure, AWS, and GCP, this provider does not allow its software to execute in virtual instances for any operation. But it runs on metal servers; Oracle also offers this kind of service. Oracle cloud is also very easy to run its apps on-premise on the cloud [18].
- **IBM:** IBM merged all of its cloud services, called IBM Cloud. It possesses more than 170 types of services for public cloud and on-premise. These services are not only limited to bare metal hosting and virtualized mode, containers, and server less computing, DevOps, AI/ML, HPC, and blockchain.

It also offers to do lift and shift on-premise apps, executing on IBM platforms [18].

- **Cisco Cloud Center:** Cisco is popular for private cloud that also offers hybrid solutions via its partner. Cisco Cloud Center is more secured to manage and deploy the applications in different data centers in both private and public cloud environments. Cisco's partner networks are Google, CDW, Accenture, and AT&T. Google is the biggest partner among them. It offers the hybrid connectivity and their solutions [18].
- **VMware vCloud Suite:** VMware provides vendor for virtualized services. It is relatively new than that of other service providers. VMware has the vSphere hypervisor. Customers can run in some known public clouds or their own data centers or cloud provider partners. These cloud providers are able to run vSphere on-premise that creates a stable hybrid cloud infrastructure [19].

1.3.1 Cloud Storage and Backup Benefits

Protection of the confidential data is very difficult. Automatic backup of cloud storage is flexible. It also provides data security.

Microsoft Azure is very effective in SaaS. Whereas, Google Cloud is strong in AI [18]. Table 1.1 gives a comparison among them.

1.3.2 Pros and Cons of Different Service Providers

All the cloud service providers have their own pros and cons. They make themselves a suitable choice for different purposes. Here, the advantages and disadvantages are described for all the providers. Table 1.2 provides a comparative study on this.

Table 1.1 Comparison between AWS Outpost, Microsoft Azure Stack, and Google Cloud Anthos.

AWS Outpost	Microsoft Azure Stack	Google Cloud Anthos
Amazon has a huge tool set and that too is rapidly growing. No service providers can match with it. But the pricing is bit puzzling. Though providing service for hybrid or public cloud is not Amazon's primary focus thus incorporation of cloud services with on-premise data is not in top priority [20]. They primarily focus on public cloud.	The customer can run in their own data center. Azure tries to incorporate with that. It provides the facility of hybrid cloud [19]. A customer can replicate his environment in Azure Stack. This is very useful in case of backup disaster and for cutting cost.	Google has come to the cloud market later. So, it does not have that much level of focus to incorporate the customers. But the strength is its technical efficiency. Some of its efficient tools are applicable in data analytics, machine learning, and deep learning.

Table 1.2 Pros and cons between AWS Outpost, Microsoft Azure Stack, and Google Cloud Anthos.

Vendor	Strength	Weakness
AWS Outpost	1. Dominant market position 2. Extensive, mature offerings 3. Effective use in large organizations	1. Managing cost 2. Very difficult for using 3. Options are overwhelming
Microsoft Azure Stack	1. Second largest service provider 2. Coupling with Microsoft software 3. Set of features is vast 4. Provides Hybrid cloud 5. Open source supported	1. Poor documentation 2. Management tooling is incomplete
Google Cloud Anthos	1. Designed to serve for cloud-native enterprises 2. Provides portability and allows open source 3. Huge discounts and suitable contracts 4. Expertise in DevOps	1. Enters late in IaaS market 2. Less services and features 3. Not focused for enterprise

1.3.2.1 *AWS Outpost*

The strongest strength of Amazon is its effectiveness in public cloud. They provide services through the world for its public cloud infrastructure. This cloud provider is very popular because of its varieties operational scope. AWS provides different kind of services. It also has a large network for worldwide data centers. The “Gartner” reported that this provider is the most mature and enterprise-ready. It also has capabilities to govern a large amount of resources and customers. But the weakness is its cost. Customers face difficulty to understand its cost structure. It is also difficult to manage the costs while running a large volume of workloads.

1.3.2.2 *Microsoft Azure Stack*

Microsoft provides on-premises software—SQL Server, Windows Server, SharePoint, Office, .Net, Dynamics Active Directory, etc. The reason of its success is most of the enterprises uses Windows and its related software. As Azure is tightly coupled with its other software applications, the enterprises, that use many Microsoft software, they find Azure as a suitable platform. This is how it builds good relationship with their existing customers. They also provide a remarkable discount on variety of services to their existing customer. But, Gartner also reported some faults in their some of the platforms [21].

1.3.2.3 *Google Cloud Anthos*

AWS and Azure offer the Kubernetes standard which is developed by Google. GCP is expert in machine learning and Big Data analytics. It provides huge offers on that. It also provides

offers in load balancing and considerable scale. Google is also efficient knowledge about different data centers and quick response time. Google stands in third in the field of market share [21]. But, it is rapidly increasing its offers. As per Gartner, clients choose GCP as a secondary provider than that of primary provider.

1.3.3 Review on Storage of the Providers

1.3.3.1 AWS Outpost Storage

- **SSS to EFS:** The storage services of AWS include its Elastic Block Storage (EBS), Simple Storage Service (S3), and Elastic File System (EFS) for persistent block storage, object storage, and file storage, respectively. It also provides some new innovative products for storage that includes the Snowball and Storage Gateway. Snowball is a physical hardware device, whereas Storage Gateway creates a hybrid storage environment.
- **Database and archiving:** Aurora is a compatible database of SQL by Amazon. It consists of different services like DynamoDB NoSQL database, Relational Database Service (RDS), Redshift data warehouse, ElastiCache in-memory data store, Neptune graph database, and Database Migration Service. Amazon also offers long term storage known as Glacier. It is having very low charges [20].
- **Storage services:** The storage services of Microsoft Azure include Queue Storage, Blob Storage, File and Disk Storage for large-volume workloads, and REST-based object storage of unstructured data respectively. Data Lake Store is another storage that is used for big data applications.
- **Extensive database:** This extensive database provides three SQL-based options. They are Database for MySQL, SQL Database, and Database for PostgreSQL. Data Warehouse service is also provided as well. The services are Table Storage for NoSQL and Cosmos DB. Its in-memory service is Redis Cache and the hybrid storage service is Server Stretch Database. Those are designed for the organizations that use Microsoft SQL Servers [22]. Unlike AWS, Microsoft offers an actual Site Recovery service, Archive Storage, and Backup service.

1.3.3.2 Google Cloud Anthos Storage

- **Unified storage and more:** GCP has enormous level of storage services. The unified object storage service is cloud storage. It also provides persistent disk storage. It also offers a Transfer Appliance which is a similar kind of AWS Snowball and online transfer services.
- **SQL and NoSQL:** GCP possesses the SQL-based Cloud and also provides a relational database known as Cloud Spanner. Cloud Spanner is designed for critical and complex workloads. It also provides NoSQL. They are Cloud Datastore and Cloud Bigtable. No backup services and archive services are provided.

Table 1.3 Comparison between VMware Microsoft Amazon AWS.

Category	VMware	Microsoft	Amazon AWS
Delivery mode	Very simple	Easy to follow	Very easy
Ability to apply the technology	Cost-effective virtualization solution, manage to virtualize the X86 computer architecture	Estimated cost was around \$4.99 per month [19]	Very affordable, \$32 to \$255 per month [19]
Integration with other applications	It is an Edge PC Virtualization, Workstation 12.5 Pro, Fusion 8.5 - Windows on Mac®, Workstation 12 Player- streamlined PC Virtualization for Business	Computes engine for networking, virtual machines, SQL databases, storage, containers, security, API integration, etc.	Web application, website and database storefront.
Security	Secure virtual box is possible to create, manages files, using SSL, SSH, etc.	Reliable	Tight
Operating system and mobile compatibility	Many operating systems like Windows, Linux and Mac, etc.	Windows 8 and Windows 10	Both Linux and Windows. Able to compute, storage, database, networking, and content delivery.
Upgrades	On demand Products available at less price.	Able to run updates.	
Service-level agreements		Azure Cloud provides Container services speedily and in simple way.	Easy
Training/support			Auditing, monitoring/ logging, storage creating
Scalability and vendor reliability			Vendor is dependable and revenue growth is stable for Elastic Cloud Compute (EC2) and database usage [19]

1.3.4 Pricing

Pricing is one of the challenging scenarios among these three hybrid cloud providers. Table 1.3 lists all the pricing related issues involved here.

- **AWS Outpost:** The pricing of Amazon is very inscrutable. Though it offers a cost calculator, many variables involved here make it very difficult for proper estimation [23].
- **Azure Stack:** Microsoft Azure is also complicated software. The licensing options and their uses are applicable in specified case discounts. The pricing structure is also difficult to understand of this provider.
- **Google Cloud Anthos:** The pricing of Google is different. It offers are customer-friendly. So, it provides the least price than that of the other providers. It also provides huge discounts and flexible contracts to fulfill the purpose of customers.

1.4 Hybrid Cloud in Education

Apart from business sectors, educational institutions can also take help of the hybrid cloud for extending their on-premise legacy system [31]. They can build some application on to the public cloud to student data management, resource management, employee data management, etc., at ease releasing their IT team to do some other jobs. An example can be some database of the student can be kept on-premise server while front end web applications for the students can run onto the public cloud. Based on specific performance or regularity needs, they can also move workloads dynamically between public and private cloud may be for the specific period of time. Student and staff and institutional data are very sensitive; they can be kept secure behind with their own firewall and antivirus. Whereas with the help of the public cloud, several attractive features can be provided, like job getting opportunity trend, research work prospect, and study and lecture material of renowned professors, virtual labs, etc., without installing any additional hardware or software solution system. Thus, by using “Build the base rent the spike” deployment model, they can save the money. But security policies have to be strict. Applications and infrastructures should be guided by different security policies. Edge systems like email server, web server, and routers should be kept protected as they can communicate with inside and outside the organization.

1.5 Significance of Hybrid Cloud Post-Pandemic

Adaptation of cloud-based services has grown tremendously after pandemic. Due to COVID-19, every sector faces losses. Rapid shifting of business into online mode is the current requirement. Organizations that have legacy infrastructure on premise cannot shift to public cloud in a day and security also is a matter of consideration. As a result, hybrid cloud is the most preferred solution.

- In COVID-19 pandemic situation, the world is compelled to move for remote work. So, the video conferencing is tremendously increasing and all the related data moves to the cloud. Enterprises are considering the cloud as a digital transformation engine and as well. As the work is done remotely, the jobs are majorly done in cloud infrastructure. Collaboration with Microsoft Teams or Google Meet becomes very strong with the companies in broader cloud ecosystem [17].
- Hybrid cloud has an aspiration to achieve target for companies. Companies are well aware about their vendors and they want to transfer their applications to clouds. The multi-cloud conception is yielded among different vendors. The vendor plug with many clouds like VMware or Red Hat [17, 18].
- Customers are getting tackier to the cloud service providers as more and more corporate data are stored on the cloud. It is known that cloud computing vendors are trying enterprises to use their platforms to accumulate data from everywhere.
- IoT, AI, edge computing, and data analytics will make difference among the top cloud service providers. The market share grab has largely gone to AWS, which was early, adds services at a rapid clip, and is the go-to cloud service provider. AWS' ability to upsell to AI, IoT, and analytics will be critical. Microsoft Azure Stack is also looking to differentiate via AI and machine learning [18].
- If we look at the records provided by IDC, in the year 2020, public cloud expenses have made a mark, for the first time, it has left behind old-style IT structure. An increase of 34.4% has been recorded in cloud including private and public. Whereas traditional IT infra fall out by 8%.
- Public hybrid cloud providers have the gap of capability between hyper scale cloud providers. Competition for enterprise workloads yields secondary markets throughout the world. The cloud service providers like Microsoft Azure Stack, AWS Outpost, and Google Cloud Anthos have become financially strong.

1.6 Security in Hybrid Cloud

A properly designed, managed, and integrated hybrid cloud is considered to be as secure as on-premise infrastructure. But reality is bit different. Gartner and WSJ [7] have recently reported that 95% data breaches occur in cloud computing due to human error. Here, in hybrid cloud, also human error plays a crucial role. Misconfiguration, misunderstanding of system use, and accidental data sharing all results threat to security. Security is essential in all application areas. Suppose in healthcare organizations patients' data should be kept hidden. Pathological reports of any patient are not expected to be accessed by any unauthenticated person. Similarly in financial industry, trust is the most important factors. Details of all customers' sensitive data have been kept like their income related info; their identification info their tax related document everything has been kept there. Customer should feel protected about their data. It happens in all sectors. With the help of public server and data centers, the business world is forwarding

toward a new server free era but security measures have to be adjusted so that it can reap up ultimate technological and financial benefits. Since hybrid cloud is a “*one size fits for all*” solution for business development, it is advisable to look into the security issues more closely as threats to sensitive data might cause problem. Here is a list of issues specific to hybrid cloud security [11]:

- **Authority:** In hybrid environment, multiple functioning components scattered through private and public cloud. Multiple services can also be taken from multiple public clouds. So, customers of hybrid cloud should decide the governance rule for components, functions, and data beforehand both for private and public cloud.
- **Portability:** Supporting infrastructure must be there so that applications and data may move between public and private cloud. Data portability causes additional risk in hybrid cloud. Private data can be made secure by applying encryption techniques but when portability is allowed then who will be responsible for the protection of data in transit need to be addressed.
- **Presence of multiple interface:** Multiple cloud may be present in a network and each of them most likely is to have their own set of security and privacy policy compounds. This acts as a back door for data breaching in case of hybrid cloud.
- **Lack of separation wall:** Cloud customers have seamless access to private and public resources. As a result of that, sometimes, intruders take an indirect entry to penetrate the delicate data.
- **Security issues handling:** Reporting and subsequent measures for security issues need to be shared to the customer as well as service providers so that they will be extra cautious from the next access. Sometimes, customers face unacceptable delay due to security issues, so in the SLA, it should be mentioned when and how they will be notified.
- **Application and data protection:** Protections offered by the cloud providers are getting stronger day by day but still they are not enough. Advanced security information and event management (SIEM) solution need to be implemented.
- **Vendor lock-in:** Sometimes, due to lack of scalability or security issues, cloud needs to be shifted from one vendor to other vendor. If the cost of switching is so high that the customer is forced to stick to the origin, it is known as vendor lock-in. Avoiding vendor lock-in needs to be included in the business policy.
- **Guard against shadow IT practice:** Sometimes, within the organization, some person or departments are using sensitive data without the knowledge of the security group. This is called shadow IT practice, and often severe risks are associated with it.

Although hybrid cloud is considered more secure than public cloud as it provides greater control over the data but still data leakage, corruption, improper or unauthorized access, and data deletion can only be handled by secure channel, access control, data validation,

and encryption. By doing the vulnerability management also security can be enhanced [32]. Risk assessment is often done to reduce vulnerability.

1.6.1 Role of Human Error in Cloud Security

As discussed, 95% of error in cloud security happens because of human error. Most of the time errors are not intentional but lack of seriousness, lack of overall knowledge of the system, poorly configured servers, misconfiguration, absence of proper authorization, etc., are players behind error generation. As a result, human expertise is not always believed to make safeguards against security threats. New kind of services and technologies are evolving every day for providing better services. There are automated security tools which can scan cloud configuration regularly and can enforce security policies which will not let intruders to get access.

1.6.2 Handling Security Challenges

When any organization is planning to deploy hybrid cloud, some box of tricks needs to apply to reduce the security threats. Though cloud vendors generally provide security measures but still they see the task as shared responsibility, also in case of multi-tenant cloud security algorithms are not same for all vendors. So, planning and standardization of all activities can handle security challenges to a great extent. Some best ever practices are as follows:

- ***Encrypt all data:*** Best possible means to secure data is to do the encryption. Encrypt all data irrespective of their location. In hybrid cloud, data often move between two or more clouds and in transit data is vulnerable. Encrypted data is less likely to be compromised. Selective encryption can be more vulnerable as it is easy to identify which is encrypted and which is not. Target selection becomes easier in this case and data becomes more susceptible to threats.
- ***Strengthen authentication and authorization process:*** Access to data should only be provided to authenticated user. Unnecessary and unauthorized access has to be prevented. In hybrid cloud, different applications run on different cloud, so access rights of different customer will not be same.
- ***Customer awareness:*** One of the most important part in security as it can reduce human error to some extent. Customers should follow common guidelines for accessing data and services. They should be aware of the security threats and will take measures accordingly. They should use strong passwords and prevent access to sensitive data by any unauthenticated application.
- ***Application of standardized process:*** Uniform standards have to be maintained; it should not be like any one can use anything. Network configuration, password structure, firewall setup, auditing and monitoring, and database maintenance everything need to be regulated. Regular updation of OS and applications is essential.

- **Strong disaster recovery plan:** Though event of system or application failure in hybrid cloud is much less than other cloud, but still it can happen. Disaster recovery plans should take action in those scenarios. Regular backup and configuration of failover system should be a part of disaster recovery plan.
- **Employ right security personnel:** Infra and network administrators have the most vital role to play in hybrid cloud computing. Employment of correct personnel with adequate knowledge and experience can apprehend potential threats beforehand and therefore can accommodate the system accordingly.
- **Endpoint security:** Hybrid cloud has more endpoints than on-premise system. Each open endpoint is also entrance for potential attackers. Strict security measures should be application for all inbound data.
- **Multi-faced approach:** It basically deals with both internal and external vulnerabilities. Protecting our network from external threats is not enough here, we need to concentrate on the internal threats also as the frequency of internal threats is higher than external and also it has bigger effect onto the organization.
- **Pervasive encryption:** It is a consumable approach for in flight and in rest data encryption. Huge amount of data can be encrypted easily and in cost-effective way. IBM Z15 is a platform which provides pervasive encryption in digital enterprise [26].

1.7 Use of AI in Hybrid Cloud

Organizations now completes for the customer satisfactions and operational efficiency. AI and machine learning are the light bearer in this regard [12, 13]. A term in this regard often circulated, i.e., “AI in the cloud”. Most of the cloud-based services provider designs their management tool where some AI-based technologies are incorporated. This helps the customer a range of facilities starting from image recognition to big data analysis [24]. The biggest advantage of this adaptation is that you do not need expertise for deployment, or configuration or management of the architecture models and prototypes are already there for the developers. Banking sectors, automobile industries, e-commerce trades, etc., all the approaching toward hybrid cloud and AI. For example in case of banking sector, they can keep their customer details in private datacenters and can leverage public cloud services for operational need. AI will help to analyze customer specific data, which can help the organization to provide loans or offers customized according to the present need of the customer. Also with help of the AI, 24x7 service can be provided, without actual intervention of customer care executives. AI can also help in incident analysis. If sometimes the system became irresponsive, AI can judge the situation and can suggest recovery measures. Disaster recovery plans can also be toughen with the help of AI. Based on the previous observations, AI can generate the pattern of the system might causes disaster, and therefore, preventive actions can be taken in advance. Automobile industries also approaching toward adaptation of AI and hybrid cloud to provide best ever services and hazard free maintenance. In case of e-commerce business, AI has most lucrative role to play. Analyzing the buying pattern of the customer not only helps business to expand, it also can serve the customer need in best possible way.

But is this adaptation sustainable is a million dollar question. Some experts commented that use of AI is a fashion. But the easy-to-use nature and strong data mining methods makes is worthy. Now, what about data privacy? Is the use of AI has any role to play in data privacy? The answer is yes. In this case, AI has a major role to play. It can analyze the attacker's behavior and attacking pattern and accordingly can guide the network admin to take corrective steps and measures.

Mainly, AI requires large amount of data for their data mining operations and these data may come from several sources some internal and some external. When AI is used in public cloud, we might hesitate to use the data which is highly secure. But the quest for data of an AI engine is huge, as a result potential threats may arise. In July 2019, an incident was happen between AWS and financial giant Capital One. A person was arrested for hacking the data from the server of Capital One containing customer financial information. That person was a former employee of AWS. Capital One uses AWS for sorting the data and also on top of cloud; they built their app for analyzing the data. FBI then called and they investigated that there was some issue in the firewall of Capital One, buy using which the intruder has gain access to the data. AWS quickly responded that there was no issue from their end and Capital One rectifies the misconfiguration in the firewall. But the data breach has already happened. So, cloud security still in immature state as old approaches for secur-ing internal data does not go the cloud. Here comes the hybrid cloud. Data security can be ensured efficiently and adaptation of AI-based technologies is also possible as internal data are kept hidden in private data centers, public cloud has no access to it.

Nutanix [27] provides a solution which is a turnkey for infra, aps, ops, and disaster recovery. A ready-made platform which helps to make a secure private cloud, streamline manual boring data operations, provides less complex management of database by using a single policy for all data, manages data in a better way by storing all data in a single storage, secures all data by providing visualization of policy and traffic works in different segments, detects and quarantines infected portion of the network, automates IT operations with the help of AI and ML, and does periodic backup of all data. This type of solution is highly acceptable in the industry. Special use of AI makes Nutanix very attractive for building secure hybrid cloud.

The amalgamation of AI into cloud has bring an evolution as AI was still complex, expensive, and high-end technology which was out of the reach of the general masses [25]. But now services of AI can be utilized by general masses without actually knowing the back-ground technology. Several mobile apps and IoT work in this regard in an effective way. Human like interfaces, self-service, and customer-oriented application are made possible through the use of hybrid cloud and AI.

Use of AI made hybrid cloud more intelligence by playing a key part in cost analysis, real-time decision-making, policy optimization, and workload distribution leaving the IT experts to work on complex things rather than doing trivial tasks. AI-as-a-service is heading toward next level. Cloud giants AWS, Microsoft, IBM, and Google all are doing investments on this to make their service better as this is a competitive world. Whoever will provide better service in less cost will be more popular.

Quantifi [28] is one such solution. They are using AI/ML to perform risk analysis, data analytics, portfolio management, and trading predictions. Some major banking sectors, asset management companies, pension funds, and financial institutions are their customer. By the use of AI, big data, Lamda architecture, and in-memory computing, Quantifi is one

of the front benchers in risk assessment. Cross platform which supports Windows, Linux, MacOS, and Adaptation of ELT layer provides various external data sources to communicate bi-directionally at ease; rich API helps to provide tools and functionalities to clients so that they can extend their business without knowing much of the technical details; real-time business analysis and predictions are just one click away. Quantifi uses Microsoft Azure for its cross platform application development.

IBM Watson [29, 30] is another pioneer in this regard. It a tool where can give their instructions using natural language. This AI-powered search engine can answer complex business queries on demand. The natural language understanding capability makes it more interesting as otherwise for getting high-end business insight may be lines of code has to be written. Watson is also used with other AI-based tools for providing a platform which provides better customer services. This allows client to run all Watson products, IBM's own AI products on IBM cloud or any cloud from other vendors. It can club private cloud services also.

Lots of other tools are also available which use AI and hybrid cloud for better customer services.

1.8 Future Research Direction

The adaptation of hybrid cloud still is in nurture state. It is not exhaust in nature. High possibility of amalgamation of different technologies makes it useful and difficult to handle also in some cases. Here is a list of future research directions:

- Standardization is a vital part of cloud architecture. No uniform standard is there for setting up the hybrid cloud architecture. Research can be done in this direction.
- Orchestration of hybrid cloud often requires huge power consumption and high-end networking. Use of green energy sources can be kept as an option.
- Security is always a concert. Intrusion detection and encryption techniques should be able to handle advanced threats. The pattern of attacks is changing every day so to cope up with that security measures also need to be updated also. Thus, it a subject of research all the time.
- Use of AI and data analytics can do wonders. Many researches are already going on in this direction but still scopes are there.
- Reliability still is a major issue in hybrid cloud computing, some portion of the network may remain unavailable for some period of time. How failover plans can be made stronger so that it can handle these issues in transparent way is a matter of consideration.
- SLA is a portion where more research should be done. Miscommunication, misinterpretation, and lack of information often cause problem. In multi-cloud system, it is more prominent.

1.9 Conclusion

Hybrid cloud offer several benefits but complex large and distributed nature makes it hard to handle. It keeps business sensitive data in private data centers for their protection and use public cloud for additional services. But still, management and monitoring of all in bound data is not always possible. As a result, security issues always happen. IT security is always challenging, and in case of hybrid platform it seems more complicated. Use of AI can do miracles in cloud computing. Adaptation of AI and hybrid cloud is new trend in the industry. So, by taking reasonable thoughts and with judiciously designed automation system in middleware hybrid cloud can offer exciting features in cost-effective way. Leading organizations are moving forward the adaptation of hybrid cloud and AI as it can provide scalable, cost-effective, flexible, user friendly, and secure solution.

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