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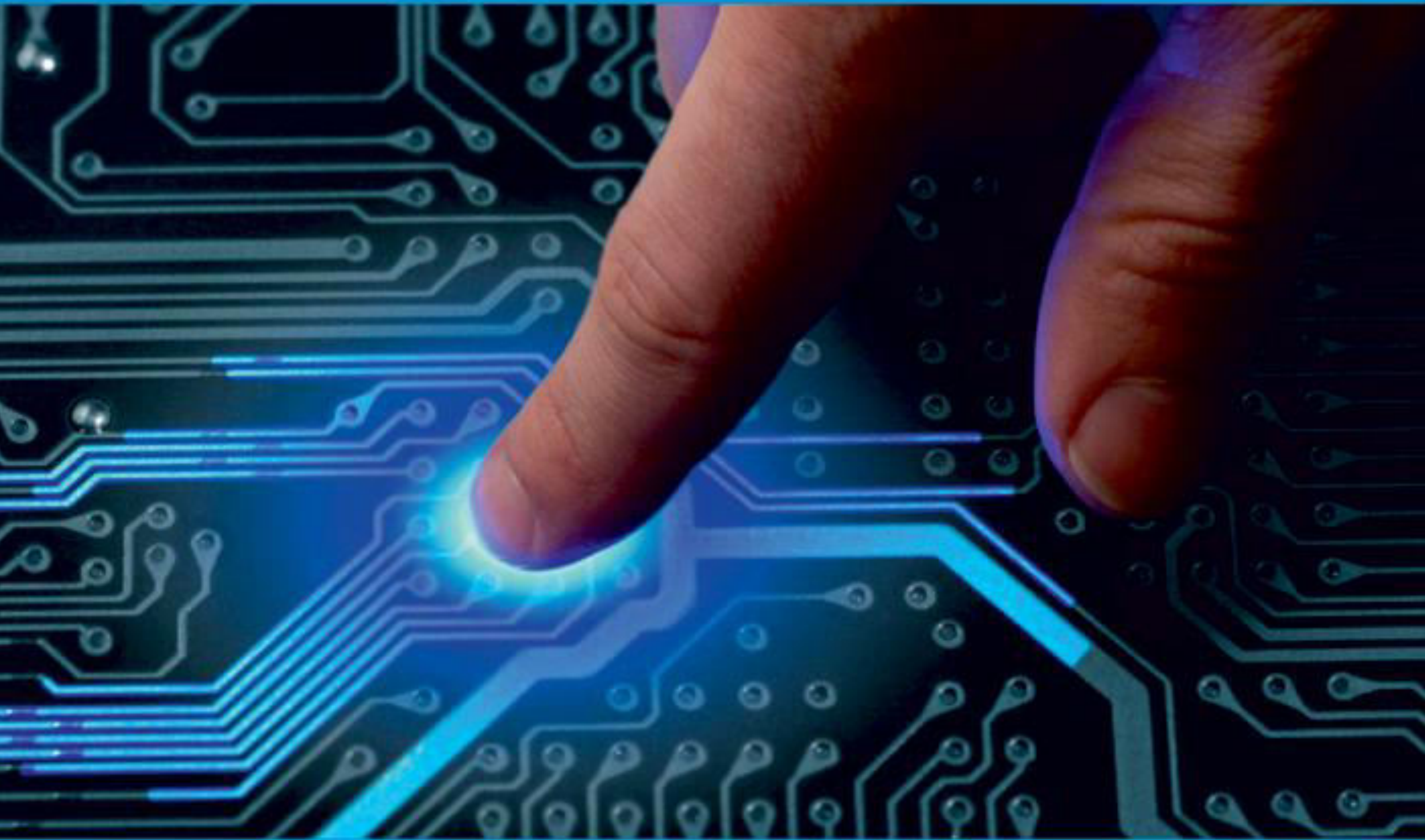

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The Advancement of Cloud Computing: From Conventional IT Infrastructure to Serverless Computing

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ABSTRACT: At present, numerous innovations and technologies take place continuously. Serverless computing is a paradigm switch from conventional cloud computing. The term 'serverless' represents that the cloud developers do not interact with servers directly, whereas they use codes and logic to do so. This feature enhanced and extended the overall performance of the serverless platform. This paper presents a comparative study of both cloud environments from conventional to platform-independent or serverless computing. Apart from this, several key aspects such as definitions benefits, limitations, challenges, real-world applications, and futuristic direction are discussed in a well-organized form.

KEYWORDS: Cloud Computing; Serverless computing; cost; infrastructure; edge computing; IoTs

I. INTRODUCTION

In the contemporary generation, the internet is a propulsion for numerous technologies that have evolved. According to the Global Overview report, there are more than 66 percent of the population of the world are internet users, and now global users have reached 5.35 billion. Cloud Computing is a massive technology among all and no one is left without its influence nowadays. It is an online service that works on prominent principles of the *'pay and use computing resources'* for end users. An interesting fact is that the end users do not need to know the physical location of stored data, they are just enjoying these services with real-time experience. The end users have to be paid only for those services which they have been served by service providers.

As stated by the National Institute of Standards and Technology (NIST) [1], "Cloud computing is a prototype for validating omnipresent, favorable, desired network access to a shared pool of customize computing resources (e.g., servers, networks, applications, storage, and services) that can be provisioned to the end users quickly and released with nominal interaction with service provider". Abstraction [2] and virtualization [3][4] are the key component of cloud computing and also they are related to each other, abstraction is a way to hide internal specific information from end users whereas virtualization is creating a virtual model enabling physical component of sole computer e.g. memory, processor, storage and other parts to be split into several virtual systems also called virtual machines, capable to run itself by using own operating system, memory, etc. However, they use a small part of actual system hardware. In other words, abstraction can be done on top of the system hardware by using a virtualization process. cloud computing has five significant characteristics [6] such as resource pooling, network access, high-speed elasticity, pay-as-per-usage, and on–demand service.

In the present study, section I discusses the definition and fundamental aspects of cloud computing. Section II comprises work done on relevant topics. Section III presents the chronology of cloud computing. Conventional Cloud computing models are discussed in section IV. After that, Section V provides the limitations of cloud computing. The emergence of serverless computing is discussed in Section VI. Then Section VII presents the benefits of serverless cloud computing. Challenges and limitations are discussed in Section VIII. Section IX depicts Real-world Applications. A comparative analysis of cloud computing and serverless computing is presented in section X. Then Section XI gives futuristic tendencies and directions. The rest of the paper is concluded in Section XII.

II. LITERATURE REVIEW

This section involves the most relevant and recent published studies. Bairagi et al. [7] discussed definitions, models, and architecture in good form. Kollolu et al. [8] present a systematic evolution of cloud computing, history, and services. Islam et al. [9] describe possible challenges and future benefits of cloud computing in detail and provide well-

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structured literature to easily understand. Hendrickson, Scott, et al. [10] define key aspects, and challenges of serverless computing. They also address the literature that is implemented and designed in the same environment. Adzic, Gojko, et al. [11] represent the impact of architecture and economic aspects of serverless cloud computing. Hassan et al. [12] discussed various kinds of literature in the form of review papers, they have taken 275 research papers and their different parameters, and methodology of research are also included. Li, Yongkang, et al. [13] proposed a survey paper whose prime object is infrastructure and relevant aspects of serverless computing. Castro, Paul, et al. [14] focused on how serverless computing extended as a hybrid environment, besides that significant opportunities and challenges were also identified.

III. CLOUD COMPUTING CHRONOLOGY

Before the rise of cloud computing, there are numerous technologies were used. Some eminent technologies are parallel computing, client-server architecture, grid computing, cluster computing [5], etc. The history [6] [15] of cloud computing started in the 1960s but it gained prominence in the early 2000s. Table 1 depicts the entire chronology.

Table 1: Chronology of cloud computing

Order	Brief Descriptions
1960s to 1970s	• Time-sharing allows simultaneous access to a single computer system by multiple users. • Utility Computing enables computing resources based on subscription,
1980s to 1990s	• The rise of the internet and www (World Wide Web) played a vital role in cloud computing. • Web hosting services and remote servers have been begun by numerous companies.
Late 1990s to early 2000s	• In 1999 salesforce introduced CRM (customer relationship model) as a Software as a Service (SaaS) model. • Here applications are also accessed by using the internet without installing on a local computer.
2006	• Introducing Infrastructure as a Service (IaaS) to the world market by Amazon Web Service (AWS) and launching EC2 (Elastic Compute Cloud) service successfully. • EC2 enables virtual servers on hiring charges and end users are also capable of scaling computing resources as needed.
2008	• Launching of Google App Engine by Google, a platform where web applications are built and hosted at its data centers. • It began the Platform as a Service (PaaS) to the global market.
2009	• Windows Azure launched by Microsoft Company, now known as Microsoft Azure. • It offers various services i.e. storage, virtual machine, and Applications services.
2010s	• Now cloud computing continuously growing, and several companies have adopted cloud services. • AWS became a powerful competitor in the market, and after that Google Cloud Platform, and Microsoft Azure takes place.
2014	• Introduced Docker containerization technology [16] by Docker Company built and organized applications that can be deployed as a container. • These containers are lightweight applications incorporated with related system libraries and dependencies. It ensures that these containers are capable of working in every domain or environment.
Late 2014 to 2016	• AWS launched a serverless computing [17] service known as AWS lambda.

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	• In this developer can able to execute code in reciprocation of the event (generated request) without deploying servers and paying only for consumed resources during code execution.
At present	• Currently cloud computing become popular all over the place • Wide range of apps and services served in the global market. There are numerous innovations are in progress such as fog computing, edge computing, mobile computing, hybrid cloud, IoTs, artificial Intelligence etc.

IV. CONVENTIONAL CLOUD COMPUTING MODELS

This section discusses the standard cloud computing models usually categorized into three main types. Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Collectively these types of models are also known as *Service Models* [18][19]. These can be explained as follows:

1. *IaaS***:** In this model cloud service providers deliver virtualized computing resources. Mostly IT architect uses these services. End users have control over the development frameworks, apps, and operating systems executed on infrastructure, and still, they are accountable for these modules. Eucalyptus & OpenStack, Amazon Web Service EC2, Google Compute Engine, Microsoft Azure VMs, etc. are examples of this model.
2. *PaaS***:** This model provides a platform that enables customers to evolve, run, and maintain apps without any difficulties. This model is for developers. End users focus on creating and deploying whereas cloud service providers maintain basic infrastructure such as servers, networking, storage, etc. Some examples are Google App Engine, Force.com, Microsoft Azure App service, Amazon Web Service Elastic Beanstalk, etc.
3. *SaaS***:** End users can be able to take direct usage of this model. It deploys application software based on pay-per-usage. Users can get access this software without installing it on local computers, for this, they can use an API (Application Programming Interface) or any browser with an active internet connection. Cloud service provider manages and host entire application software as well as application code, middleware, and infrastructure. Microsoft Office 365, salesforce, Dropbox, Google Workspace, etc. are popular examples of SaaS models.

Apart from these conventional models or service models, there are another well-known models are *deployment models* [18][19]. Service models and deployment models are closely related to each other. Service models describe the services offered by cloud providers whereas deployment models represent the way of service made available for end users that can be further divided in the following manner:

4. *Public Cloud:* In this model end users get services as well as resource sharing among them, offered by third-party service providers over the internet. Public clouds are the most cost-friendly alternative and provide flexibility and scaling. E.g. Google Cloud Platform, AWS, Azure.
5. *Private Cloud:* It is a type of cloud computing domain dedicated to solely an organization or privately owned data center. As compared to the public cloud, it offers high security, control, and customization. It can be owned by the IT department of the organization or a third-party cloud provider. For those organizations who prefer precise security and good performance, a private cloud would be the perfect option for them. HPE, OpenStack, and VMware are examples of private cloud.
6. *Hybrid Cloud:* It incorporates the benefits of both public cloud as well as private cloud. It delivers flawless data and application flexibility between privately owned data centers and the public cloud. Public clouds can be used for scaling workloads whereas private clouds ensure keeping sensitive data secure. Amazon, Microsoft, Google, Cisco, etc. provide hybrid cloud services.
7. *Community Cloud:* When several organizations use together the shared infrastructure for common objectives such as compliance standards, security, official requirements, regulations, etc. then the selection of a communication cloud could be beneficial for them. Community members get more customized solutions during resource sharing compared to the public cloud. Community cloud is often controlled by third-party service providers or organizations. For example, several government departments perform various transactions together on the shared platform using a kind of community cloud.

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V. LIMITATIONS OF CLOUD COMPUTING

While cloud computing provides numerous advantages, it has some limitations [20] too. Some of them are as follows:

1. *Accessibility and Downtime:* Cloud services are dependent on an active internet connection. Lack of proper internet connection leads to poor experience. Sometimes due to hardware failures, system maintenance, and bugs, cyber-attacks can cause downtime and outages of cloud services. Organizations or firms must implement such a mechanism or strategies that reduce failover and interrupted conditions.
2. *Service Cost Management:* cloud computing services offer a cost-friendly environment by using the *pay-per-usage* principle but if not maintained properly it may cause unexpected lavishing due to overloading, overprovisioning, and lack of resource utilization. With proper implementation of cost-observing strategies, and optimization techniques one can help to overcome expenses.
3. *Security and Privacy:* In cloud computing security is a crucial part because the organizations or users share their sensitive information, data, or applications with the third-party cloud service providers. If it is not properly implemented unauthorized access, data breaches, and data loss may occur. Use of compliance and regulations of data encryption. Control access etc. can overcome these concerns.
4. *Vendor Lock-In:* This occurs when the cloud services are taken from specific cloud service providers because organizations are dependent on the service provider. In between migration will lead to costly and complex too, however applications and data are convenient to the service provider's platform. Using portability and interoperability helps to overcome this kind of problem.
5. *Response and Performance:* It is well known that cloud computing depends on internet connectivity. Due to some factors such as geographical location, and shared resources, network congestion can lead to low latency and poor performance. Using hybrid cloud service, edge computing that can balance the workload can help to mitigate these conditions.

VI. EMERGENCE OF SERVERLESS COMPUTING

In cloud computing, the emergence of serverless computing [21][22] depicts a remarkable paradigm shift, uprising the building process by developer, delivery, and management of applications.

1. Definition and Framework

Serverless computing takes out the convolution of server handling allowing developers to focus only on writing code or functions to control particular tasks or event acknowledgement. By this approach developers get away from provisioning, scaling, or managing servers, enabling efficient and productive software for delivery. The serverless cloud computing model was launched [10] in 2014 by Amazon lambda in the cloud market, followed by Microsoft and Google in 2016. Serverless Computing appends an extra abstraction layer over the cloud software or paradigm and also removes server-side management from the cloud developer [7] and replaces it with application logic and codes. The term 'serverless' used FaaS (Functions as a service) alternatively. The executions of functions are automatically maintained and configured by this platform.

2. Architecture and key elements

There are some key aspects of serverless computing are as follows:

2.1 *Event-Driven Architecture:* Serverless build an application based on the event-driven, counter to particular triggers or events such as file uploading, task scheduling, database changes, and requests. The cloud provider invokes related serverless functions by itself whenever an event occurs. These functions sun the associated event code.

2.2 *Pay-per-usage Pricing Model:* It follows a pay-per-usage pricing model, where the actual amount of usage of various resources and code execution time, are charged by the organization. It helps to optimize cost.

2.3 *Stateless Implementation:* In this, stateless functions are built, which means no need to maintain determinant connection or state info between invocations, and allows fault tolerance and scalability.

2.4 *Automatically Scaling:* It is enhanced with automatic scaling features, based on task load, resources are dynamically allocated without any interference, and functions can be scaled in real-time to maintain various traffic levels, offering high accessibility and optimizing performance.

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2.5 *Control Infrastructure:* As already discussed serverless cloud platforms take the complexity of server provisioning, scaling, and maintaining. Therefore cloud developers focus on writing codes for applications and direct workflows that are based on event-driven rather than server management, runtime environment etc.

These are the key aspects that describe the way developers work and improve the efficient utilization of resources, optimization cost, scalability, and other services.

3. *Evolution from Conventional Clouds Models:*

As discussed in section 3 conventional models lead to complexity and higher latency of applications to the cloud market. However, serverless cloud computing emerged to overcome these limitations of conventional cloud models, which aims to take out the complexity of server handling, and resource provisioning.

VII. BENEFITS OF SERVERLESS COMPUTING

This section comprises numerous advantages. Serverless cloud computing platform offers the following benefits [12][23][24]:

- Scalable and easy to deploy
- Cost effective
- Fastest in the cloud market due to decreased latency
- Improved flexibility
- Minimize operational complexity
- Global accessibility and higher availability
- Event-driven architecture
- Server side Management
- Improved production of developers

VIII. CHALLENGES AND LIMITATIONS OF SERVERLESS COMPUTING

Apart from the benefits, serverless computing has some challenges and limitations too [13][24], some of them are as follows:

1. *Cold start latency problem:* One of the foremost challenges of serverless cloud computing is cold start latency. After the request is triggered by the user for the first time or after an interval of inactivity, then it may be delayed because the cloud service provider arranges the provisions, and begins the environment to execute the response of various applications influenced by these delays. Response-sensitive task loads or real-time applications are more affected by this factor. To overcome this problem computing resources will be kept at the first calling of function.
2. *Vendor Lock-In:* In serverless cloud computing organizations become dependent on the proprietary technologies of service providers. If any organization decides to migrate to another platform from a serverless cloud platform, they may face challenges like integration, compatibility with services, implementation, etc.
3. *Resource Constraints:* There are some resource limitations, for instance, memory allocation, maximal execution duration, functions synchronization, etc. If any application surpasses these limits, then it may encounter various kinds of issues such as resource exhaustion, timeouts, etc. To overcome these kinds of problems, developers should carefully design optimal functions to intercept these constraints.
4. *Performance Considerations:* This platform considers dependencies, maintenance interrelation distributed task flows, adaption between services and functions, etc. These operations increase the complexity of serverless architecture. Obtaining scalability, and reliability, requires additional tools, skills, and experience.
5. *Monitoring and Debugging:* There is limited observability into basic infrastructure and executive environments are complex to detect and diagnose the operational issues, failures, and errors. Although serverless computing provides numerous logging tools and monitoring aspects it may require more investment in troubleshooting and monitoring.
6. *Compliance and Security:* Apart from the availability of logging tools, and services, it may be influenced by some common security threats such as data breaches, injection attacks, etc. To reduce security risks and protection of sensitive data, it is mandatory to ensure compliance with regulations, access handling, and robust security.

To overcome these challenges, organizations must evaluate them properly while adopting this architecture.

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IX. REAL-WORLD APPLICATIONS

A lot of benefits of serverless cloud computing made it popular in the cloud market, some real-world applications [25] [26] are as follows:

- This platform is well-suitable for creating web applications and application program interfaces (APIs) with the feature to predict huge traffic patterns, and profile management by AWS lambda.
- Streaming and event processing can be performed seamlessly. E.g. IoT platforms use it to provision services in smart devices.
- It can be used for batch processing and data processing. For instance, A wholesale company can use this platform to evaluate data regularly and provide vend reports for other management.
- It is capable of backend processing and small services such as image and video processing. Example - Media streaming Platform.
- It provides a messaging platform for conversation with cloud users. E.g. chatbots.
- Edge computing and serverless computing collaborate to create various applications.

These key points ensure resourcefulness and wide utilization of serverless cloud computing services.

X. COMPARATIVE ANALYSIS: CONVENTIONAL CLOUD VS SERVERLESS COMPUTING

Here Table 2 depicts the comparison [7][8][9][11-16][between traditional cloud computing and serverless computing, these comparison based on some parameters are as follows:

Table 2: Conventional Cloud Vs Serverless Computing Key Difference

Parameters	Conventional Cloud Computing	Serverless Computing
Infrastructure Supervision	• It focuses on provision, handling, and configuring VMs, servers, storage, etc.	• Apart from handling basic infrastructure, developers focus on code writing for applications.
Cost Factor	• It follows an approach where the organization fixes the amount to be paid for resource deployment, despite the actual usage. The amount includes the cost of VMs, networking, and data transmission, with differentiation based on types and consumption.	• This platform goes with pay per use pricing model, where price charges are based on actual consumption of resources, memory, and additional services.
Development with Deployments	• Cloud developers are accountable for handling infrastructure, deploying applications, and configuring environments.	• Cloud developers are responsible for describing event-driven task flows and code writing. After that designed function automatically deployed applications and other services.
State Handling	• This platform may depend on stateful elements such as caches, handling sessions between requests, and databases. To be stateful, the organization is required to control synchronization, scalability, and data consistency.	• This platform uses serverless functions that are designed to rely on stateless, which means there is no need to control the tenacious state between requests. This kind of stateless data is handled by using various storage solutions. E.g. cache, scalability, database, fault tolerance etc.
Performance Complexity	• Configuring the environment, handling infrastructure, and observing applications may lead to complex performance in this traditional cloud platform.	• Serverless services take out infrastructure handling and task operation that reduce complexity, cloud security providers, control VMs, and server provisioning, monitoring, and scaling, which enables organizations to focus on writing code and logic.

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Although conventional cloud computing provide controlled infrastructure and flexibility, but serverless computing offers scalability, comprehensibility, event driven, cost-effective applications in enhanced manner.

XI. FUTURISTIC TENDENCY AND DIRECTION [12][13]

As the technologies continuously enhance and full fledge grow, the future of serverless computing is also full of innovations and advancements that would help to shape the future. From the future perspective as edge computing [27] attains eminence, serverless computing architecture enhanced it by extending network edge, allowing serverless functions deployment to end users and smart devices. This integration is called a *hybrid serverless environment* that flawlessly collaborates edge computing with the serverless cloud environment. It offers real-time access and minimum latency. Presently serverless computing supports stateless functions that do not need to be tenacious between requests. Although our developers express their interest in stateful function support and working on it to enable the storing and management of functions during execution. Apart from these developers are still working on serverless computing with containers that would offer efficient scalability, controls, and flexibility. Security and compliance with regulations are major concerns in serverless computing.

In the future, advanced approaches will be used to satisfy customers' requirements for privacy and sensitive data. Developers also work on serverless cloud tools environments that will be full of new frameworks, tools, applications deployment, and API standards. From an industrial point of view, serverless computing gains optimized & efficient results, and cost redundancy, and may also include innovative tools such as machine learning, and IoTs [28], etc. from the working point of view serverless computing may require experts, well well-skilled developers. so here requirement of trained skillful cloud developers is also one of the major concerns in futuristic trends that will be obtained by organizing proper training sessions and workshops from time to time.

XII. CONCLUSION

This paper represents the comparative analysis of conventional cloud computing and platform-independent cloud computing which serverless cloud is computing. Each section well defines the key concept of both frameworks. As cloud computing offers resource deployment, scalability, flexibility, etc., at the same serverless computing also provides these features with more enhancement and advancement. Here term 'serverless' does not mean that servers are not present or participate here, rather then it indicates that developers do not deal with servers directly, for this, they use codes, logic, and function. In the future, this study will help to understand the fundamental key aspect and main difference between conventional cloud computing as well as serverless computing to the researchers who are interested in cloud environment.

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