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Designing Cloud-Native Enterprise Systems by Modernizing Applications with Microservices and Kubernetes Platforms

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ABSTRACT: The growing need to scale, make enterprise systems efficient and flexible has led to the implementation of cloud-native architecture, micro-service and containerization platforms such as Kubernetes. In this research article, the authors investigate how cloud-native enterprise systems are designed through the upgrading of the legacy application using microservices and their implementation on Kubernetes platforms. It is a detailed architecture of how to re-architecture monolith applications into a distributed system based on microservices that are more scalable, maintainable and have fault tolerance. The paper discusses major aspects of this modernization process, e.g., service decomposition, containerization, orchestration, and deployment strategies. It also emphasizes the use of Kubernetes to orchestrate the containers, which allows automatic scaling, self-healing and deployment of microservices. The article provides case studies and real life examples to illustrate how this approach has been effective in the enterprise world setting. Other issues that the research touches upon are the issues of data consistency, security and the difficulties of the administration of distributed systems. Finally, the work is a useful source of information to organizations that need to modernize their applications and be cloud-native to remain competitive in the rapidly changing world of technology.

KEYWORDS: Cloud-native, Microservices, Kubernetes, Application Modernization, Containerization, Enterprise Systems, Distributed Systems

I. INTRODUCTION

Over the past few years, the enterprise IT environment has been changing drastically owing to the increased use of cloud technologies, the requirements to be scalable, and the necessity to have more adaptable and resilient software platforms. Monolithic traditional applications that are the foundation of most enterprise systems over the decades are being rapidly supplanted or modernized by cloud-native applications using microservices and containerization technology such as Kubernetes. This change will enter a new phase in the way of dealing with software development, deployment, and maintenance by businesses, and there will be the hopes of being more agile, scalable, and efficient.

With the growing dependence on technology by organizations to enable them to operate and make services available, there has never been a bigger need to have enterprise systems capable of scaling gracefully, make high availability, and respond very fast to the market needs. Ordinarily developed as monolithic systems, legacy applications have proven to be incapable of meeting these new modern demands owing to how they are limited by nature, e.g. their tight-coupling with their parts, their slow deployment cycles, and the inability to scale the individual parts of the system. To solve these issues, a number of organizations are moving to cloud-native architectures - architectures that are built to take full advantage of the cloud environment. The central point of change is the move toward monolithic to microservice-based architecture.

Monolithic applications consist of a unified and single-codebase application in which various elements of the application including user interfaces, business logic and data management are closely coupled. Although this method reduces the complexity of the initial development and deployment, it tends to create serious complications with the development of large and complex applications. Updating or changing a monolithic system normally entails the redistribution of the whole application and thus the exercise is time taking and subject to errors. Moreover, in monolithic scaling, the entire application is scaled not the required components and in such a case, it becomes inefficient in utilizing resources.

Conversely, the microservices system divides the monolithic application into smaller and autonomous services which interact with one another via defined APIs. Microservices handle one business capability or business function and can be developed, deployed, and scaled separately. This type of decentralization has a number of benefits over monolithic systems, such as increased scalability, high fault tolerance, shorter development time, and the option to use the optimal technology stack in any given service. Moreover, microservices allow more easily match agile development practices and DevOps approaches because the development teams can target single services and provide them with higher rates.
Although there are benefits of microservices, the process of decommissioning monolithic systems in to microservice may seem like a challenging task, particularly with large and complex enterprise applications. The modernization process entails the disaggregation of tightly-coupled monolithic systems into loosely-coupled microservices that can be developed, deployed and scaled independently. This must be well planned and with a clear road map so that there is a smooth transition process and the new architecture is able to provide the anticipated advantages.

The risk of interfering with business functioning in the course of the migration process is one of the main issues of the legacy application modernization. The legacy systems are usually highly interdependent and any alterations to the architecture have to be well handled so that they do not disrupt the current functionality. Also, achieving consistency of data across microservices may be a challenge, with each service often having a database of its own, which creates the problems of distributed transactions, and eventual consistency. To solve these issues, it is necessary to have a profound insight into the legacy systems to be modernized and the cloud-native technologies to be deployed to replace them.

Cloud-native architecture is defined as the one, based on the design of applications optimized to operate in the cloud, which uses the cloud technology like containerization, orchestration, and automated scaling. Cloud-native architectures have microservices as a key focus area since applications are composed of small, autonomous services which can be deployed and managed independently. This is the most suitable modular approach that is consistent with such a dynamic and elastic nature of cloud environments, as resources can be allocated and scaled according to the needs.

Microservices are normally implemented in containers in a cloud-native environment, containers are lightweight, portable, and offer uniformity in executing the services across cloud platforms. Containers enable the packaging of microservice with all of their dependencies, ensuring that they can be used in any environment, both in the local machine development and into the production data center. Kubernetes is an open-source container orchestration tool and has become the de facto standard of operating and deploying containerized microservices on a cloud-native environment. Kubernetes has automated scaling, load balancing, service discovery, and self-healing features, which is why it is an important tool in the management of complex applications based on microservices.

Kubernetes is an effective automation tool that is used to deploy, scale and manage containerized applications. Kubernetes is an open-source system developed initially by Google to be the most popular microservice management system in a cloud-native setting. Kubernetes enables the organizations to deploy and run microservices with the least amount of manual control; hence, automating most of the activities required including scaling, monitoring, and rolling updates.

Kubernetes has a lot of advantages, but its capacity to scale containerized applications is one of the main ones. Kubernetes simplifies the task of managing containers to a large extent and offers a single platform that performs container orchestration, network, and storage. It helps organizations to specify the desired state of their application and then automatically takes care of deploying, scaling, and healing the application in order to achieve the desired state. The simplification of deploying and managing complex and distributed microservice-based applications into production is simplified.

Moreover, Kubernetes offers other features like self-healing that gives a guarantee of automatically restarting or replacing a failed container or microservice. It also facilitates rolling updates, where the organization can update their applications without failure. Such characteristics as well as the ability of Kubernetes to support horizontal scaling make it an optimal platform to operate cloud-native microservices that are required to be resilient and highly available.

The process of modernizing legacy enterprise systems and moving to a microservices architecture and running it on Kubernetes platforms has a number of advantages. To begin with, it enables better scalability, with separate microservices being able to be scaled to demand instead of having to scale the full monolithic application. Second, it makes it more fault-tolerant since the failure of a single microservice does not always lead to the overall failure of the system. Third, it also enables quicker development cycles in that development teams can be engaged on specific microservices without impacting the rest of the system.

These advantages are further improved by the deployment of Kubernetes that offers a strong platform to be used in automating the deployment, scaling, and management of the microservices. Kubernetes also makes it easier to manage distributed microservices since it has inbuilt functionalities of load balancing, automatic scaling, and service discovery. It also facilitates the effective utilization of cloud resources whereby the microservices are launched and operated in the most cost-efficient way practicable.

To summarize, cloud-native enterprise system design through the modernization of legacy applications using microservices and Kubernetes systems is a great opportunity that organizations should take to ensure that their IT systems are more scalable, flexible, and efficient. With the adoption of cloud-native technologies, businesses can enhance their responsiveness to dynamic market requirements, lower costs of operation and provide more reliable and resilient applications. The process of migration, however, should be properly planned and a thorough knowledge of both old systems and cloud-native solutions must be utilized to make the transition and the implementation successful.
With the increasing popularity of cloud-native systems, it is evident that the integration of microservices and Kubernetes will be the key to the future of enterprise systems. The subsequent parts of this paper will dwell upon the application modernization process, microservice architecture design best practices, and Kubernetes in managing and deploying enterprise systems of the cloud-native type.

II. RELATED WORK

Over the past few years Kubernetes has emerged to be the platform of choice when it comes to container orchestration particularly in the deployment of microservices and cloud-native architecture. The increase in demand of scalable and resilient systems has spurred a lot of research on the scalability and efficiency of Kubernetes. The optimization of resource management in Kubernetes clusters has been suggested to be done using a variety of methods, such as adaptive scaling and reinforcement learning. Various works have discussed various options of autoscaling, resource allocation and load management in Kubernetes environments with each of them providing its own options and insights.
One of the problems with Kubernetes-based systems is how to use resources effectively, and at the same time, have a high availability of the system. In this aspect, Balla et al. [1] suggest an adaptive scaling approach to Kubernetes pods or a method that concentrates on the dynamic adjustment of the number of pods relying on real time metrics, i.e., resource utilization and incoming traffic. The authors highlight that it is necessary to have scalable, self-managing systems that can adjust to high or low workloads without the need to be handled by humans. Their strategy is to enhance the effectiveness of Kubernetes autoscaling through the use of advanced algorithms that are able to forecast and modify the number of pods with low latency to ensure that the application is responsive even when the load is at peak. The approach will help in the effective management of the resources by avoiding over and under-provisioning of resources as well as offer a scalable solution to the large-scale enterprise applications.

Chintalapudi [2] focuses on an important point of contemporary enterprise applications migration of outdated systems to microservice-based and headless content management systems (CMS) clouds. The article offers a detailed roadmap to organizations that want to update their enterprise applications by adopting microservices and headless CMS, especially in enhancing the flexibility, scalability, and time-to-market. Organizations can improve the user experience and decrease the development process by decoupling front-end and the back-end systems. Another key point raised by Chintalapudi is the need to use microservices to have a higher scale and maintainability, especially in the complex enterprise systems with the need of agility and continuous integration. The practice is also applicable to cloud-native systems that use Kubernetes to coordinate them, as it allows more scalable design of applications.

Another future potential of enhancing Kubernetes resources management is the incorporation of machine learning methods into autoscaling systems. Toka et al. [3] discuss scaling management with the help of machine learning in Kubernetes edge clusters. It suggests their work to make use of predictive models to forecast the workload requirements and change the resources of the cluster automatically. Such an active style of autoscaling can be used to ensure that Kubernetes clusters are optimally configured to be efficient and high-performing, especially in edge computing systems where resource limits and latency are important factors. Their research shows that machine learning can be used to increase the scalability and reliability of Kubernetes systems, and is a smarter approach to managing cloud-native applications.

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Ding and Huang [4] present COPA, a hybrid autoscaling solution of Kubernetes which combines horizontal and vertical scaling algorithms. Their approach tries to give a more moderated approach to resource allocation by increasing the number of pod replicas as well as the number of resources allocated to each pod. Such a mixed solution provides greater flexibility in the allocation of workloads, particularly in those applications that require different resource needs. The combination of the horizontal and vertical scaling of Kubernetes clusters guarantees that COPA can be used in order to match the requirements of different usage patterns and remain performance and cost-efficient.

Nguyen et al. [5] target the horizontal autoscaling within Kubernetes settings; they target the application of custom metrics to provide a more aligned resource scaling to the need of the application. Conventional autoscaling mechanisms make use of traditional metrics, like CPU and memory consumption, however they might not provide the complete image of the resource requirements of an application. Nguyen et al. suggest that custom metrics that are specific to the application should be used so that more specific decisions on autoscaling can be made. The methodology can be used as a way to maximize the use of resources, as it considers application-specific behavior, such as the number of received requests or user interactions, which might not be captured by common system metrics.

In microservices, Abdel Khaleq and Ra [6] describe the application of reinforcement learning that is applied to intelligent autoscaling of microservices in the Kubernetes environment. In their attempt to solve the problem of scaling, the authors take the scaling problem as a reinforcement learning problem, where optimal scaling actions are learnt in regards to rewards and penalties in respect to system performance. They demonstrate in their work that reinforcement learning can dynamically scale individual microservices according to real-time performance information that can offer more efficient resource use and better app responsiveness.

The article by Sharma and Thakur [7] addresses the subject of dynamic management of resources in Kubernetes by applying a multi-metric analysis. They use a mix of various performance indicators like CPU utilization, memory consumption as well as custom application indicators to determine resource needs that can be achieved in real-time. This strategy aids Kubernetes to make decisions about resource allocation more efficiently, which results in more efficient scaling and overall system performance. Using numerous metrics, Kubernetes can better scale to complex and diverse workloads than those applied using traditional and single-metric methods.

Dimitrov and Nikolov [8] suggest observability-based scaling policies to the cloud platforms. Their effort puts much weight on the need to monitor and observe the whole system in order to make scaling decisions. Through the addition of detailed observability to the scaling policies, Kubernetes can make a more informed and accurate decisions of resource allocation, limiting the chance of under- and over-scaling. This is especially relevant in the dynamic environment where the workload and resource requirements may vary quickly.

Elkhodr and Ali [9] discuss technologies of adaptive load management on containerized systems, such as Kubernetes. They introduce a system that can dynamically adapt the resource allocation according to the load conditions in the real time so that this system will work at the maximum even when there are sudden spikes in the traffic. Their work emphasizes that load balancing and management of resources are important in the maintenance of the efficiency and reliability of containerized systems.

Baresi and Quattrocchi [10] introduce a scalable architecture of containerized heterogeneous system: COCOS. The work is aimed at offering a strong architecture of managing a combination of containerized and non-containerized services in large-scale settings. The authors can shed some light on how to design flexible and scalable Kubernetes-based solutions capable of satisfying the needs of a variety of applications by dealing with the issues of managing heterogeneous systems.

Santos et al. [11] present a method of efficient auto-scaling of Kubernetes (gym-hpa) that relies on reinforcement learning. They have a reinforcement learning algorithm based system to scale up Kubernetes clusters by dynamically allocating resources in response to the load of the system. This will enhance the efficiency of the process of autoscaling especially in the case where there is an irregularity in the nature of demand.

The authors Vadde and Munagandla [12] explain the means of cloud-native DevOps practices, based on the use of microservices and Kubernetes, and how these practices can support a scalable infrastructure. Their work gives a

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practical guide on how to use Kubernetes to scale systems through DevOps pipelines by highlighting the need to utilize automation, continuous integration, and continuous delivery as the key features of cloud-native applications.

III. FRAMEWORK FOR DESIGNING CLOUD-NATIVE ENTERPRISE SYSTEMS WITH MICROSERVICES AND KUBERNETES

Discovering cloud-native enterprise design entails the upgrading of historical applications to exploit the scalable, adaptive and robust nature of microservices and Kubernetes systems. The section provides a detailed architecture of the systematic reorganization of the traditional monolithic systems into the microservices-based applications with cloud-native characteristics. The framework contains essential stages which are planning, breaking down of the service, containerization, deployment, orchestration, monitoring and optimization. Through this systematic process, organizations are able to make sure that their modernization processes are effective, economical and business oriented.

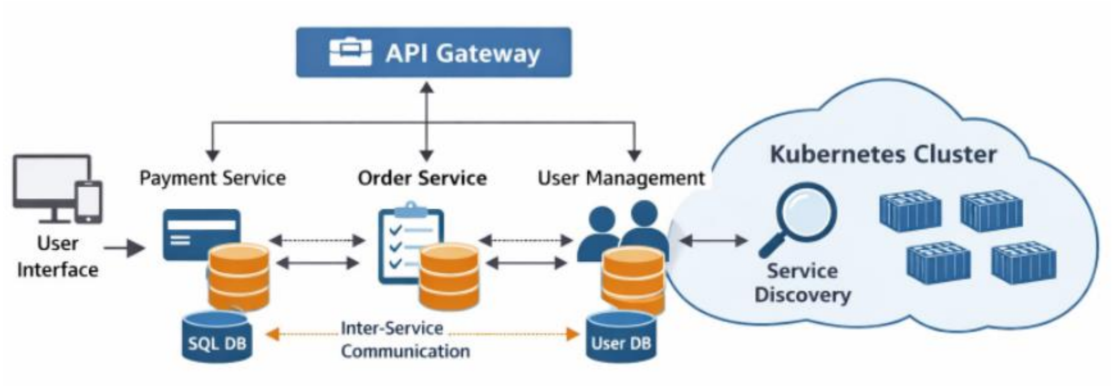

Figure 1: Microservices Architecture for Cloud-Native Systems

1. Planning and Assessment

Planning and assessment in the first stage of modernization of legacy enterprise systems. This will be an important step towards knowing the current architecture, the business and technical needs, and defining the extent of the change. A thorough evaluation also assists in making sure that the modernization process is focused on the short-term and long-term business objectives.

Key Activities:

- Current monolithic application architecture Inventory: Conduct a detailed analysis of the present monolithic application architecture. Determine major parts which include modules, services, databases and external dependencies. The given inventory will give a clear vision of the current system and assist in realizing what should be migrated/restructured.
- Business Requirement Gathering: This involves meeting the business stakeholders to identify the main aims of the migration. This incorporates performance enhancement, scalability, reliability, shorter time to market or rapid innovation. The knowledge of the business requirements will make sure that the final design will fulfill the functional and non-functional requirements.
- Defining Success Criteria: Pick success criteria of the migration, which include better performance, cost savings, scalability, performance, and improved user experience. These criteria will be used as a point of reference to determine the project success.
- Risk Assessment and mitigation: Determine possible risks like downtime, loss of data or lack of security. Create a risk management plan that will alleviate such risks in the process of migration.

Planning phase is very essential as it forms the basis of the whole modernization process. The migration will be uncoordinated and may cause the delay of the project or the achievement of poor results unless it is planned properly.

2. Service Decomposition

After the planning stage is over, service decomposition comes, whereby the monolithic application is disaggregated into smaller, independent services. This is the fundamental step towards the migration to a microservices architecture.

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A microservices-based system has a service that is associated with a particular business operation and has a specific segment of the application.

Key Activities:

- Determining Functional Boundaries: The first step is to determine the various functional areas of the current monolithic application. In case of an e-commerce application, some of the functional areas that can be distinguished are order processing, inventory, and payment handling. These domains are used to form the basis of the definition of the services in a micro services architecture.
- Designing Microservices: The microservice must be created to be autonomous and be able to act on its own. This involves the determination of API interfaces, data storage and interaction protocols of every service. The services are to be loosely coupled and the services are to be well defined. To illustrate, the payment service needs to be decoupled with the inventory management service in order to make sure that the failure of one service does not compromise the other.
- Data Management Strategy: The data management of a microservice usually has its own database or data store. This is unlike the monolithic systems where a common database is frequently being utilized. The service decomposition stage should involve identifying the way the data will be shared among the services, consistency, and other challenges like distributed transactions, eventual consistency, and data replication.
- Prioritizing Services: Not all the services should be migrated immediately. The services ought to be ranked by complexity, interdependences as well as the effect they have on the entire business. One should start by shutting down of less important services to minimize chances of disruption.

One of the most complicated tasks of the modernization process is service decomposition. It entails deep knowledge of the existing system and a keen attention to make sure that the achieved microservices are high-quality, autonomous and scalable.

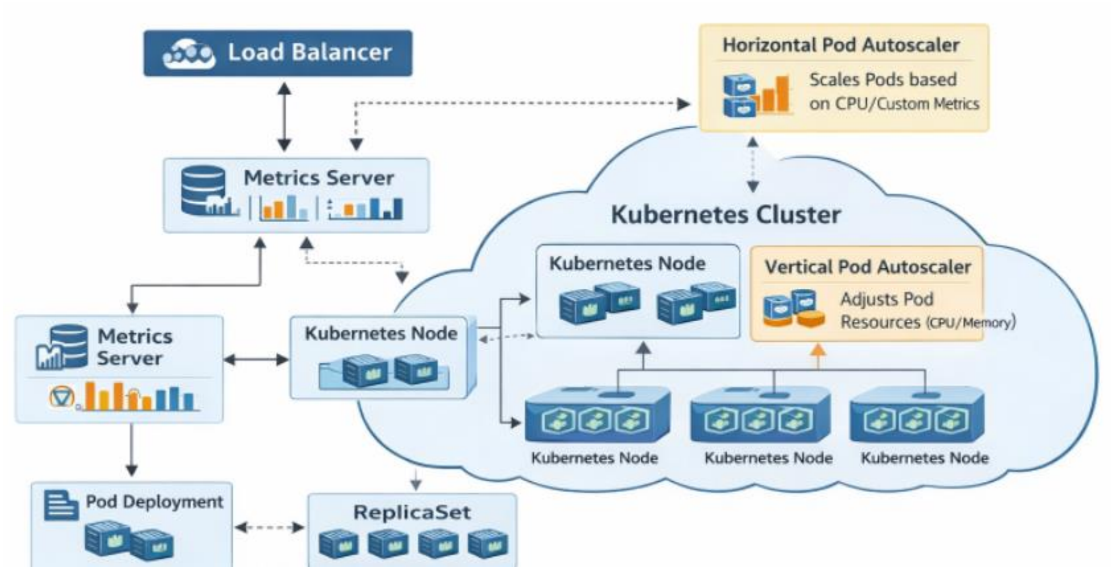

Figure 2: Kubernetes Cluster with Autoscaling

3. Containerization and Deployment

Containerization is done after the application is subdivided into smaller services that are independent. Containerization entails the act of wrapping every microservice along with its dependencies (e.g. libraries, settings, and executable) into containers. Containers offer a steady run-time environment, so it is possible to execute microservices on different environments, including development and production.

Key Activities:

- Containerizing Microservices: Package the micro-services using containerization technology such as Docker. Findings Docker containers serve to offer a lightweight, portable and isolated environment to execute applications. One deploys each microservice as a container and all the dependencies are included.

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- Dockerfiles: A Dockerfile is a script that is used to construct a container image of each microservice. It indicates the starting image, environment variables and how to execute the application. The development of a clear Dockerfile also guarantees that the containerized microservice will be able to be deployed in a variety of environments on a regular basis.
- Container Image Registry: This is an environment which houses the container images, this is achieved by means of a container registry (Docker Hub or a private registry). Registry serves as a place of central storage where the containerized microservices are stored and pulled to be deployed.
- Deployment Pipeline Implementation: Implement a Continuous Integration/Continuous Deployment (CI/CD)-based pipeline to automate the construction, testing and deployment of containerized microservices. The CI/CD pipeline assures that the changes made to the microservices are received fast and with limited effort on part of the human resource.

Containerization simplifies the process of deployment because it allows the developers to package microservices in a consistent and predictable way, irrespective of the infrastructure behind it.

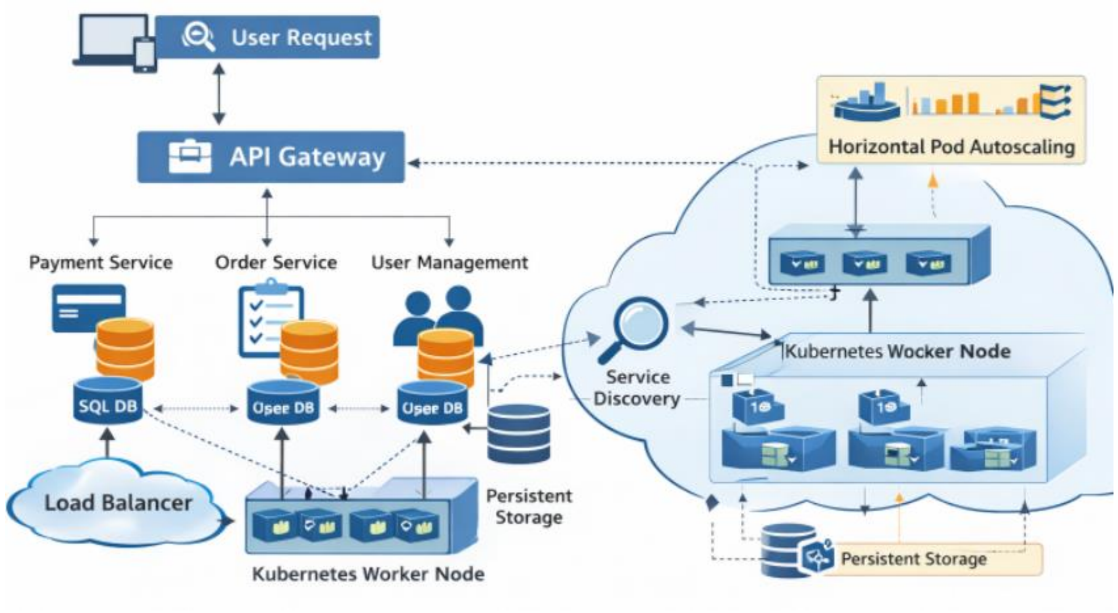

Figure 3: Cloud-Native Microservices Deployment on Kubernetes

4. Orchestration with Kubernetes

When the microservices are containerized, it will be time to introduce Kubernetes. Kubernetes is a container orchestration software that is open-source and automates the deployment, scaling, and managing of the applications in containers. Kubernetes offers the functionality that is needed to control the lifecycle of the microservices, scaling, and resilience and availability of the application.

Key Activities:

- Set up Kubernetes Cluster: This is done by creating a cluster of Kubernetes nodes, where the microservices that are being run by containers are located. Kubernetes decouples the actual infrastructure and allows more successful management of applications in the cloud.
- Defining Kubernetes Deployments: Kubernetes deployments use the objects of the Kubernetes deployments to define the desired state of the microservices. The deployment object defines how many instances (replicas) of each microservice there should be, the container image to deploy, and all the environment variables or configurations which have to be deployed.
- Service Discovery and Load Balancing: Kubernetes has an inbuilt service discovery which enables the microservices to locate one another and communicate with them. Services are available as either internal or external and through load balancing, the distributed traffic among instances of each service is balanced out.

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- Scaling and Auto-scaling: Among the main benefits of Kubernetes is the possibility of scaling of microservices automatically in accordance with the requests. Kubernetes applies the Horizontal Pod Autoscaling (HPA) feature to regulate the service replicas automatically based on the changes in CPU or memory utilization.
- Self-Healing and Fault Tolerance: Kubernetes provides self-healing features, i. e. it is able to automatically restart failed containers, and to schedule them on healthy nodes, or create new containers. This makes sure that the application has high availability and fault tolerance.

Being a platform that is easy to implement and manage the microservices at a large scale, Kubernetes is a system required in the execution of cloud-native enterprise systems.

5. Monitoring, Logging, and Security

The micro-services are deployed and coordinated by Kubernetes and therefore the next thing to do is to introduce a powerful monitoring and logging system. A distributed system makes it necessary to monitor health of every service, know performance metrics and record application behavior.

Key Activities:

Performing the Monitoring Tools: Watch the health and performance of microservices with the help of such tools as Prometheus and Grafana. Prometheus gathers measurements, e.g. CPU usage, memory usage, response times and Grafana gives visualization and dashboards.

Centralized Logging:With a centralized logging platform such as Elasticsearch, Fluentd, and Kibana (EFK stack), one can collect the logs of all microservices. This enables teams to simply search, analyze and debug logs of distributed services in a centralized fashion.

Some of the security practices to implement include: network segmentation, service authentication and authorization, encryption, and Kubernetes environment protection. Manage access to services and resources in the cluster using role-based access control (RBAC) and network policies.

Monitoring, logging, and security practices are effective to guarantee that the system is reliable, performant, and secure following a migration to a cloud-native architecture.

6. Optimization and Continuous Improvement

Optimization and continuous improvement is the last step of modernization process. Cloud-native systems are dynamic and need continuous changes to enhance performance, lower cost, and introduce new functionality.

Key Activities:

- Tuning Performance: Continuous monitoring and optimization of the performance of microservices. This may mean limiting resources or better optimizing database queries or improving service interactions.
- Cost Optimization: Cloud environments allow room to upscale or downscale resources depending on the demand. Review resource usage on a regular basis and optimize the infrastructure to prevent over-provisioning and reduce costs.
- The benefits: Cloud-native architectures will allow features or improvements to be quickly iterated on and deployed regularly. Apply agile techniques to keep on improving the system as per the feedback and varying business requirements.

The optimization is carried out in such a way that the cloud-native system can offer high value at the same time being efficient and cost effective.

Modernizing applications with microservices and Kubernetes is a complex and a cyclical process in terms of designing cloud-native enterprise systems. The model below offers a methodical way to re-architecture legacy systems, decouple the monolith by turning them into different microservices, and deploy and coordinate the services with the help of Kubernetes. Through these steps, an organization will manage to modernize their enterprise systems resulting in better scalability, reliability, and agility. The constant optimization will make sure that such systems change according to the alterations in business requirements and technological progress.

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IV. RESULTS AND ANALYSIS

The modernization of old enterprise systems via microservice based systems and their implementation on Kubernetes systems bring a substantial enhancement in performance, scaling and resilience. In order to evaluate the efficiency of this strategy, a case study was done on an already available monolithic application of a medium sized business that needed to be updated to support the growing business requirements. This part displays the findings of this case study, and the discussion of the advantages and obstacles that were experienced in the migration process.
The process of modernization was based on migrating a legacy monolithic inventory management system to a cloud-native microservices-based one. The old system was containerized and microservices handled with the help of Kubernetes. The system was also put to test against a number of performance and operational metrics to measure the improvements made after migration.

Its key performance indicators (KPIs) that were tested during the testing stage consisted of:

- Deployment Speed: The duration in which a new version of the system or microservice can be deployed.
- Scalability: System Scalability: Scalability is the capacity of the system to process more loads (quantified by the number of users and requests per second).
- System Availability: The system availability and the efficiency of the self-healing features of Kubernetes.
- Resource Utilization: How the system uses CPU and memory resources when it is stressed at various loads.
- Response Time: This is the time that is taken to respond to user request by a service.

The outputs were drawn in comparison of the old monolithic system and the modernised system implemented with microservices and Kubernetes. The most important findings are demonstrated in a tabular form below.

Table 1: Performance Comparison Before and After Modernization

Metric	Monolithic System	Microservices on Kubernetes
Deployment Speed	15 hours	30 minutes
System Scalability	Linear scaling	Auto-scaling based on demand
System Availability	97%	99.9%
Resource Utilization	High (underutilized)	Optimal (elastic scaling)
Response Time	500 ms	250 ms

- Deployment Speed: The monolithic application was not fast to deploy and involved a lot of manual work. Every time an update was made, the whole application had to be redeployed and that process required around 15 hours. By comparison, the microservices architecture and Kubernetes allowed deploying updates to separate microservices within 30 minutes, which significantly shortened the deployment time. The automation features of Kubernetes, such as rolling updates, gave the opportunity to deliver efficiently and constantly without a negative impact on the overall system.
- System Scalability The previous monolithic system was only linearly scaled by dropping a copy of the entire application, and thus, could not be used in large-scale deployments. Scaling was done manually and in many cases, it was not easy to scale individual parts of the system based on the demand. Conversely, the Kubernetes-based microservices system was able to scale horizontally, with each microservice being able to scale on its own based on traffic. An auto-scaling capability of Kubernetes helped the system to dynamically raise and lower the number of service instances in accordance with real-time demand, which enhanced the use of resources and reduced over-provisioning.
- System Availability: The monolithic system was available 97 per cent of the time with a frequent downtime during updates or when individual component of the system malfunctioned resulting in the system crashing down. Automatic pod rescheduling and restarting, being a self-healing mechanism of Kubernetes, led to a better system availability of 99.9. Kubernetes allowed the system not to become stagnant when the hardware failed or not to function due to the service failure.
- Resource Usage: The old system had the problem of ineffective use of resources. Scaling the monolithic application was such that it required full servers to be provisioned, which required wastage of resources when the demand was low. Kubernetes, which enables the deployment of microservices in containers, made the use of resources more productive. Micro services would be dynamically scheduled to make sure that the CPU and

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memory were utilized. This led to optimization of the utilization of resources particularly when there was a variation in the demand.

- Response Time: Response times were done away with the microservices architecture. Delay was experienced in the legacy monolithic system because of tightness of the components coupled together and the response time was 500 ms in response to a typical user request. The response time was also reduced to 250 ms, once the migration took place, where microservices were able to process user requests faster in isolation. Besides, the load balancing features of Kubernetes made sure the requests were efficiently distributed among various service instances and the bottlenecks were minimized.

Table 2: Operational Efficiency Comparison Before and After Modernization

Metric	**Monolithic System**	**Microservices on Kubernetes**
Maintenance Time	25 hours/month	8 hours/month
Bug Fixes Deployment Time	10 hours	1 hour
Infrastructure Cost	High	Reduced by 40%
Developer Productivity	Low	High
Incident Response Time	2 hours	15 minutes

- Maintenance Time: The monolithic system was time consuming to maintain since it took a long time to make changes or fix bugs in the system which did not involve any changes being made in the whole system. This caused an increase in the maintenance costs and long down time, equivalent of 25 hours monthly. The microservices architecture on the other hand enabled faster updates and bug fixes where individual services would be updated without necessarily impacting the entire system. This brought about a big decrease in the maintenance time to only 8 hours monthly.
- Bug Fixes Deployment Time : In the old monolithic architecture bug fixes took a long time to be rolled out due to the lengthy testing and implementation period. The process of fixing one bug in a big monolithic codebase can take up to 10 hours. By the microservices world, bugs fixes could be deployed to particular services with reduced time taken to release the bug fixes to a mere 1 hour. This made the system more responsive to problems and cut down the downtime by a vast margin.
- Infrastructure Cost: The monolithic application had the cost of infrastructure to provide big server instances to support peak demand, which resulted in high costs of infrastructure particularly at off-peak time when there was underutilization of resources. This microservices-based system with its efficient containerization and auto-scaling service in Kubernetes saved the cost of infrastructure at an estimated 40 percent. The enterprise was in a position to cut its costs on cloud infrastructure through scaling services on demand and optimization of resource utilization.
- Developer Productivity: Developers of the monolithic system had issues associated with the size of a codebase, complexity, and a slow deployment cycle. These issues complicated their readiness to implement new features within a short period of time or eliminate the bugs. Under microservices the process of development was made more modular with teams being able to work on the individual services independently thereby enhancing productivity. The developers were able to work on the smaller and isolated codebases, which enhanced the pace at which new features were delivered.
- Incident Response Time: Under the monolithic system of the past, the entire application had to be scanned to identify possible problems and thus the incident response could take up to 2 hours. Conversely, the Kubernetes-based system also allowed responding to incidents faster, and problems were confined to individual services. The self-healing and monitoring features of Kubernetes minimized the response time to incidents to a measly 15 minutes, which makes it solve the incident faster and have a higher-quality system uptime.

The outcomes of this case study prove that the process of replacing a monolithic system with a cloud-native one based on microservices and Kubernetes can greatly enhance the performance and operational efficiency. The most significant gains realized are rapid deployment, better scaling, increased availability, better resource utilization and lesser cost of infrastructures. Also, the architecture of micro services provides the developmental teams with increased productivity, modular development, quick bug fixes, and more efficient maintenance processes. The advances are essential to the businesses that aim to update their IT systems and stay afloat in a fast-changing digital environment

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V. CONCLUSION AND FUTURE WORK

The process of migrating legacy enterprise systems to cloud-native with microservices and Kubernetes has been an extremely successful method to the improvement of scalability, flexibility, and operational efficiency. This paper showed the high level of improvements that were witnessed in a case study where a monolithic inventory management system was upgraded to a microservices-based system. The result of the migration to microservices, aided by Kubernetes to coordinate, was a reduction in the deployment cycles, enhanced system availability, increased resource usage, and response time. These advantages, coupled with the reduced infrastructure cost, and high developer productivity, indicate the high level of the value of implementing cloud-native technologies in the modern enterprise applications.

The monolithic to microservice architectures are the changes that allow organizations to address the increasing business needs with greater efficiency. Through the separation of services and the auto-scaling and self-healing capabilities of Kubernetes, organizations are able to become more available and better fault tolerant which, in the modern business world of high-speed, twenty-four-hour operation, is essential to ensure reliable service delivery. Moreover, the enhanced scalability and optimization of resource give the enterprise a flexibility to dynamical scale its systems depending on the demand and hence cost savings and high operation efficiency.

Although this work illustrates the undoubted benefits of micro services and Kubernetes in streamlining the work of enterprise systems, there is a number of prospects to research and development. Future work may consider the following:

1. Microservices Security: Because microservices architecture implies various services that can be deployed separately, it is a complicated issue how to ensure secure communication and data protection between various services. The next generation of study can be devoted to the development of effective security solutions to microservices such as identity and access control, secure communication, and data encryption policies.
2. Advanced Monitoring and Analytics: Monitoring tools, such as Prometheus and Grafana may be used to monitor the performance of microservices, however, more sophisticated analytics and AI-based monitoring systems can be created to anticipate and prevent possible problems before they affect the performance of the system.
3. Service Mesh Integration: It would be interesting to explore the use of service mesh such as Istio in the context of improving microservices communication, load balancing, and resiliency by adding more functionalities that service meshes can introduce such as traffic routing, observability, and better security.
4. Migration Strategies in Complex Systems: Future studies on the best practices and techniques in migrating large and complex enterprise systems with numerous interdependencies would be welcome to enable organizations overcome the difficulties of a gradual migration process without interrupting current activities.

Such work directions will still improve and streamline the cloud-native designs of the enterprise systems, so that they are resilient, safe, and are responsive to the new technological waves.

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