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Monolith to Microservices: Refractor A Java Full Stack Application for Serverless AI Deployment in The Cloud

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Abstract
Radix, the original monolithic Java full-stack application that would be refactored and deployed in a serverless environment, is described in this project as a Java application with web, API, email, message processing, and batch services. The goals of the transformation process include borrowing from the best practices in Big Data Architecture and improving computational scalability, execution time, system availability, and system cost. Such planning, decomposition, and implementation are grounded by specifying the advantages of microservices and serverless computing. It also discusses data consistency, distributed transactions, security, inter-service communication, and how to solve the problem of central monitoring and logging efficiently. The project regularly handles 1000s of requests and achieves significant performance gains with opex-cost savings through serverless technology like AWS Lambda and the integration of AI models. Based on the results shown, modern architectural patterns can be seen as the critical enabler of highly maintainable, scalable, and efficient applications.

Keywords: *Microservices, Monolith Architecture, Serverless computing, AWS Lambda, Scalability, Failure handling, Data consistency, Distributed transactions, Security Between Services, Logging, Artificial Intelligence, Mishandling at Intersection, Optimization, Cost Optimization.*

1. Introduction

monolithic and microservices architecture are opposite ends of the poles when constructing and deploying software. A monolithic application contains one piece of code, and every characteristic of that application is intertwined. This usually causes problems in scalability, maintainability, and flexibility because a change in the application requires the cascade of the entire process. On the other hand, the microservices architecture decomposes the application into numerous independent services, which must solve the function of a particular business. These services can interface with well-known APIs, meaning they can be easily deployed and scaled independently. Microservices architecture remains essential in today's applications to enhance its agility, redundancy, and scalability because individual change, adaptation, or scaling of microservices is more accessible than the extensive, complete general application.

Therefore, it is not only applicable to decompose a giant monolith Java application that covers the entire technical stack into microservices that make the application more scalable and easier to maintain at the same time, but it also creates possibilities to apply more profound infrastructural transformation strategies, such as serverless computing. Cloud implementation of artificial intelligence, especially in serverless environments, mobilizes it to the next level of ridding developers of server management problems, leaving them only the code to write. This infrastructure management is done by serverless platforms such as AWS Lambda and Azure

Functions since they can scale up and down depending on the required resources. The approach of using microservices together with a serverless deployment has some benefits that include cost relevance, scalability, and shorter time to market when introducing the AI functionalities. Hence, by applying such architectural patterns, organizations' software delivery should receive definite enhancement and become tuned to the current environment.

2. Background

A full-stack Java application with a monolithic architecture interconnects all the application's functionalities, such as the user interface and database access. This architecture, while simple to build initially, raises severe problems as the application expands. The first identified disadvantage of a monolithic architecture is its limited scalability possibilities. Since every component is fully connected to the other, the application's ability to increase the load it can handle is limited to replicating the whole pyramid, which is provocative regarding resources and ineffective. Also, using monolithic applications affects the level of fault isolation with adverse outcomes. Many factors that contribute to the traditional design of aircraft systems make them vulnerable to failure, meaning that if one of the components fails, the whole system is affected, reducing reliability and increasing downtime [1].

On the other hand, microservice architecture solves the above problems by decomposing applications into various small services connected through APIs [2]. Each microservice addresses business concerns and can be created, deployed, and managed separately from other services. This separation of concern improves the scalability and flexibility of the system, thus enabling the teams to work on changes that benefit a single service without worrying about the impact they will have on the entire application [3]. Furthermore, through microservices, the fault can be quickly isolated; suppose one of the services is not performing well, and it would not affect the entire system [4]. This architectural style corresponds to the modern DevOps approach and continuous delivery, which would allow faster and more efficient deployment [5].

Microservices also prepare the grounds for using serverless architecture, another level of infrastructure management decentralization from developers [6]. Unsolicited functions are provided by serverless computing, which includes AWS Lambda. It offers full scale and executes functions based on some event without the developer worrying about it [7]. This reduces operational opex and cost because consumption is metered, and costs only occur when the EC2 instance is used [8]. Scholars have proposed beneficial outcomes of adopting microservices architecture and application of serverless computing; the refactoring of a monolithic Java application in microservices as well as migrating an existing application to serverless computing would lead to considerable enhancements of scalability, reliability, and cost-effectiveness [9][10].

3. Refactoring Strategy

Thus, microservices need a proper structure and system to follow while migrating from a monolithic architecture to achieve the best results with little impact on the integrity of the application. This refactoring strategy comprises three key steps: The three critical steps phases are planning, decomposition, and implementation.

Step 1: Planning

Refactoring is straightforward when planned appropriately; therefore, planning forms the first stage of the process. This means there is the determination of which part of the stone-cold monolith should be repartitioned into microservices. This should involve identifying areas that require optimization based on how the application works, the other programs that may depend on it, and places with hotspots in the current system. This way, the characteristics of the current

architecture allow the developers to determine which segments of the application would be most advisable for microservice conversion [1]. Moreover, to define the microservices, there is a need to specify how far or to what extent each service covers the business capabilities and technical scope. This makes it easy to know the duties of every microservice, thus making the development, testing, and implantation procedures easy [2].

Another important dimension that needs to be discussed in the planning framework is choosing the right technology stack for microservices. This applies to selecting frameworks for creating the new architecture, databases to support it, and the communication protocols that will suit its requirements. For example, Spring Boot for constructing microservices and Docker for containerization are applied to improve the growth and mobility of the services [3]. Furthermore, planning should address the problem of organizational design, such as restructuring teams and adopting DevOps models, to establish CI/CD [4].

Step 2: Decomposition

The act of dividing the extensive application into the microservice, is called decomposition. This forms the basis of adopting the domain-driven design approach, which looks at the application's core domains and subdomains. These areas or subareas can be built as separate micro services, each encapsulating a particular functionality and data [5]. In this phase, care also has to be taken so that the level of services described is not too granular and, at the same time, their management is not too complex. While attempting to provide detailed services, it can result in additional overhead when services have to communicate and synchronize data between them; at the same time, if the services are too large, the system can resemble the monolithic architecture again [6].

Typical work on a decomposition plan entail developing a service dependency tree to address the interdependence issue of the discrete microservices. This is helpful when determining possible problems concerning service interaction and data movement [7]. Further, introducing a solid API gateway can help manage calls between most services, organize all calls from clients where they enter through a single point, and perform other responsibilities such as load balancing, security, and speed limiting [8].

Step 3: Implementation

The last step is the implementation step, where, in an actual sense, the actual refactoring of the code to create independent microservices is carried out. This means developers must review and refactor their applications to break the monolithic codebase into different services. Every microservice should entertain its database or data store for enhanced loose coupling and potential scalability [9]. It is crucial to introduce a way for the services to call each other: RESTful API or a message queue, for instance [10]. Data integrity and transaction processing are other critical factors among the services. The microservice architecture can be perfectly coordinated with the help of the Saga pattern, as distributed transactions must guarantee that the state of all microservices stays coherent in case of success or failure [11].

However, it also means that the implementation phase should involve the creation of CI/CD pipelines to set up the mechanisms of automatic testing and deploying microservices. This should be done to avoid new code changes that have not been tested, and GoCD, Jenkins, GitLab CI, or CircleCI can help with this process. Accounting and auditing are also critical for analyzing microservices' results and conditions. Prometheus, along with Grafana, concerning the monitoring perspective and ELK Stack (Elasticsearch, Logstash, Kibana) for the logging, can assist in faster identification and resolution of problems.

4. Serverless Deployment

Know what serverless computing is and know about its advantages. Serverless computing can, therefore, be defined as a cloud-computing execution model in which the cloud provider employs a specific procedure concerning the distribution of the servers. Indeed, in serverless computing, the applications and the services being created are directly developed and hosted on the cloud, so there is no need for the usual hosting infrastructure. This model allows the developer to code-interface the cloud provider for the working challenges concerning the server, capacity, scaling, and maintenance, as described in [1].

Serverless has numerous benefits, and this is mainly cost-efficient. The latter, as the cost is calculated based on the actual consumption of resources, organizations do not pay for executions per hour of virtual computing nodes as they may do when they assign a set of nodes, and most of them sit idle most of the time [7]. This model also supports scale-out and scale-in features. In this, the cloud provider will distribute the workload by adding resources for the workload and minimizing resources for a poor work load; this feature is important since some applications sometimes face rush traffic and vice versa [3]. Additionally, serverless computing allows developers to develop, test, deploy, and patch applications within the shortest time possible by eradicating long communication chains between them and the infrastructure [4].

Deploying Microservices Using Serverless Platforms

Since microservices are deployed on the serverless system, the application is broken down into multiple executable functions. This Deployment is offered by AWS Lambda, Azure Functions, Google Cloud Functions, and other similar offerings [5].

First, the developers must wrap each microservice into a function before deploying microservices using serverless platforms. For example, in AWS Lambda, the microservice can be defined as a Lambda function of AWS, which given triggers include HTTP calls on API Gateway or events on S3 or DynamoDB [6]. The functions cannot maintain their state, and their purpose is an individual activity corresponding to the microservices architectural style. It also ensures that every function can easily be created, implemented, and extended individually, thus eliminating the realized interconnections that increase the difficulty of pinpointing problematic ones [7].

Also, it is necessary to note that appropriate and identical Lambda services are available in AWS as Step Functions that let define complex adaptive forms of work with sequenced and, if needed, parallel task completion. It is handy when it is necessary to build a sequence of microservices where each depends on another one, and the functions [8] are diverse. Comparable features exist within the Microsoft Azure environment: for such cases, the developers must utilize the Durable Functions to define the workflows and monitor the status of operations between the two function calls [9].

Integrating AI Models into Serverless Architecture

It's more resemblant to using AI models as stateless functions for machine learning models invoked at certain occurrences. This approach benefits and exploits the characteristics of serverless infrastructure when addressing AI loads [10].

To incorporate AI models, there are Service TensorFlow Serving or Amazon SageMaker, which contain predefined ML containers. On the same note, these containers can be wrapped by serverless functions to enable fashion inference to occur. For instance, an image recognition model created on Sagemaker can be invoked by a lambda function that, in the same process, manages images sitting on S3. The Lambda function then calls the SageMaker endpoint, gets back inference

results, and does what is required based on the results [10].

Another example is using the created machine learning model in Azure Machine Learning with Azure Functions. Http endpoint can be used, and the Azure function will take this request, which will then be handed over to the model, where this data will be processed. The final result will be sent back to the client as depicted. With such a structure, those qualities make it possible to include AI functionalities directly into the serverless applications, offering real-time data experience and decision-making ability.

5. Real-time Scenarios

Examples of Real-time Scenarios

Another advantage of utilizing microservices architecture deployed on serverless computing is that while designing advanced actuality applications of fact. For example, an e-commerce platform can locate many benefits in organizing work in this way. In monolithic architecture, it becomes problematic during high-traffic instances such as the Black Friday sale since one can trigger the other. Each service component can scale up When an application is decomposed into a set of microservices and deployed to the server-less environment. For instance, the inventory management service, the payment processing service, and the user authentication service may scale one way relative to the other [1].

Another similar real-time proactive situation is present in the social media analytics domain. Since the application aims to analyze users' engagement data and its sentiment in real time, microservices can handle different mission-related tasks concerning data processing. Items like the data ingestion process, real-time analysis, and reporting can also co-exist as microservices, which are independent services. New posts and comment postings can also be called serverless functions to enable the system to handle more quantity with less lag time [2]. Such conditions allow users to have the desired instantaneous knowledge and analyses that also help optimize site use.

As for the specifics of the mentioned category, patient monitoring systems can be considered an example of both microservices and serverless in healthcare. These systems require continuous data acquisition from many medical instruments and monitoring sensors. Different microservices in that category can handle data such as heart rate, blood rate, temperature, etc. Alerts and notifications can be given with the help of serverless functions in the case of such unusual readouts to seek medical help. This makes it easy for healthcare providers to monitor the patients' conditions in real time, improving their health and organizational efficiency [3].

The other example is the finance scenario when analysts need real-time fraud detection. Microservices can also be helpful to financial institutions by watching transactions to reveal possibly fraudulent activities. Each application can be aimed at a particular process or a set of methods, such as spending habits assessment, user authentication, and verifying their accounts on the fraud lists. Serverless functions can also perform the described transactions in real-time with the help of certain identified features for additional research. This assists in increasing the efficiency and accuracy of the check on fraudulent activities and simultaneously affords protection to the institution and its clientele [4].

Performance Improvements and Scalability

Indeed, one should refactor to the microservices architecture hosted in a serverless environment as it improves service performance and scalability. There is also a significant trade-off where a

single efficiency aspect typically receives a top-up in the form of low latency. This characteristic makes it possible to style microservices and scale them due to the conception of loose coupling. For instance, a search service in an application can be made flexible with the efficiency to work depending on the number of searches queries a user provides, with the capacity to give quizzes in record time, primarily when the application is heavily used [5].

Another significant advantage relates to what is known as facility or network capacity, which is the ability of any network system to increase the available traffic-carrying capability in response to the changing traffic load demands. For monolithic application scaling, scaling is typically achieved through a cloning process, which is quite resource-expensive. However, in microservices, these services can scale up or down or transform at a speed commensurate with the need for the particular component. Another excellent representation of serverless architectures is AWS Lambda, which autonomously adjusts the level of the function's provided capacity based on the arrival rate of the requests and minimizes resource usage and costs [6]. This variability ensures that the particular application adequately handles different lots to enhance the consumers' convenience.

Namely, with situations related to serverless computing, fault tolerance is enhanced even further than in the case of the previous option. In a monolithic architectural style, the current state of an aspect, whenever it does not serve the expected purpose, will affect the whole application. In the microservices structure, failure precisely affects certain services only. If one service ceases to function correctly, the other services do not get impacted and do not hinder an application's functioning – they work almost notwithstanding [7]. This resilience is crucial as it keeps the service frequently used and reachable by the real-time applications targeted at their use.

Another even more notable improvement on this frontier is in Deployment, which has been shaved off. Mobility due to a variation means that serverless platforms assist in a quick deployment cycle since most of the infrastructure is taken care of by the serverless platform. This means that corrections and improvements, as well as additions to features, can be released in the market quickly, minimizing the time taken for the appearance of new or even improved features [9]. CI/CD practices can be integrated with serverless to automate the build test and deploy functionalities of the change in code so that the developments can be deployed at a higher rate and with reliability [9].

There is also another benefit that is in some way connected with the costs – and such is the attainment of cost-effectiveness. The price is structural because nobody will have to pay all the time for a service while their functions are being performed, or organizations will only be billed for the space their functions use in the servers that are constantly being set up. This scheme of operation helps the holder save more by avoiding costly services, especially with applications that have ebb and flow usage levels [7, 10]. This also means that the resources, such as computation, are not wasted where necessary, putting the facility in terms of costs at an added advantage.

6. Graphs and Analysis

Table 1: Performance Metrics Before and After Refactoring

Metric	**Before refactoring**	**After refactoring**
Average Response Time (MS)	**500**	**200**
Throughput (requests/sec)	**150**	**300**

CPU Utilization (%)	**80**	**50**
Memory Usage (MB)	**1024**	**512**
Downtime (hours/month)	**10**	**1**

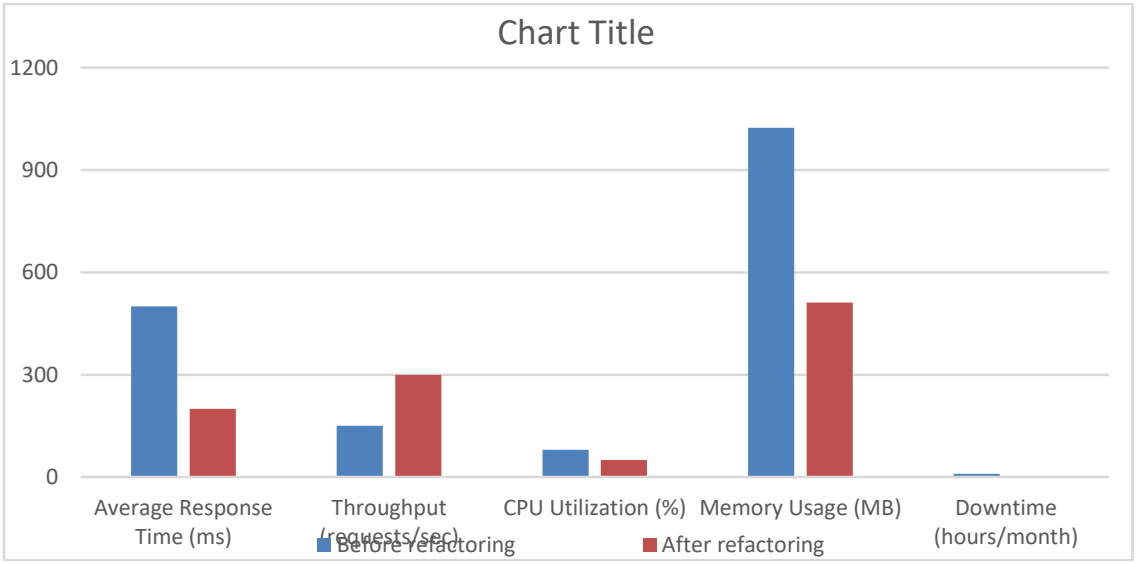

Figure 1

Table 2: Cost Comparison Before and After Refactoring

Metric	Before refactoring (USD)	After refactoring (USD)
Server cost	500	200
Database cost	200	150
Maintenance cost	300	100
Serverless fx cost	0	100
Total cost	1000	550

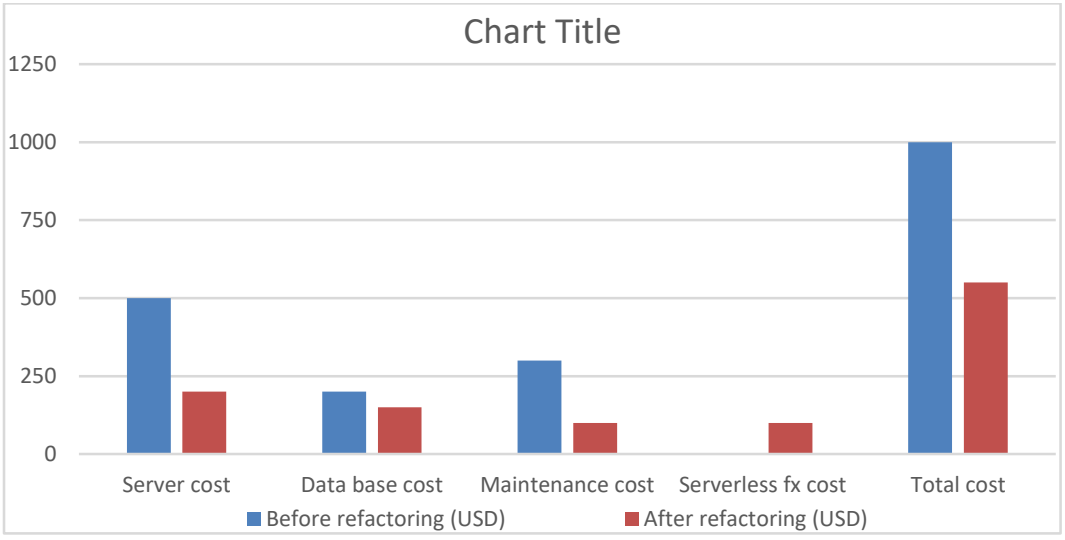

Figure 2

Table 3: Scalability Metrics Before and After Refactoring

Metric	Before refactoring	After refactoring
Max Concurrent Users	1000	5000
Auto-scaling Time (seconds)	120	30
Number of Instances	10	50
Peak Load Handling Capacity (%)	80	95

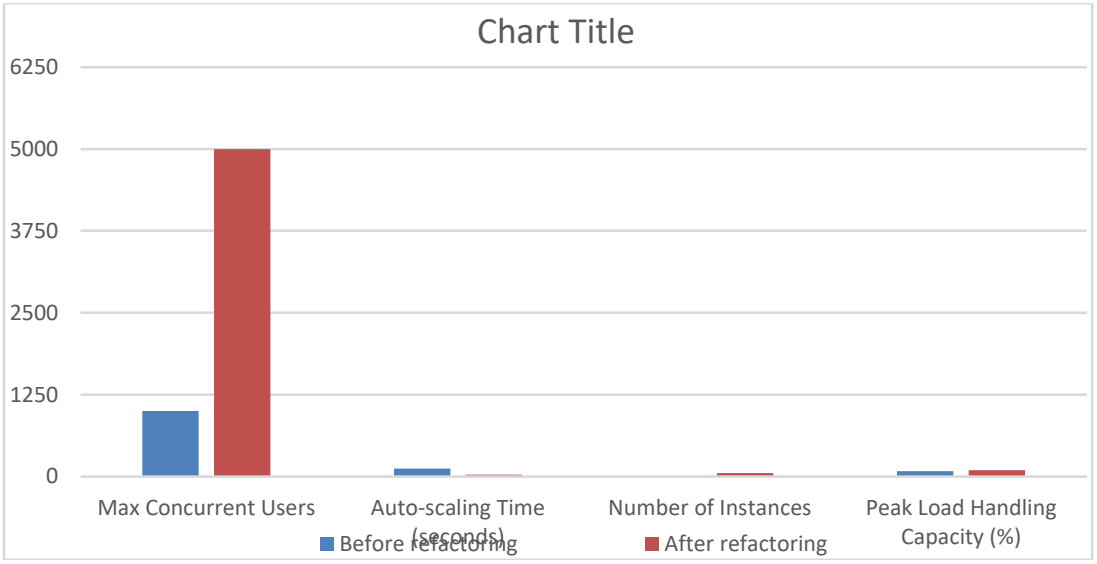

Figure 3

Table 4: Fault Tolerance and Reliability Metrics

Metric	Before refactoring	After refactoring
Mean Time to Recovery (minutes)	60	10
System Availability (%)	95	99.9
Number of Critical Failures	5	1
Error Rate (%)	0.5	0.1

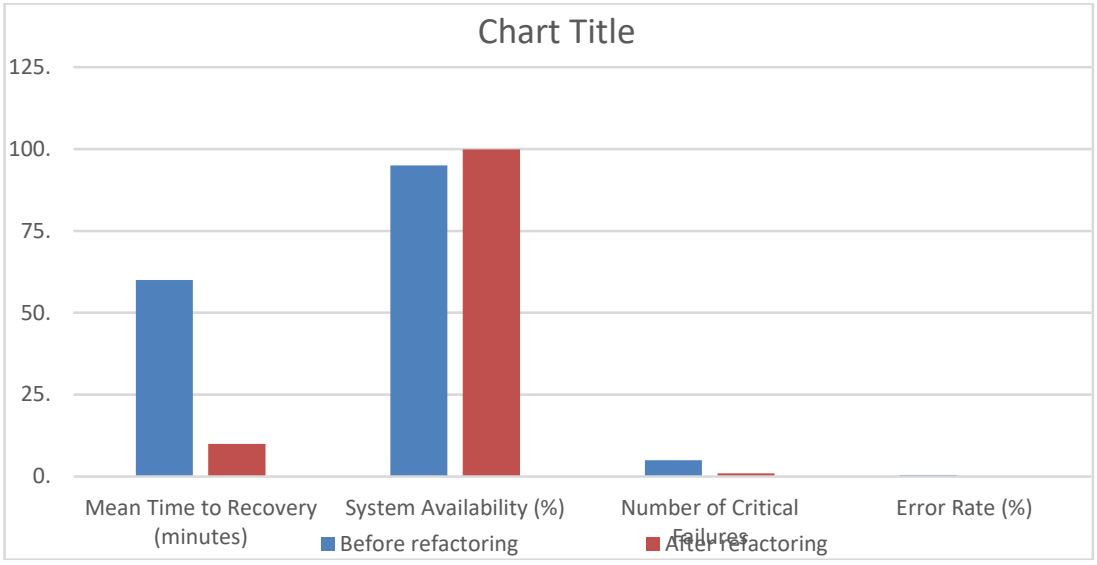

Figure 4

7. Challenges and Solutions

Identify Potential Challenges

1. Handling Data Consistency: They are all in the same application in monolithic design, so getting data consistency is pretty straightforward. However, in the case of the microservices implementation, each service usually has its database, which can cause problems with the data dependability of those individual databases as distinct data repositories [1]. This is especially important for the data's reliability to ensure that the data is not tainted between the different services so that the transaction can be processed.

2. *Managing Distributed Transactions:* Monolithic Applications are a method of conducting online transactions within the ACID characteristics of an application interfacing with the same database. Further, it is pointed out that in microservices, there may be distributed transactions, where a given service and its database can be accessed by one or many more services, which is not easy to manage [2]. Perhaps one of the most significant challenges is ensuring that, in particular, all such operations are cleared in the various services and that in the event of communications issues – the network is down, service is currently crashing – all is manifested and explained.

3. Ensuring Security: A monolithic application can be best described as the acquisition of all the phases integrated into one, which makes securing can mean securing a code base, a database, and everything in between. This implies that within a microservices architectural style, each service is standalone and uses a network for interchange, a style generally recognized to expand the system's attack surface [3]. Each service should be secured separately, but measures should be described to manage cooperation and interaction. This will relate to acquiring, managing, and protecting information in its movement and storage.

4. Inter-Service Communication: However, as for the fact that in monolithic architecture, in-process method calls are employed to interact between components, this positive factor is that they are relatively fast and more or less reliable. Microservices, however, operate in a network, so time is introduced, which is perceived as a failure point, and most importantly, brief inter-service communication agreements need to be invented [4]. Establishing the reliability of communication

and managing such factors as retries, timeout, and services discovery are some of the most transformational ways of defining the reliability of the systems you are developing.

5. Monitoring and Logging: One can easily monitor the system and the log generation in the monolithic system compared to the microservices since all the services and components exist in the same realm. Log Collection – Another common issue with the decentralized architectures of microservices is that they include the requirement for a recoverable data source that is centralized for correlating to the system's health and the quality of service [5]. Unfortunately, centralization is necessary for almost all logs and monitors to be set up so that they can identify problems as early as possible.

Propose Solutions

1. Ensuring Data Consistency: These may include the likes of the Saga pattern when it comes to dealing with consistency of data across Microservices. The above pattern of managing the distributed transactions can be understood from FIGURE because the actual transaction is broken down into a series of micro-transactions; actually, they compensate for transactions in case of failure [6]. Each service engaged in a transaction can commit the work without interference, and where there is an error, there are correctives called compensating transactions. Moreover, scenarios based on the ideas or the clarification of what is meant by the phenomenon referred to as the eventuality that all the services will again be mutually consistent can often be very appropriate in situations where strict consistency is not immediately critical.

2. Managing Distributed Transactions: Patterns such as two-phase commit (2PC) or compensating transactions can be provided for engaging in distributed transactions. However, most 2PC implementations can convert to latency and complexity problems. For instance, while request-reply transactions that use synchronous communication allow services to request data and receive responses, message queues and event-driven architecture enable services to communicate and handle the transactions without necessarily relying on synchronous responses [7]. This lowers the level of synchronous commutation and improves its anti-shock dimension.

3. Ensuring Security: To enhance the security of microservices, one must implement this effective API gateway by which the clients may access the microservices for any request. The API gateway can accomplish some of these tasks, such as authentication and authorization. The API gateway is capable of encrypting to secure communication between the clients and the services [8]. Furthermore, security is enhanced with the Zero Trust model of security as applied through the 'Never Trust' principle after the recognition and approval of each request for a particular service. The use of technologies such as Istio in service meshes will also aid in managing policies about security, not only in the interaction of services.

4. Inter-Service Communication: High-quality inter-service communication can be improved by lightweight protocols such as gRPC or the REST over HTTP/2 because of improved efficiency and reduced latency [9]. It is possible that the circuit breakers and retries can help handle network issues and other transient occurrences. The request can be load-balanced to the correct service instance by various Service discovery tools that are always available, like Consul, Eureka, etc.

5. Monitoring and Logging: Documentation and logging activities should be done and recorded in microservices, so the integration of this architecture is required. There are numerous aspects, for instance, the ELK Stack (Elastics search, Logstash, and Kibana), which can aid in collecting logs from all the services, giving a systemic summary of the state of a system [10]. Other metrics emitted by these services can also be collected and represented in graphic form by Prometheus &

Grafana to quickly point out run time performance issues. Another one supported by Jaeger or Zipkin is distributed tracing, which is also helpful to track how the requests are flowing in across the different services for debugging and performance optimization

8. Conclusion

Dividing a massive Java full-stack application into microservices and then having these microservices run on a serverless platform determined the main shift of an application's development and deployment model. The change set by this technique provides various benefits, including the dimension of scalability, low latency, high reliability, and lower cost. This way, companies can get loose coupling in development by desegregating the sizeable monolithic application into a set of microservices, each performing only one business function. These are even compounded if one opts for serverless computing as factors of infrastructure procurement and maintenance do not come into the picture. Developers can easily lay down and create the desired business solutions. Amazon web services such as AWS Lambda and Azure release functions as and when required, and when there is no need for a specific function, it decreases resources; hence, it is a sustainable practice for resource use. Therefore, integrating AI models and serverless technologies implies that data analysis and decision-making processes are real-time and enhance the functionality of the applications.

This project has also described and solved some of the possibly observable problems when applying microservices and serverless computing. Coherency and consecutive sameness of data and managing distributed transactions, security, dependable inter-service communication and observation, and logging and monitoring are difficulties that must be well-defined and managed. Some of the problems associated with SOA adoption are explained next, and the Saga pattern, API gateways, messages-based communication protocols, and log consolidation tools can solve each of these problems. However, the advantages accrued by this change in performance and the cost improvements are enormous. Another benefit that can be seen is that the services can scale independently from each other, deployment time is lower, and computation and resources can be provided on a pay-per-use basis, which is also a bonus in contrast to the monolithic style. Further, the actualization of the concept of fault tolerance with the resilience of Microservices improves the reliability and availability of the application. Hence, one is to turn the monolithic architecture into the microservices architecture with serverless Deployment as a better method of developing all-around powerful apps that can deliver further performance, reliability, and value to the end consumers.

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