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Exploring event-driven architecture in microservices- patterns, pitfalls and best practices

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Abstract

Event-driven architecture (EDA) solves architectural problems when an application responds to events, which are actual occurrences or changes in status that can happen quickly, can be large-scale, and require vast flexibility and elasticity. It proves highly useful in microservices, which consist of components that operate autonomously and use asynchronous messaging to work more effectively and efficiently. In a microservices architecture, EDA stands for Event Driven Architecture, which helps to achieve loose coupling between the services so that many components of the system work in parallel, thus minimizing the chances of bottleneck formation in the system. This paper aims to present the potential and realization of EDA integration with microservices and discuss the advantages of microservices, such as scalability, flexibility, and fault tolerance ability. Nevertheless, it also solves problems such as whether distributed services are homogeneous, debugging difficulties often occurring, and even a proposal for event tracing. This paper aims to dissect certain patterns like publish-subscribe, event sourcing, and the saga pattern, as well as the best practices when it comes to implementation, to ensure that the complexity of handling events is adequately handled. It also looks at EDA's challenges, especially in handling service conversations and guaranteeing consistent finality. Therefore, this paper seeks to expose organizations to EDA's design principles and patterns. The insight gained could help them design systems that reflect the dynamism and resilience required for today's distributed environment. By understanding the strengths of EDA and its weaknesses, organizations will be able to identify best practices for implementing this architecture to enhance the quality, opacity, and elasticity of their microservices-based applications.

Keywords: Event-Driven Architecture (EDA); Microservices; Asynchronous Communication; Event Sourcing; Eventual Consistency; Event Brokers; Scalability; Distributed Systems

1. Introduction

Event-driven architecture (EDA) is an architectural style and implementation of software services design that involves the generation, discovery, and processing of events. In this approach, an event means a major event in a system, which can be a user event, a system event, or a data event. An event as such is normally a message or signal which, in return, prompts a response from a component or even the entire system. EDA helps components process these events concurrently, which means that the components will not have to wait on each other as they function. This is quite different from other, more conventional asynchronous communication models whereby systems have a single authority point for communication and control. In contemporary software design, especially with the introduction of microservices architecture, EDA has proven popular because the systems involved are complex and ever-evolving. Microservices divide a large-scale monolith application into a set of fine-grained, self-contained services that communicate with each other through a network. This paper reveals that the integration of microservices and EDA is highly beneficial in developing both robust and elastic systems. This means that individual microservices can respond to events as they happen in real-time, making them more scalable and responsive.

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EDA is critical in microservices, and no single microservices architecture can operate without considering EDA. Another fundamental aspect of microservice architecture is that the services can be implemented in isolation: it is possible to work on a certain service without affecting the others. In a distributed system, the only way to achieve live communication and avoid services waiting for one another is to use events and have all communication asynchronous. Event-driven services are loosely coupled services that can pass asynchronous messages to another service and do not expect a response immediately. This leads to a more efficient system where there is less of a risk of bottlenecking and where response times and consequent scalability can be improved. Furthermore, EDA does not require services to be tightly synchronized and is flexible for introducing new features and dealing with failures. As a growing number of organizations adopt EDA, this approach also poses some great challenges as well. Ideally, distributed systems strive to be unanimous in their behavior, and the activity of any node should be transparent to other nodes; hence, the first challenge is consistency. Interprocess synchronization aspects are less of an issue in a traditional, closely coupled system because all the components are tightly bound together. In an event-driven system, though all these services work independently, ensuring a setup where all the data is at the same time consistent across all these services is a real challenge when dealing with Eventual Consistency as well as having more complex mechanisms of handling the event delivery, ordering, and retries. These aspects can become much more difficult to manage as the number of services grows, so it is crucial to invest in reliable event-driven interaction tools and patterns.

Another challenge is debugging and tracing the events that occur within a distributed system. Unlikely in traditional systems where one could track the flow of data and control, EA is made of quite a few parts, most of which work with events. This can complicate an understanding of the nature of a problem since events transition through several services before culminating in a failure. Thus, distributed tracing and sophisticated monitoring are the crucial tools required to maintain the observability and stability of the system. Nevertheless, the benefits of EDA surpass the difficulties by far, especially for organizations that wish to devise fashion large-scale systems in order to respond to events in real-time. The adaptability and the ability to make decisions in short time intervals offered by EDA make it suitable for systems that need fast integration and constant availability.

This paper aims to define an event-driven architecture for microservices and discuss its strengths as well as its weaknesses. Explaining design patterns, implementation methodologies, and best practices of EDA in the microservices architecture will be the focus of this paper. Through a critical analysis of EDA and its principles, organizations will be in a position to determine how the EDA integration can deliver the flexibility, reliability, and scalability that is sought in the current software development.

2. Fundamentals of Event-Driven Architecture

2.1. Definition and Principles of EDA

Event-driven architecture (EDA), on the other hand, is a software design pattern whereby the components of a system run through producing and consuming events. In this context, an event can be described as an occurrence which reflects a significant change or an update of the status of a system in the context of other system components. These events cause processes or actions that will maintain the system being responsive, scalable, and flexible. EDA allows for a reactive, loosely coupled architecture for building systems that are designed for asynchronous communication, which makes it applicable in large-scale distributed systems such as microservices (Liu et al., 2020).

The key concept concerning EDA is the fact that component dependencies are to be minimal or weakly coupled. Event producers who create the events do not have to know about the event consumers who will use that event. Likewise, the consumers and actors within the events sphere are autonomous, which results in high flexibility and scalability regarding services (Tufano et al., 2019). This separation of event production and consumption is another positive quality of the system. It allows for adapting to the development of new types of events separately from the adaptation of the events themselves.

The other general protocol of EDA is that the participants' communication can occur independently of each other. While synchronous conceptual models declare how services expect responses from others, event-driven models state how the services can emit events and do not have to wait for a response. This enhances the steadiness of the system, eliminates possibilities of bottleneck incidences, and is ideal in environments that require high availability and failure reorganization (Ward & Duffy, 2017). Moreover, EDA utilizes eventual consistency, which means that all the defined services will be consistent in the long run, even if the changes to these services occur in parallel. EDA also facilitates event-based processes, where services work based on events instead of a fixed set of activities. These processes can include decentralized componentized design, which can result in independent and free system design (Cheng et al., 2019). Altogether, all these principles enhance EDA, making it suitable for enabling organizations to cope with dynamic and distributed systems and, more importantly, with flexibility and strength.

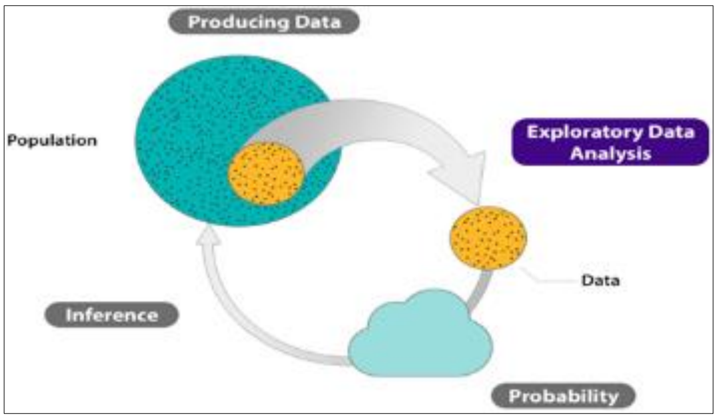

Figure 1 Principles for Effective Exploratory Data Analysis

2.2. Core Components of EDA

Event-driven architecture has five significant elements: events, producers, consumers, channels, and brokers. It is essential to comprehend these aspects to apply EDA properly.

- **Events:** Events are central to the EDA process. An event reflects a change of state in a system to other components. For example, a payment processing system can produce an event when a transaction is done. Surprisingly, events traditionally should be minimal, having just enough information to notify the consumers of change and not more (Richards & Ford, 2018).
- **Event Producers:** These are elements or functionalities that produce events. Publishers record and broadcast specific events in the system, for example, when a user makes inputs or there is a change in data in the system. For instance, in an e-commerce application, an event producer may be a product inventory service, which informs that the number of items of a certain product has changed. The important characteristic of an event producer is that it does not have to know that it is producing the events that are going to be consumed by certain components (Tufano et al., 2019).
- **Event Consumers:** Event consumers are the services or components that are available to handle events. It responds to events by performing appropriate actions in accordance with the information enclosed in the events. For instance, whenever a payment confirmation event is received, the process of shipping the ordered item in an order fulfilment system may automatically be activated. Consumers, on the other hand, do not create the event but respond to it in some way or the other. The external autonomy between the producers and consumers is clear in EDA, since both components can work and grow without being influenced by each other's size (Tufano et al., 2019).

Table 1 Core Components of Event-Driven Architecture

Component	**Description**	**Example**
Events	Represents a state change within a system, providing relevant data to other components.	A payment confirmation event or inventory update event.
Event Producers	Components or services that generate events when specific occurrences are detected.	An inventory service emitting an event when stock levels change.
Event Consumers	Services or components that receive and process events by executing actions based on event data.	An order fulfillment system processing a payment confirmation event.
Event Channels	Pathways through which events are transmitted from producers to consumers.	Messaging queues, event buses, or stream processing platforms like Apache Kafka or RabbitMQ.
Event Brokers	Manage the distribution of events, ensuring delivery to appropriate consumers and supporting scaling.	Platforms like Kafka or AWS EventBridge handling event routing and advanced features like retries.

- **Event Channels:** These are the channels by which information flows from one user to the other or from producers to consumers. Another form is event channels, where events go through in order to help support the flow of communication. They can be accomplished using messaging queues, stream processing technologies, or event buses. This guarantees that the events get to the correct consumers without the Producers having a direct interaction with the Consumers (Dellaert, B. G. (2019; Richards & Ford, 2018). In a cloud-native architecture, these channels may be realized through applications such as Apache Kafka or RabbitMQ.
- **Event Brokers:** Industry refers to the intermediaries who organize the flow and exchange of events between the event producers and event consumers. These brokers make sure that the events are well delivered to the target consumers and also have event delivery assurances. Event brokers are important in the scaling of event-driven systems, as they allow various producers and consumers to transact with each other without having to be aware of each other's existence. Event brokers can also be more complex and are capable of things such as redelivery of failed delivery attempts, persistence and replay of events, and event ordering (Liu et al., 2020).

Taken together, these constituent parts help leverage the service separation process and empower the development of agile, scalable, and resilient systems. Event-driven communication is a concept that brings efficiency and structure to the way organizations are tackled, which can be described as more flexible and capable of embracing change.

3. Key Concepts in Event-Driven Microservices

Microservices based upon event-driven async architecture imply that services can work in parallel to each other and communicate using only events.

3.1. Asynchronous Communication and Service Decoupling

One of the primary characteristics of event-driven architectures that fit with asynchronous communication is that services send messages and do not expect a response before moving on to the next activity. This communication does not block the application and improves its performance and capacity to provide numerous services simultaneously. The fact that most services get decoupled in such architectures offers many benefits, including flexibility and the possibility of expanding or contracting the size of services. The independence of these systems means that they are easier to build and maintain since there is no constant demand to have all the services run in parallel. This communication style has problems, especially when managing progress on different services. Since many services are performed concurrently, the current state of a service is sometimes hard to identify, particularly if there is no state management in place. Furthermore, making the system's state consistent across all services is another burden of the intermediate layer. For example, while sending an event, the receiving service has no direct response. Thus, it becomes difficult to determine whether the event has been processed (Eger, 2020).

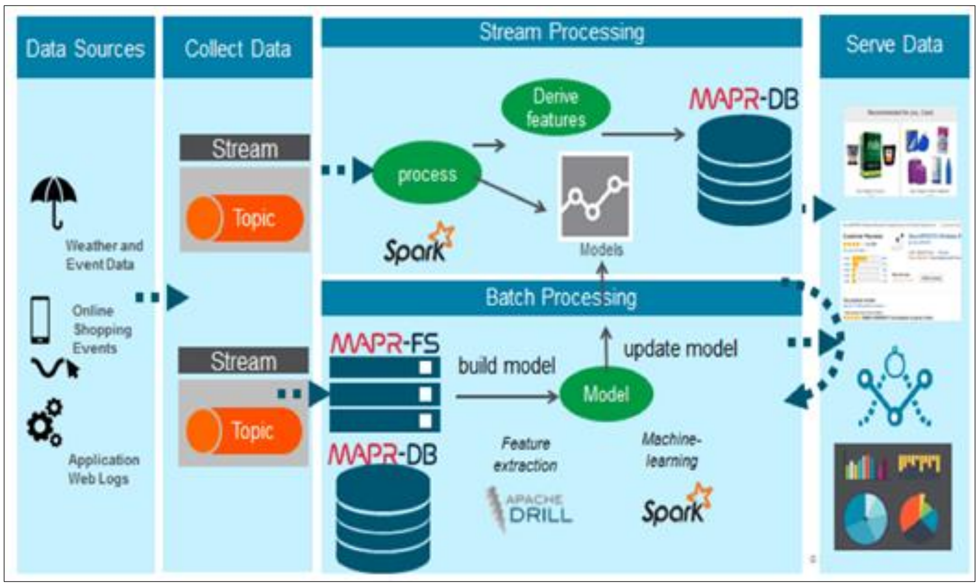

Figure 2 The Event Driven Microservices Solution Architecture

3.2. Eventual Consistency

Eventual consistency is an important phenomenon in distributed systems such as event-driven microservices. Event-driven systems are different from conventional systems that require consistency of all the services at that moment. It is postulated that all such services will eventually be in an event-based system. This is especially the case when data is duplicated in different services, and the system must guarantee that all the changes are eventually reflected across all those services (Brewer, 2020).

For scalability and fault tolerance, eventual consistency is highly valuable because it maintains services' freedom to operate non-synchronously. However, this means that some level of inconsistency can exist temporarily, and this causes problems when special operations that depend on data consistency are required. In particular, to address eventual consistency, the appropriate and strong mechanisms to resolve conflicts and reach synchronization are necessary (Vasic & Brkic, 2021).

3.3. Event Sourcing

In event sourcing, state changes are captured in an event format that describes the changes made to an application architecture. Such events are then recorded in an event log that acts as the system's reference point. In contrast to storing an application's state, event sourcing lets the system recreate the state by using event records (Ming & Wu, 2019). This pattern is valuable for systems where it is critical to record changes occurring in the environment.

There are also benefits from the point of view of scalability, as the system operates with a large amount of event information. It helps popularise CQRS (Command Query Responsibility Segregation) to separate reads and writes and make them work faster. However, attaining scalability is problematic because more events means a higher burden on systems to store or process them and ensure the event replay or the state reconstruction is correct and performed efficiently (Zhang, 2021).

3.4. Idempotency

It is a characteristic of an operation that will produce the same effect; however, often, it is applied to promote dependable and stable methods. In event-driven microservices, each received event message carries out the same operations due to the idempotent nature of the event messages. It is important for system reliability lest processing an event many times should confer an inconsistent result whenever it is processed (Koyuncu & Şahin, 2020).

Idempotency ensures that the execution of a request does not cause any harm, and the system will act the same way regardless of the failures that might have occurred. For instance, if a service informs the system of an event to update the status of an order, the system will need to ensure that repeated attempts to process the same event do not result in conflicting order status. This can be done by adding an ID that differentiates one event from another or applying the deduplication solution within the consumer service. Thus, even though idempotence is crucial for the correct work of the corresponding handlers, it complicates the design and work of event handlers (Ming & Wu, 2019).

3.5. Event Choreography

Event orchestration is a more concise approach to event processing whereby services handle events without a centralized coordinator. In this model, the different services send and receive events, and each service makes its own decision independently from the others according to the events with which it is delivered. This is dissimilar to orchestration, where the sequence of service interaction is held under the charge of a main component. The advantage of choreography is that it provides more flexibility and modularity compared to the orchestrator since services can vary and change over time and are executed at different times or paces without being coordinated by a specific orchestrator (Ming & Wu, 2019).

The challenge with choreography is in how event flows are orchestrated and ensuring that every event is done correctly. There is a lack of a single coordinating component; thus, it becomes hard to link up several services and ensure that the correct event is fired at the correct time. Furthermore, capturing the flow of events as services become more distributed can also be challenging, and we know that events may not always propagate as expected or may do so incorrectly (Eger, 2020). Although the event choreography provides modularity and fault tolerance, it is necessary to constantly design and control the problems of events and their organization.

4. Architectural Design Patterns for Event-Driven Microservices

Event-driven architecture (EDA) has emerged as the best way to design microservices systems that can scale, adapt well, and be robust. The key benefit that can be concluded when implementing EDA in microservices is the quality of the possible real-time communication between the services with a potentially low coupling level. This section focuses on different architectural patterns for event-driven microservices. It evaluates how these patterns can be combined with other architectures, how events are handled, and what specific patterns provide options for scalability and redundancy.

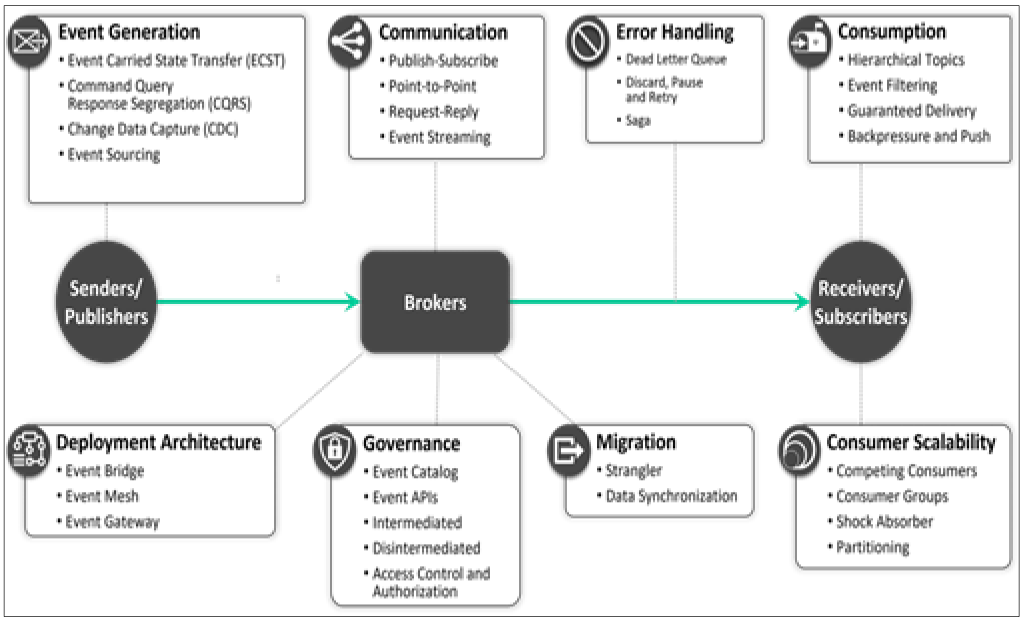

Figure 3 A Guide to Event-Driven Architecture Patterns

4.1. Overview of Architectural Patterns

Several architectural patterns are crucial in the architecture of EDA when implemented in the microservices environment. They describe how services communicate through events and let the system grow correctly.

4.1.1. Publish-Subscribe (Pub-Sub)

The publish-subscribe (Pub-Sub) pattern is one of the most widely used architectural patterns in event-driven systems. In this pattern, publishers put out events that different subscribers handle individually. Pub-Sub has a unique advantage in separating the producer of events from the consumers of those events. This allows for services to execute on their own rather than waiting for each before the next one, enhancing the system's expansiveness and efficiency (Liu et al., 2020). Pub-Sub is most suitable for use in situations where it is mandatory to publish events to subscribers, and immediate response is highly desirable.

4.1.2. Event Sourcing

Event sourcing is an architectural style that maintains an ever-growing list of events in the system. In contrast to other systems that save some entity's current state, event sourcing enables the system to rebuild the state for every point in time needed. This enhances the trace history of the system changes and debugging, auditing, and keeping the consistency of data across various services. Event sourcing guarantees that every state change of an entity is documented, which affords a detailed history of the problem area (Lewis & Fowler, 2020). However, this means that event versioning must be handled with great care to address this issue as the system grows.

4.1.3. Event Mesh

An event mesh is a focused layer that can be compared to the network layer in a physical network that passes and directs events across many services, potentially across regions or cloud providers. It also offers a good platform that helps to manage and disseminate events across the different geographical locations of microservices (Vasilenko et al., 2021). The event mesh pattern also works for point-to-point and Pub-Sub messaging communication, providing better reliability and fault tolerance for event-driven architecture. It assists with managing flow complications concerning events and ensures the delivery of events irrespective of network breakdowns.

4.1.4. Event-Carried State Transfer

Event-carried State Transfer (ECST) is an architectural pattern where an event carries all the information needed to describe a state change completely. This pattern delegates out of the target system's ability not to require that they query the producer system for more data. ECST makes handling events easier for the receiver, promulgating that the receiver has all the pertinent context they will need (Zimmermann et al., 2020). This is useful, especially in distributed systems where increased operational independence of each module enhances system scale and reliability.

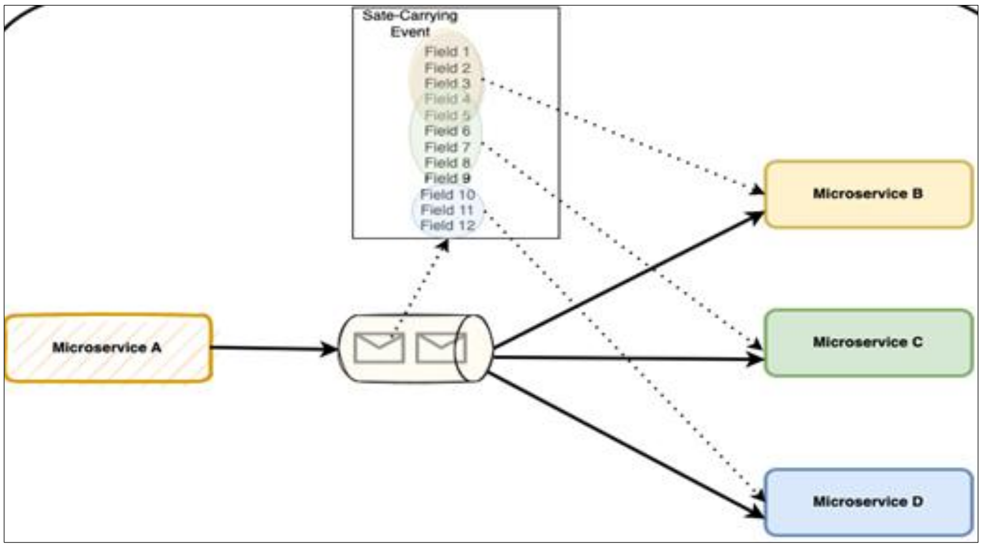

Figure 4 Event-Carried State Transfer Integration in Microservices

4.2. Integration with Other Architectures

EDA can be synchronised with other architectural styles, including microservices and serverless architectures. Microservices can be combined with EDA because it ensures asynchronous communication between microservices, thereby decreasing coupling and enabling system scalability. In microservices, each service is supposed to have independent deployability, and EDA gives the interaction interface that was requisite for decoupled services. Event-driven systems also follow Domain-Driven Design, particularly when events embody domain changes in a system. EDA helps to manage modular faulting and allows services to grow with scalability and no adverse effect on the whole system (Firouzi et al., 2018).

The nature of processing events in event-driven applications makes it suitable for serverless architectures where the capabilities of auto-scaling and execution are based on events for maximum efficiency. In serverless systems, microservices are implemented as stateless functions invoked by events. By unifying the serverless and event-driven models, services become stateful and reactive, maintaining the proportions in response to event volumes. The serverless functions' scalability and reduced cost characteristics make them a suitable companion to EDA in contemporary distributed systems (Kumar, 2019; Li et al., 2020).

4.3. Handling Event Ordering, Retries, and Dead-Letter Queues

As with the event-driven system, the sequence of their handling can often be decisive to the system's work regarding its correct and non-arbitrary operation. Quite fittingly, Event ordering guarantees that events are processed in a specific order, especially when such events stand for state transitions with dependencies. For instance, in a banking application, a withdrawal event should be processed before a deposit event to keep the right balance of financial probabilities.

Event retries are also another important factor. In distributed systems, it is sometimes possible that the event processing fails, and a retry is used to check that the events have not been lost. Event brokers such as Apache Kafka have integration features attached to events for retrying failed ones when message queues come with configurable time-to-lives (Bhatnagar et al., 2020). However, attempts have to be made with control so that there is no repetition of work or execution in the wrong sequence. Dead-letter queues (DLQs) allow for the dealing of events that fail to be processed multiple times. Some events are considered to be failed, and therefore, they are rerouted to DLQs for system administrators to assess the root problem. DLQs guarantee that the nature of the event-driven system does not fail and that no permanent loss of any crucial event occurs (Mishra & Verma, 2021).

4.4. Command Query Responsibility Segregation (CQRS)

The Command Query Responsibility Segregation refers to a pattern that divides data handling into reading and writing commands. For event-driven microservices, CQRS enhances the ability of systems to scale up due to the separation of the command side from the query side. The above pattern is especially helpful if the level of reading data is significantly higher than the writing level in the system's high-performance scenario.

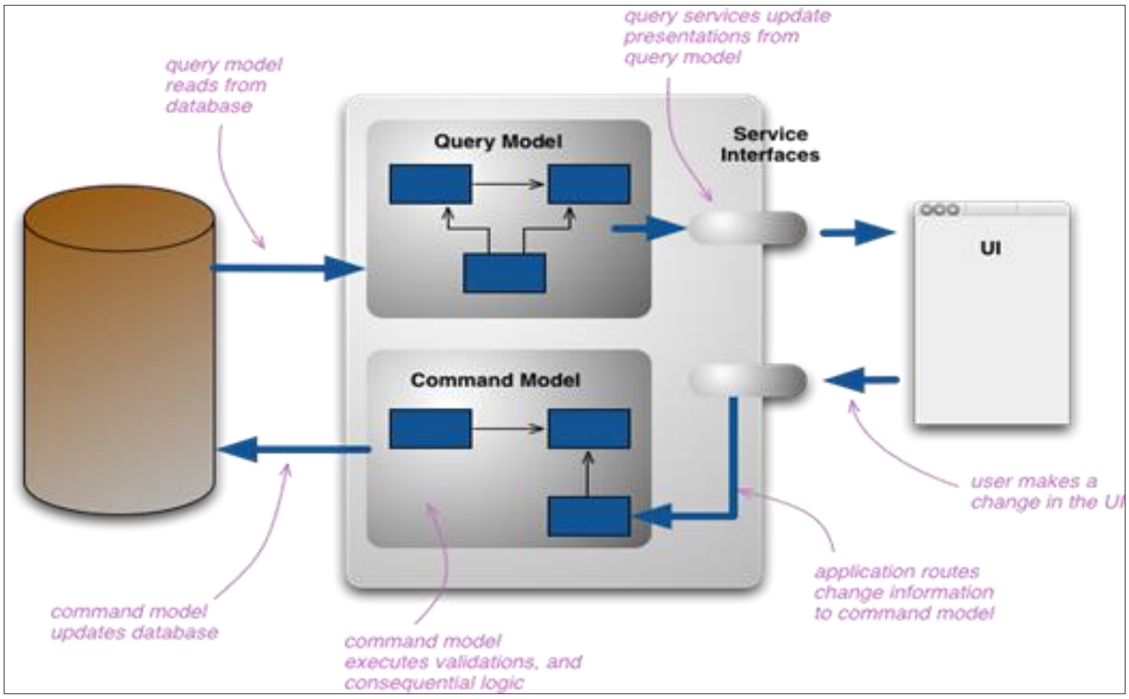
query model reads from database
query services update presentations from query model
Query Model
Service Interfaces
UI
Command Model
user makes a change in the UI
command model updates database
command model executes validations, and consequential logic
application routes change information to command model

Figure 5 An Overview of Command Query Responsibility Segregation (CQRS)

The advantage of using CQRS when implementing event-driven systems is that the load of Readers and Writers can be scaled independently. The event sourcing pattern can work using CQRS, where events are the primary record of both the command and query sides. In CQRS, microservices can manage many queries, and this does not affect the right side, which increases the ability to offer scalability and performance (Martin, 2020).

4.5. Saga Pattern

The Saga pattern is the base-level technique for dealing with extended transactions in a distributed environment. It is particularly useful in microservices architectures since transactions may be broken between several. Unlike the significant monolithic transaction often employed in long-running transactions, the Saga pattern decomposes a long business transaction into a series of short transactions based on events. The alternative approach here is to have each service execute its specific transaction tasks and push events to denote the new stage of the saga (Vasilenko et al., 2021).

In case of failure, sagas ensure that the system can be brought back to life by compensating for a particular transaction that failed. This is done through the compensation events, which reverse the light and sound of certain steps in this saga. The Saga pattern guarantees maximum system availability and smooth tracking of distributed transactions, which can recover from failures without constant centralized control (Vasilenko et al., 2021; Li et al., 2020).

5. Design and Implementation Aspects

It is crucial to consider the specific elements that earthquake the EDA design and implementational process to achieve positive outcomes such as scalability, reliability and efficiency in the distributed system. These aspects span from the event serialization and protocol choice, the event taxonomy, and the use of streaming platforms to effective data management and utilization.

5.1. Event Serialization and Protocols

Event serialization is central to the EDA process since it empowers the processes of transforming event data into a format fit to be transmitted between various services. Some popular serialization formats and communication protocols are JSON, Avro, Protobuf, and Kafka, all of which have unique benefits depending on the needs of a given system. JSON may be in text form and, therefore, readable by a human, but the language experiences criticism for slow processing and lack of built-in means of enforcing a schema. Avro and Protobuf offer a less verbose binary format, better performance, and the advantage of schema validation (Gonzalez et al., 2019).

Kafka, the most commonly used system in streaming architectures, employs a distributed publish-subscribe system that is well-suited to processing real-time streams of events. Kafka is highly available, has a high throughput, and has as low latency as is needed for most large-scale systems (Kreps et al., 2011). For its part, RabbitMQ and MQTT, using the publisher-subscriber model, contain message services with high availability and scalability relevant to the enterprise. Specifically, RabbitMQ provides advanced routing of messages with great attention paid to message delivery assurance (Vinoski, 2020), and MQTT is a protocol for future IoT devices that are not very powerful, so it supports a small payload (Hossain & Fotouhi, 2020). Another important protocol is gRPC, intended for high-efficiency and low-latency inter-process communication between microservices. It uses Protocol Buffers (Protobuf) for value serialization, which means efficiently handling and transferring data in high-density situations.

5.2. Event Taxonomy and Classification

Event taxonomy and classification are about sorting out the various forms of events so that they can be well managed within the system. Domain events, integration events, and system events can be seen as the three different event types in general, with each playing a specific role within architecture.

Domain events are major business actions or states that require changes in the business and generate valuable information or knowledge; for instance, a user purchases an item or makes a payment transaction. Business logic usually enjoys these events and elicits other domain events or processes within a system. Integration events enable communication between various services or systems by changing one domain from another. They encompass technical or infrastructure modifications, including server downtimes or system upgrades, mainly received by monitoring and operation solutions (Kuyoro & Olayemi, 2019). The correct identification and categorization of an event prevent it from being missed or produced where it is not needed, depending on its position in the system. Moreover, clearly defined taxonomy helps policy and scale since different teams in a big and geographically distributed organization may handle different events (Gonzalez et al., 2019).

5.3. Event Streaming Platforms

Event streaming technologies provide a means of dealing with the large volume of real-time events that are usually incorporated in an EDA. Frameworks like Apache Kafka, AWS Kinesis, and Azure Event Hubs are some of the most crucial components for processing, storing, and consuming events reliably and with the required level of scalability. Apache Kafka is an open-source distributed event streaming platform and remains one of the most popular technologies for consuming high throughput, fault-tolerant, scalable event streams. They also support real-time processing of events and consequently make it possible for event data to be consumed by several other services. It allows event replay, successful failing, and stream partitioning for its design, which makes it suitable for large-style microservices system architecture (Kreps et al., 2011).

AWS Kinesis is a relay system completely managed and used to process large volumes of data streams in real time. Kinesis makes it straightforward for the user to collect, process, and store streaming data, with support for AWS-related services for analysis and machine learning. These inherent self-healing topology characteristics, including data replication and scalability, are well-suited for a cloud system (Lakshman & Malik, 2020). Other event streaming platforms exist, such as Azure Event Hubs, which is available but lacks some features offered by Kafka and Kinesis but operates within the Microsoft Azure cloud solution. Event Hubs help process and analyze the huge streams of events in real time, which is always important for most cloud-native applications (Kuyoro & Olayemi, 2019).

5.4. Event Retention and Replay

Event retention and replay are so important that they can be used to review, debug, or reprocess events in the case of failures and bugs. Recording event information allows a system to use event information to reconstruct the state for troubleshooting or audits. For example, Kafka and AWS Kinesis both support the ability to persist events for a specific amount of time; after this time, events are evicted or migrated to a different storage.

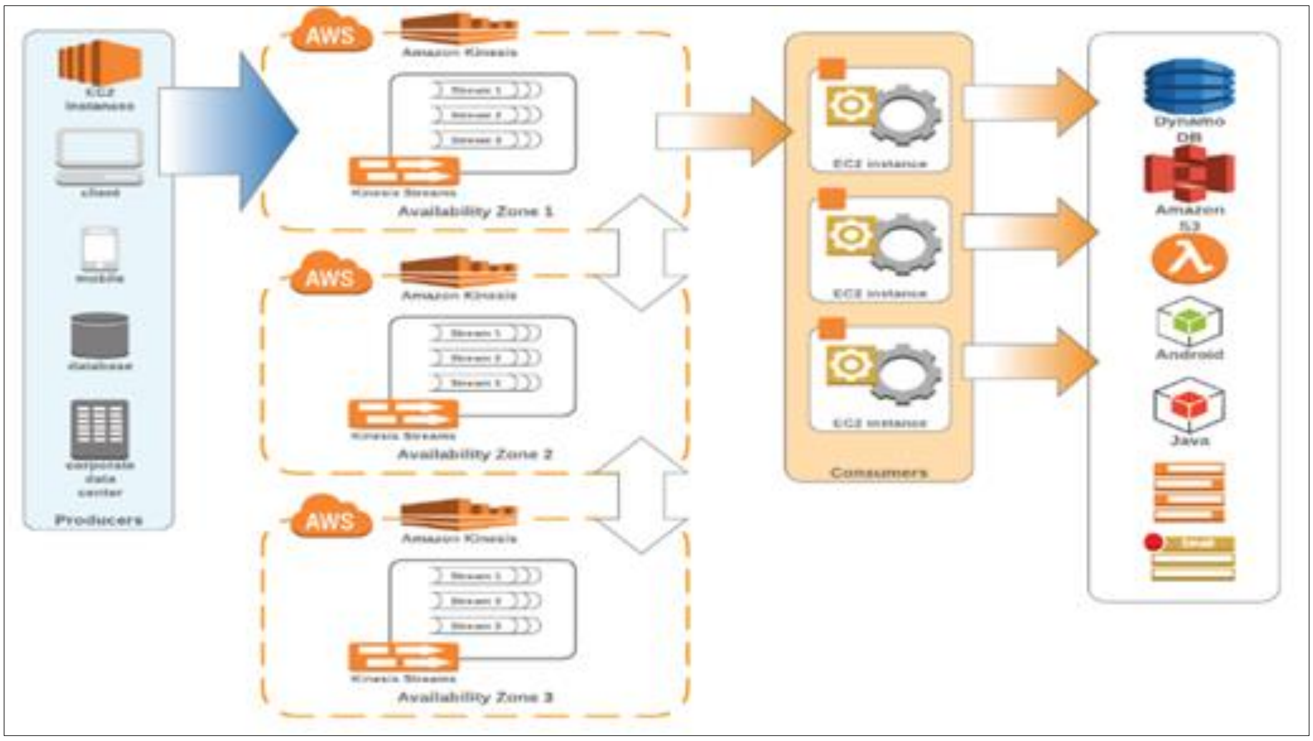

Figure 6 A comparison between AWS Kinesis and Kafka

Event replay can reconstruct the state by processing event details from the event log. This is especially useful in architectures, such as microservices, where a particular service may need a different version of the event data from another. To minimize the unreliability of the systems, where applicable, event storage must be done with precision so that no data is lost and the cost of storage alongside the performance of the storage solution is optimized (Gonzalez et al., 2019). Furthermore, retention techniques should correspond with business needs since some events must be retained longer, especially in highly regulated industries (Jalali & Ranjan, 2018).

5.5. Data Partitioning and Sharding

Data partitioning and sharding are techniques for achieving scaleout in event storage and processing. Partitioning can be defined as slicing the data into convenient subsets to allow concurrent processing, while sharding is the act of distributing data between different databases and/or servers. These techniques allow the system to scale to accommodate a high throughput of data, avoiding blocked input and output operations and allowing each microservice to process its part of the data in parallel (Gonzalez et al., 2019).

Event-driven systems facilitate partitioning in the stream of events wherein the distribution and consumption of each partition are wholly independent. Applications such as Kafka can also support partitioning because users can allocate events in multiple topics or partitions. That said, sharding is most helpful for ensuring that every service in a distributed system has what it needs to perform its job while not overloading a single service. These strategies guarantee scalability, performance, and dependability in large systems' integration (Kuyoro and Olayemi, 2019).

5.6. Schema Management

Schema management guarantees that the incidence is agreeable to the various services and system versions. In new service development, event schema must also implement backwards and forward compatibility since changes in event structure create breaking changes to the system. Some systems, like Event Hubs, also offer schema definition and validation through tools such as Avro and Protobuf, which help to check that events fit certain formats.

Schema evolution is critical in event-driven systems because the decoupling services necessitate that the event formats being generated and consumed eventually be related. Modifications to the event schema should be approached with some measure of care, and versioning can be used to ensure compatibility. Schema management is achieving correct data representation, format, and location. It is crucial as it prevents problems like data corruption, service failures, or communication that might be caused by mismatched event formats (Vinoski, 2020) that an effective schema management strategy makes it possible to update the schema of databases in a distributed system easily and without necessarily disrupting the integrity of data or even bringing down the system completely, which is why he regards it as a best practice for scaling event-driven architectures (Nyati, 2018).

6. Operational Aspects of Event-Driven Architecture (EDA)

Event-driven architecture, commonly known as EDA, is another architectural style that is very effective for building large-scale, reliable, and elastic systems or applications, especially in Microservices-based systems. The architectural style has numerous advantages, including coupling services, scalability, and real-time processing, but it comes packaged with some operational complexities. Due to these reasons, the operational aspects that need to be handled properly for reliable and performing event-driven systems include distributed tracing, monitoring, observability, fault tolerance and resiliency, security and backpressure.

6.1. Distributed Tracing

Distributed tracing is one of the most important mechanisms of tracking events in distributed systems. An event moves through an event system, and when an event-driven mesh of microservices operates concurrently, knowing how the event gets processed becomes challenging. Distributed tracing, on the other hand, enables one to track the flow of an event from one service to another. When each event is given a unique name, the developer or operator can identify where the event is from and where it is going. This will enable one to realize that a certain event has slowed down, stalled or even failed within the system.

Some technologies for implementing distributed tracing in EDA include OpenTelemetry, Zipkin, and Jaeger. These tools capture the tracing data in services to help fully monitor event trails. In addition, end-to-end visualization of attribute data allows one to identify allows one to identify the exact points within the overall process where an error or a delay occurs, which enables enhance need enhanced understanding of system performance (Gill, 2018). Distributed tracing also allows the teams to enhance the level of system observability, which is crucial for the health of microservices architecture.

6.2. Monitoring and Observability

The availability of monitoring and observability features has determined event-driven system reliability trends. ONF noted that the event-driven architectures you have resulted in substantial asynchronous messaging among various services, likely creating latent problems that may require better monitoring. Proper observability also means that if all teams collect metrics, logs, traces, or any other event stream from running systems, these teams gain real-time insight into system behaviour.

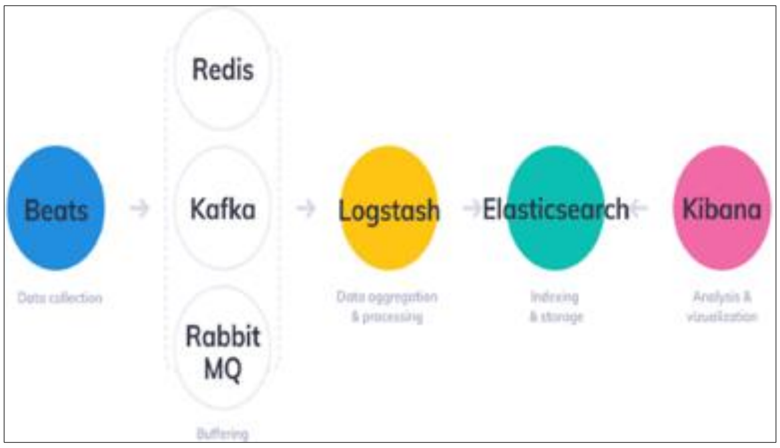

Figure 7 The Complete Guide to the ELK Stack

In order to monitor work, teams should concentrate on the desirable KPIs that apply to event-drive systems, including processing time for event, throughput, error rates and service availability. A best practice is to gather logs from the different services and store them in one place, particularly on a logging solution like ELK Stack or Splunk that will enable one to trace back problems with speed. Furthermore, predefined threshold-based alerting mechanisms should be implemented to inform operations teams of suggestive behaviours and trends to solve problems early and effectively (Almeida et al., 2020).

Observability, however, is not just a matter of monitoring as it stands today. It helps construct a generalized image of the system that can be useful for different teams to understand the dependence between services and how events spread across the architecture. Using tools such as Prometheus for data monitoring and Grafana for data visualization enables teams to monitor the health of the systems and alert users before they feel systemic flaws (Brown & McNamara 2020).

6.3. Fault Tolerance and Resiliency

EDAs are, by definition, self-healing because they are structured to deal with failures based on events. However, managing these systems' fault tolerance and resiliency remains critical, particularly concerning processes like retries or the deduplication of events and the usage of circuit breakers. In an event-driven system, it is possible that events are not processed properly because of network problems or services being down. Automatic retries can be set to combine them with exponential backoff guarantees that events can be retried without putting more stress on the system (Chaves et al., 2019).

In event-driven systems, it is easy to implement event deduplication logic to cater for reprocessing of the same event due to failure or retry. This helps keep the system consistent, even as it will refer to each event repeatedly throughout its functioning. Another important pattern is the circuit breakers that let a service pause processing failing events for some time to minimize the impact of interaction failures across the system (Pahlavan & Chien, 2020). These various forms of resiliency mechanisms assist with maintaining the integrated event-driven architecture as stable as possible if things do go wrong.

6.4. Security in Event-Driven Architectures

One of the greatest challenges in any distributed system, like event-based systems, is the issue of security. Common ways of interacting between the services in an event-driven system involve messaging systems like Kafka or RabbitMQ, which are prone to security threats like unauthorized access, data leakage, or man-in-the-middle attacks. That means, in order to ensure the system's integrity, the events and the channels of communications used need to be protected.

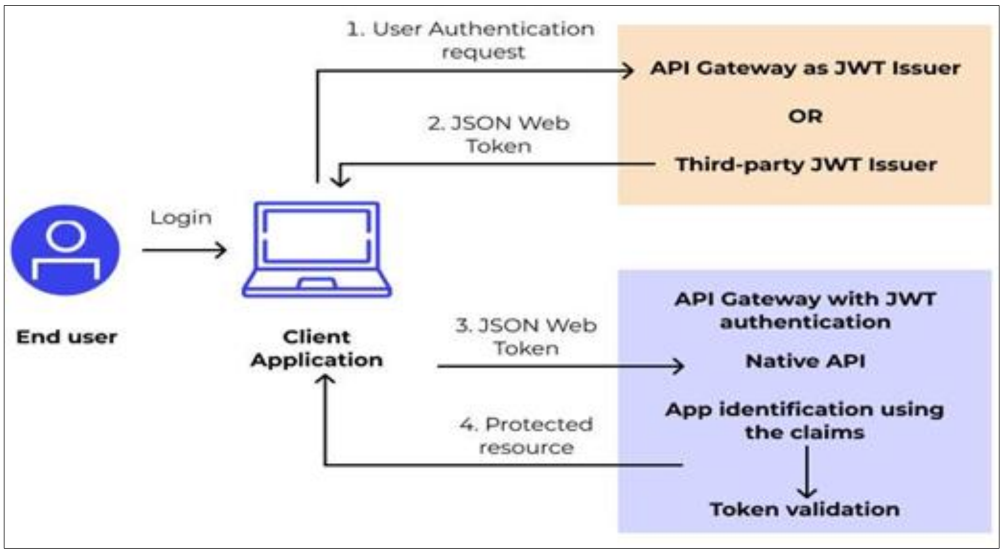

Figure 8 An overview of difference between OAuth and JWT (JSON Web Tokens)

Event security in EDA can be effectively implemented through encryption techniques that guarantee event security. The payload of the event traffic and the channels between and towards the various nodes are also encrypted so that no illicit parties get hold of the sensitive data when conveyed between the hardware pieces of the mesh network. TLS provides the encryption layer among the services, and AES can encrypt the event data, as Kozlov et al. (2020) suggested. Furthermore, authentication and authorization should regulate the production, consumption, or event subscription. For instance, OAuth and JWT (JSON Web Tokens) may be used to authenticate service requests and guarantee that only services with permission to access specific events can do so (Zhao et al., 2019). Other important security measures are access control policies and event-level checks to improve the security of event-driven architecture. RBAC and ABAC are helpful models for defining access rights to different events so that only permitted users or services can generate or subscribe to certain types of events.

6.5. Backpressure Management

Backpressure management is another approach to preventing systems from being overloaded by controlling the flow of events. In such event systems, services may be deluged with too many events, leading to resource depletion, excessive delay, and system crashes. To prevent such problems, mechanisms for back pressure are used to regulate the rate of events processed in the system.

There are several realizations of backpressure, where backpressure can be directed toward reducing the number of concurrent event consumers or toward throttling the rate of the events issued by the event producers. For instance, flow control systems present in Kafka or other messaging systems provide ways through which consumers effectively indicate their capacity to handle the events. Further, queuing of events or event prioritization reduces the impact of backpressure on the system performance (Kumar et al., 2020). Another mechanism is rate limiting, where a given system restricts the number of occurrences a given consumer can process within a given duration. This helps avoid pressure on consumer services and guarantees maximum performance in high loads. Effective management of backpressure is critical to ensure stability and the ability to respond to event-driven design paradigms, especially under high variability in event loads.

7. Methodologies for Designing Event-Driven Systems

EDA has tremendous benefits in developing elastic and reliable systems and supporting a consistently growing number of users. In contrast, a clear framework of how the events will be modelled, designed, and matched to business domains is needed to perform EDA and implement all its aspects successfully.

7.1. Event Storming

Event Storming contains several modelling strategies used to map the stream of events in a system with teams' assistance. This came into development in 2013 and was created by Alberto Brandolini; in this approach, stakeholders from various fields, such as developers, business analysts, and domain experts, assemble to map the business events' flow through different systems and processes (Brandolini, 2013). The coherent concept of Event Storming is focused on gathering the whole working team to discuss and depict events that understand the business processes. Event Storming, whose objective is to bring out essential events within a system that elicit business logic. Such status events as "Order Created" or "Payment received' trigger actions and responses throughout the system. It also allows teams to recognize the exact events and the summation of the actions that follow as a consequence, the process flows that rely on the events mentioned above, and systems/interface Separation.

During the Event Storming sessions, the participants draw sticky notes about events, commands, and aggregates. As a rule, events are shown in orange, commands are in blue, and aggregates are in yellow. These notes are located on a big flat surface such as a wall or a whiteboard, which can be ordered by participants chronologically or according to the interactions of the system. It should draw potential issues or situations where system behavior might require excellence to encourage extended discussions highlighting business rules and technical specifications. One of the advantages of event storming is that it ensures all the stakeholders have a common vision of the system in question, thereby helping prevent conflicts between technical and other business stakeholders. It provides a check and balance so that event-driven systems of applications are not built independently without paying attention to requirements back at the business level, as well as to provide impetus to adapt to the dynamic needs in the future continuously. In addition, Event Storming allows one to define the spectrum of the domain, which is essential for structuring microservices in an event-driven context (Patton & Palmer, 2015).

7.2. Domain Storytelling

Domain storytelling is similar to event storming but is concerned with narrating and drawing out a domain's stories. It is a narrative approach to modelling business processes developed by Steffen (2017). Domain storytelling differs from Event Storming in the way it visually models the process—while the latter uses sticky notes to describe events, Domain Storytelling employs flowcharts or diagrams to tell the stories. Domain Storytelling intends to describe the events and interactions within a system from the point of view of business users. People are asked to narrate the steps of a business process or event-driven behaviour in the form of a story. The storytelling process is social and cyclic; the members must share what they know about the subject regarding a specific domain. The picture emerging after the results focuses not only on the events in the system but also on actors, actions, and interactions to clarify the requirements of the system and the interconnections between them.

As for the disadvantages of Domain Storytelling compared to Event Storming, the former is simpler and based on storytelling, which is wider and more easily understandable for business people who may find some technical descriptions like Event Storming confusing (Fowler & Hunt, 2012). Domain storytelling helps to manage the process of defining an organization's business processes and fosters better communication between domain-oriented specialists and IT specialists. Furthermore, using narratives to present the business logic helps one track the narrative flow and ascertain resistance points in the workflow. Domain Storytelling is a handy methodology but is typically employed with other design tools, including Event Storming, since Domain Storytelling focuses on the business domain. At the same time, Event Storming concentrates on the technical side of the system. To get an enriched perspective of the domain and the event-driven processes in question, the envisioned principles of visual storytelling and the proposed approach to decision-making within the brainstorming session complement each other.

7.3. Domain-Driven Design (DDD) and Bounded Contexts

Domain-driven design (DDD), pioneered by Evans (2004), entails the strategic modelling of software systems, emphasizing the business domain. DDD allows for establishing borders (called Bounded Contexts) within which some models or events are meaningful so that different parts of a whole can develop in parallel with no contradiction. Regarding event-driven systems, DDD and bound contexts come into the picture for mapping events to the business domain they are representing. In DDD, the emphasis is placed on de-composing the systems into smaller components or reasonable sub-domains called Bounded Contexts. A Bounded Context describes an area within the business where rules and concepts remain intact and integrated. In each Bounded Context, teams can create events, aggregates, and services particular to the business sphere for which they are liable. These Bounded Contexts provide obvious frameworks into which teams may encode, create, and deliver microservices without intruding on other teams' capacity, which optimizes the freedom of the system (Evans, 2004).

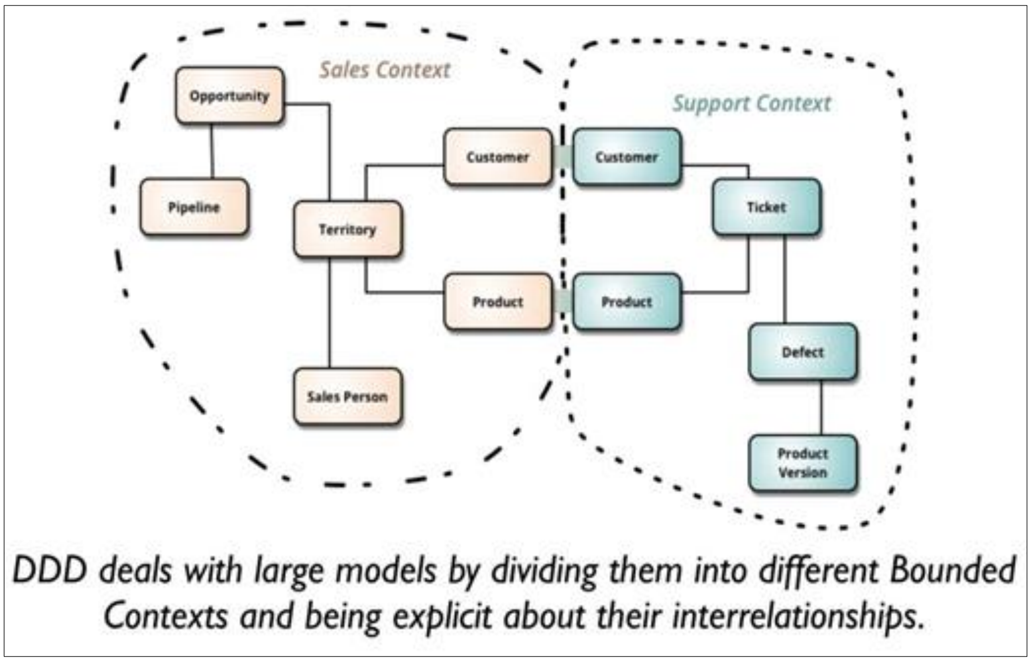
Sales Context
Opportunity
Pipeline
Territory
Customer
Product
Sales Person
Support Context
Customer
Ticket
Product
Defect
Product Version
DDD deals with large models by dividing them into different Bounded Contexts and being explicit about their interrelationships.

Figure 9 Domain Driven Design (DD) in Microservices

The first advantage of DDD in event-driven architectures is that it assists the teams in assuming the correct stance where the design choices result from business priorities. If external events or services deviate too much from the business logic they represent, then it is best to bind the context of this team to ensure that changes are consistent with the business logic of this team. They also allow for the separation of services; the various Bounded Contexts can share data using events and not necessarily be connected. This is important for the growth and adaptability of the system because nothing is fixed. However, since microservices are loosely coupled, all system parts may be developed separately. However, all parts will agree on the fundamentals to provide a uniform framework (Vernon, 2016).

Bounded Contexts also assist in controlling the design of Event-Driven systems because the events are aligned with the domain of operation. In this way, DDD indicates where a boundary should be drawn so that the flow of events does not become enshrouded in confusion and complexity. This makes it easy to coordinate integration between various microservices and also offers consistency across the system. Integrating DDD with Bounded Contexts into an event-driven design makes it easier to map the technical solution to the business requirements by constantly focusing on the principle of change and adaptability (Khononov, 2021). It also prevents the often convoluted nature of event-driven systems from becoming a major issue by offering a clear system for managing how different teams communicate and define responsibilities.

8. Challenges and Considerations in Event-Driven Architecture (EDA)

EDA has many benefits regarding microservices, including improvement of scalability, flexibility, and responsiveness. But still, the integration of EDA is not without a hitch. These problems are mainly related to complexity management, testing, coordination of interrelated functions, change of event types, and ownership distribution. All these problems pose significant issues that mean there is a need to give adequate thought to implementing and functioning an EDA system.

8.1. Complexity Management

Another risk one must embrace when working with event-driven architecture is that the facility's evolution and system management are complex. This structure makes it difficult to follow the flow of events within an EDA. As systems become more complex, this causes complexity in components' interactions, making it hard to track event flows, debug problems, and discover the dependency relationships within an EDA. Eventuality has become more dynamic compared to imperative, therefore, and invariably causes difficulties in managing and evolving services to fit this model.

In addition, EDA needs strong processes to deal with the situation, such as when some parts of the system will be immediately aware of an event. At the same time, others will never know it occurred. For example, some parts will know about it immediately, while others will not, and both will accept it anyway; for instance, two clients sent messages to each other, but one never received an acknowledgement, and no one knows. The challenges of deriving this consistency increase where systems are cross-domain or even cross-geographical. To mitigate these complexities, event logging, monitoring, and alerting must be installed to provide data about the flow and processing of the event in real-time mode. However, even with these systems in place, managing complexity in EDA is a non-trivial undertaking that remains challenging and requires strategic planning and continued attention (Bertolino et al., 2021).

8.2. Testing Challenges

The execution of testing in an event-driven system poses challenges that are not easily responded to, especially while performing unit-integration testing. One of the problems of microservices is that since services are communicating asynchronously, it becomes possible that events will not be processed at all, or worse, some of them will be processed before others, which makes testing a real challenge. Such testing becomes intricate when controlling or executing unit testing since it is complicated to train events individually. Integration testing is still complex because it is laborious to test interactions between the various services, most of which address the different aspects of event flows.

The decoupled nature of services suggests that each service cannot be tested independently without regard for the entire range of services that constitute an event. To overcome these difficulties, some tools like mocks, stubs, and in-memory event brokers exist; however, even their use demands extra effort to guarantee the integration test covers all possible use cases. Thus, an investigation of effective testing approaches for EDA implicates notable investment in structures and the formation of unique testing paradigms (Leavitt, 2020).

8.3. Cross-Functional Team Alignment

A core aspect of EDA is dealing with cross-functional teams, which often create tension. Integration of various teams regarding event modelling, domain, boundary, and business process is essential for the architecture. In practice, this is often difficult for the main reasons; for example, teams may have conflicting objectives or goals, and the team can have different degrees of expertise or different points of view on how the event should be modelled or handled.

Managing alignment requires efficient communication of expectations and desires by the executive in charge and sufficient knowledge of business processes. Event Storming and Domain Storytelling are widely used methods to elicit event models and construct a common language about event patterns and flows. These methods can help guarantee that teams operate under assumption consistency, assuming that more than one team may be involved when developing a particular set of services or a certain aspect of the whole system (Brown & McCool, 2019). Such alignment is essential for the success of EDA, while teams that are misaligned with each other may create discrepancies or issues in the sequence of the event.

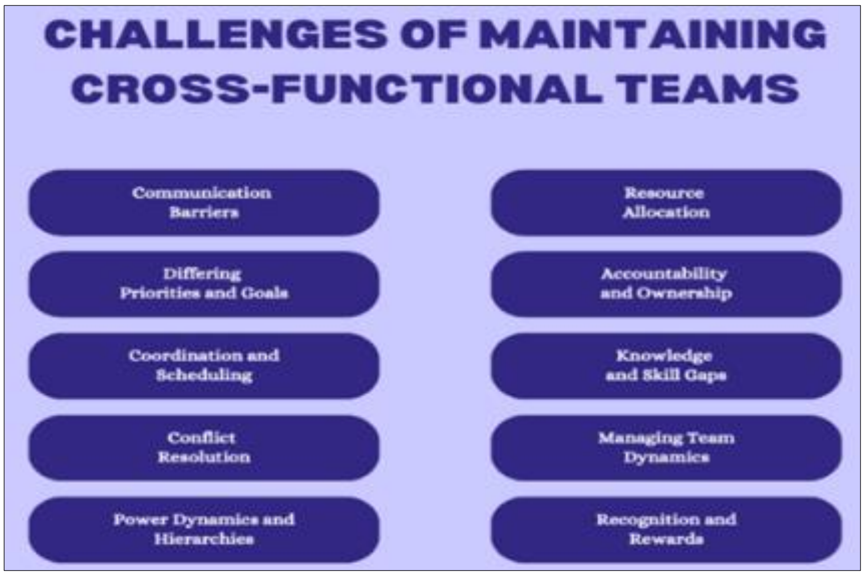
CHALLENGES OF MAINTAINING CROSS-FUNCTIONAL TEAMS
Communication Barriers
Resource Allocation
Differing Priorities and Goals
Accountability and Ownership
Coordination and Scheduling
Knowledge and Skill Gaps
Conflict Resolution
Managing Team Dynamics
Power Dynamics and Hierarchies
Recognition and Rewards

Figure 10 Some of the Challenges of maintaining Cross-Functional Teams

8.4. Event Changes and Compatibility

Event type modification and backward compatibility consideration are also crucial in EDA. For example, as systems change, adding new event types or changing the actual event schema may be necessary. However, modifying event types must be done delicately so as not to disrupt downstream services that depend on those events. Ensuring the new changes are backwards compatible is very important to system integrity and continuity of services.

A versioned event schema is one way to approach the event change management process. This means that new event types or changes can be introduced without interrupting the existing services, depending on the prior versions of the events. Moreover, ordinary people can also use the event replay techniques to test how these changes will impact the system without disruption. However, the solutions mentioned above do not eliminate the problem of managing event changes without the emergence of compatibility issues, especially when working with extensive systems comprising various interconnected components (George & Ruland, 2020).

8.5. Distributed Ownership and Governance

Shared ownership and management is another major factor hindering EDA as its operations are decentralized among various stakeholders. It becomes challenging to ensure that all the concerned teams follow certain standards and industry best practices since a system might involve several teams owning different services (Kasauli et al., 2021). This decentralization of event handling and processing implies that there should be well-articulated guidelines on how events are defined, managed, and processed in the entire system.

One requirement is to set up an unambiguous system of norms and values for event processing. However, decision-making is not simplified in a distributed environment because one team might utilize a different tool, technology, or strategy to complete a specific system part. Therefore, any deficiencies or inconsistencies in or suboptimal designs for events must be addressed by developing robust governance procedures to establish standards for designing events, testing, and continually monitoring these activities and their outcomes (Pucella & Tov, 2018).

9. Agility and Evolution in Event-Driven Systems

9.1. Supporting Agile Development

EDA can be seen as barely compatible with Agile since it successfully complies with the Service Separation principle and supports modularity. This decoupling allows a more flexible systems development environment where some parts of the services can be changed with less effect on the overall setup. In EDA, services interact in a message-passing asynchronous manner. The services do not synchronously require explicit responses from other services. This non-blocking interaction is fundamental to scaling and staying responsive while embracing agile to integrate and deploy changes easily (Newman, 2015).

As the EDA can scale services independently, they can work on new features, enhancements, and fixes in individual components without waiting on other teams. This results in a shorter feedback loop, or other words, an aspect that is commonly seen and propagated in agile development environments where changes can be tested and validated quickly. With decentralized services, it becomes easier for the developers to change something about the system segment, which is not linked to other segments, thereby eliminating the need for frequent extra-large overhauls (Leavitt & Lee, 2020). In addition, managing events and respective states in the event 'stream' also improves elasticity as systems can process real-time data and alter it based on business requirements. The model makes it possible for innovation to occur much faster than regular implementations while not compromising the system's reliability and how it will function (Hohpe, 2020). By adopting EDA, organizations can easily meet the change in market demands, making it well-suited for enterprises who want to remain relevant in today's dynamic market.

9.2. Domain-Driven Design and Agile Practices

DDD is especially helpful when using EDAs because Domain Driven Design provides a method for mapping the business flow to the technical side. DDD is aimed at continuous communication with the business representatives to model the system according to the actual business flow within the organization it is created to support. This alignment is attained through creating bounded contexts, which split the wide system into sub-systems, each dealing with a particular area of interest. The bounded context concept helps support EDA since each service acts as bounded domain logic and contains specific events that portray changes within its own given business domain (Evans, 2004).

Due to the specificity of DDD, it helps in the work in different fields in an agile way, as decision-making is mostly decentralized. It gives teams the capability to work independently and avoid the need to coordinate with other teams, and, as a result, teams work fast and advance quickly to the next stages. Every team claims ownership of the domain they are involved in and their events, which are fully explained within the system. This decentralized ownership corresponds well with the agile principle of trusting the teams to make decisions quickly based on domain knowledge when a decision needs to be made (Vernon, 2016). In addition, DDD supports iterative development because it enables a team to build evolving and more accurate domain models. During Agile Events or in workshops, it remains updated on what the business domain is about, and thus, it changes the appearance of the event-driven system. This cyclic process is instrumental in guaranteeing that the given system's change is in harmony with business requirements to adapt or grow with the organization (Fowler, 2018). This means that by integrating agile practices to design event-driven systems, organizations can improve the culture in their enterprise architecture regarding agility and change.

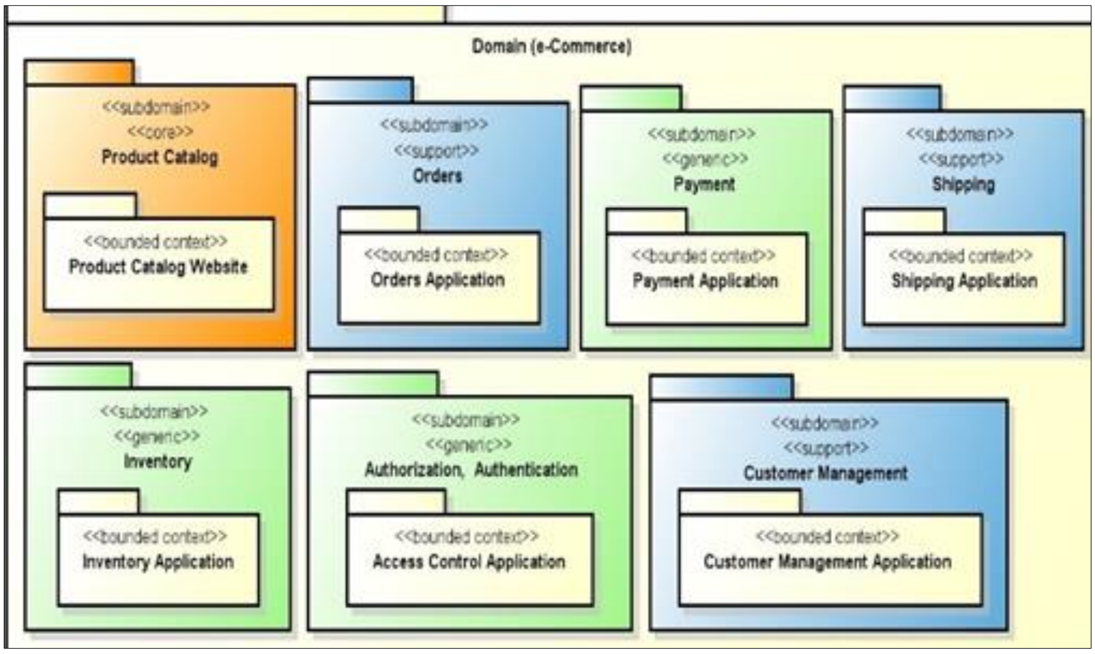

Figure 11 Domain-Driven Design on an Agile project

9.3. Common Pitfalls to Avoid

As with most developmental approaches, however, there are general issues that organizations adopting Event-Driven Architectures must be aware of. One of them is the excessive complexity of the structure with as many services and events as possible; these raise issues with the subsequent management of the architecture and result in increased technical debts. To prevent any occurrence from being unaddressed, teams can end up designing an incredibly convoluted event flow that is hard to fix or modify without significantly interfering with the overall flow (Hohpe, 2020). There can also be great costs in managing such an over-designed system, defeating the concept of agility. Simplicity and adding complexity only when needed are very important to remain agile for the system.

One additional concern commonly seen in EDA systems is the absence of visibility. Since EDA is mainly characterized by asynchronous messaging and distributed services, it becomes challenging to provide monitoring and status tracking to the flow of events across the system (Laigner et al., 2021). This occurs especially when teams are not equipped with the right tools for monitoring potential problems that may present themselves within the event stream, such as inefficiencies or outright failure. This lack of visibility ails the speed of responding to acute problems, especially in agile development projects. Consequently, it becomes necessary for teams to commit to the wide implementations of smart tools for observability consisting of distributed tracing, metrics, logging, and other mechanisms to allow the teams to identify and solve problems in the shortest time possible (Leavitt and Lee, 2020; Nyati, 2018).

Another challenge that can cause or hinder the success of EDA is the tight coupling of events. Although the primary gain of EDA is decoupling, undesired event structures result in tight coupling between the services. Event payloads and business logic can cause changes in tightly coupled services to create cascades of failure or altered system behaviour. This tight integration, though, goes against the concept of EDA and Agile, where the architecture is decentralized and free-flowing. To prevent this, teams should aim to organize loosely coupled events where changes in one service do not cascade through the remainder of the system (Vernon, 2016). A lack of efficient schema evolution induces the disturbance of the efficient evolution of an event-driven system. Schemas may also be dynamic and could change periodically depending on new changes in any business. Lacking a proper plan for schema versioning and backward compatibility, the teams may encounter situations when new events negatively impact existing consumers. This can hinder easy progressive build and thus decelerate the overall flexibility of the system. There is the problem of accommodating schema changes that lead to such issues, including when the changes are introduced and how they are done since implementing strategies approaches to schema modifications such as versioning and backwards compatible changes can help to ensure flexibility in future changes (Fowler, 2018).

10. Conclusion

EDA has been identified as a revolutionary technique for adapting to microservice development since it amplifies scalability, flexibility, and responsiveness. By allowing services to work with events separately and respond to events as they happen, EDA makes systems modular and decoupled, which is critical for today's large-scale distributed applications. This architecture's ability to manage data and services separately improves system efficiency, achieves high availability, and allows for integration updates and additional features without affecting the entire system. Using EDA has its share of difficulties, like every other technique in the actual application. One of the main challenges organizations experience is achieving data consistency across multiple services. As stated earlier, EDA has lots of dealings with some eventual consistency, so it is crucial to possess tools specifically regarding data synchronization, retries, and error handling. Additional problems are associated with managing events and log flows in a distributed system regarding tracing, debugging, and monitoring events. With the increase of services, it becomes difficult to monitor the evolution of the events through distinctive components, hence the need for monitoring and tracing tools that will easily identify faults and conflicts that require mere correction.

Coordinating the relationships between services and keeping services isolated from one another is also challenging. A disconnection between event producers and consumers is flexibility, but the disadvantage is that event failure can arise from miscommunication or poor event delivery. Different event brokers, such as Kafka or RabitMQ, help organize how the events go from one component to another. If and when organizations extend their systems with event-driven architectures, keeping them efficient and easy to manage as they scale becomes an issue that is easier said than done, and it must be done right and consistently. Additionally, some aspects related to EDA's functional nature, such as security and fault tolerance, need to be well addressed. Since event channels must not be accessible or modified by unauthorized entities, security measures and some fault tolerance techniques, such as circuit breakers and event retries, are required to maintain system stability in case of service failure. They make the system robust under many configurations of failure; thus, the business can operate without interruptions most of the time.

Solutions for event-driven systems must be worked out on possibly experiencing Schema Changes and thus the necessity for versioning. When more than one type of service or a new event comes into the picture, backward compatibility is the greatest consideration. The guidance must be set to define the testing approach clearly and avoid overall system degradation as it develops. However, integrating event-driven architecture into microservices can pose problems, but the advantages of using event-driven architecture in terms of scalability, flexibility, and responsiveness cannot be doubted. Organizations using this approach must expect to spend on the appropriate tools, techniques, and approaches to guarantee that their systems are sustainable, manageable, and capable of accommodating evolving business processes.

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