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A Review of Security, Compliance, and Governance Challenges in Cloud-Native Middleware and Enterprise Systems

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ABSTRACT: The implementation of cloud-native notions is also changing the middleware of organizations and is moving the business systems off the monolithic systems to the modular, robust, and scalable systems. The trend that is growing is the use of containerization, microservices, and orchestration systems, including Docker and Kubernetes, by companies to make their business more agile and fast-track their digital transformation. The new technologies contribute to the flexibility of things and also make the situation more complicated in terms of the security of data, adherence to rules, and handling the remote situation. Among the most essential issues to be concerned with are securing vulnerable information, ensuring identities, implementing zero-trust security, and ensuring that various platforms are compatible. It is far more difficult with regulations such as GDPR, HIPAA, and NIS2 and needs powerful structures and automatic implementation of policies. Moreover, governance programs should address the issue of vendor lock-in and cross-border data sovereignty to ensure transparency and accountability. The article provides a comprehensive preview of the security, compliance, and governance issues in cloud-native business systems and middleware. It classifies gaps in research and gives suggestions of how to create sustainable, safe and compliant corporate ecosystems by analyzing foundations, threats, and solutions. The next steps should be AI-based orchestration, governance that is compliance-driven and standards related to secure multi-cloud ecosystems that are cohesive.

KEYWORDS: *Cloud-Native Middleware, Enterprise Systems, Security Challenges, Governance Frameworks, Compliance Standards.*

I. INTRODUCTION

Cloud-native computing has completely transformed how businesses build, deploy, and run huge digital infrastructures. Organizations can now become flexible, resilient, and quicker in the innovation cycle by moving out of the inflexible monolithic systems to a more modular and service-based architecture [1][2]. Middleware is crucial as an interface between applications and infrastructure, providing interoperability, automation, and scalability in a distributed environment. In particular, cloud-native middleware leverages containerization, microservices, and orchestration layers, such as Docker and Kubernetes, to provide elastic middleware, fault tolerance, and dynamic workload management [3]. Cloud-native middleware is crucial in advancing the digital transformation because it fosters agility, efficiency and continuous delivery as compared to the traditional ERP systems that were mostly complex, costly and difficult to modify [4][5].

Despite these advantages, numerous thorny issues arise regarding the extensive use of cloud-native middleware. One of the most pressing ones is security since the enterprises must safeguard the information, deny access to the third-party, and reduce the risks of cybersecurity threats that advance with the course of time in the decentralized environment. Security breach protection is becoming extremely important in the zero-trust security paradigms and identity and access management [6], and encryption techniques. The governance and compliance issue is critical, particularly since business is supposed to follow laws such as the GDPR, HIPAA and NIS2 and be transparent and accountable in their operations in various sections of the globe. The lock-in issue of vendors, Interoperability and cross-border data sovereignty is also challenging to adopt the latter and, therefore, to proceed with the operation in a sustainable fashion, good governance systems and policy implementation processes must be in place. [7].

Considering such opportunities and issues into account, an in-depth examination of cloud-native middleware and enterprise systems is critical to identifying what they are, and what their vulnerabilities are [8], and what are their regulatory requirements. The paper outlines the architecture features of the cloud-native middleware, its role in business innovation, and the drawbacks of traditional ERP systems. It also examines the security threats [9], compliance conditions and business governance structures that have been synthesized based on academic literature and business experience [10]. The analysis unified various perspectives and identified gaps in the research, while also planning how to develop safe and robust infrastructures that comply with regulations. The essay further discusses future developments, including AI-powered compliance monitoring, smart orchestration, and unified standards for cross-cloud governance. Ultimately, the goal is to provide researchers, practitioners, and enterprises with a holistic perspective on how to strike a balance between innovation, accountability, and trust in cloud-native ecosystems.

II. FOUNDATIONS OF CLOUD-NATIVE MIDDLEWARE AND ENTERPRISE SYSTEMS

Cloud-native middleware forms the backbone of modern enterprise systems, enabling modular, scalable, and resilient architectures through containerization, microservices, and orchestration platforms like Docker and Kubernetes. It supports automation, security, interoperability, and governance, facilitating dynamic data workflows and integration. Unlike rigid legacy ERP systems, cloud-native middleware fosters innovation, flexibility, and efficient digital transformation across distributed enterprise environments.

A. Architectural Components of Cloud-Native Middleware

Cloud-native middleware is a specialized software layer that exists between cloud-native applications and underlying cloud infrastructure, and the software is intended to deliver critical services (e.g., communication, integration, security, monitoring and scales) in a manner that is fully cloud-native (i.e. acknowledges cloud-native concepts such DevOps automation, elasticity, dynamic orchestration, microservices, and containerization). The principles in cloud-native data architecture are that flexibility, scalability, and resilience can be achieved:

- The first is modularization, which is implemented using microservices and containerization, whereby components can be created, deployed and scaled without the risk of failure of the entire systems [11].
- The second is scalability with the help of scalable and elastic cloud resources that are able to scale to the demand, thus reducing costs and eliminating waste.
- Third, automation is used to orchestrate, monitor, log, and deploy pipelines, which provide effective and trustworthy operation.
- Fourth, distributed designs result in resilience and fault tolerance, replication and redundancy reduce the downtime and data loss.

- Fifth, security and governance are implemented at each of the layers, and access controls, encryption, and compliance tracking are crucial to sensitive data.
- Lastly, interoperability securing integration between various systems based on open standards and APIs, vendor lock-in is avoided and flexibility is ensured.

B. Middleware in Cloud-Native Environments

The middleware for cloud-native data engineering is the orchestrator. The orchestrator is an engine managing and monitoring what is called a choreography: a template of the desired transient data ecosystem, bootstrapped by a reusable blueprint, and any number of deployed plausible instantiations, called workflows [12]. In cloud-native data processing ecosystems, as well as in a distributed system of programmable automation, the orchestrator is what controls inter-process data interactions, making the scattered processing of the transient data within the processing ecosystem cohesive, by composing the operating data gales into downtime-generic data umbrellas.

The orchestrator operates complicated workflows within distributed services, which however, also come with security, compliance, and governance issues. Business organizations need to guarantee information secrecy, implement uniform access measures, and ensure auditing in coordinating dynamic data interactions.

- **Data security & confidentiality:** This provide protection to sensitive data on a cross-service basis and on cross-service communication
- **Identity and access management (IAM):** The management of secure access to microservices, APIs, and distributed environments.
- **Zero-trust implementation:** The use of role authentication and authorization measures between and inside services.
- **Compliance management:** Adhering to regulatory standards like GDPR, HIPAA and PCI DSS in dynamic and distributed systems
- **Interoperability and standardization:** System integration of heterogeneous systems and avoiding lock-in to a vendor.
- **Policy enforcement and auditability:** Maintaining governance, tracking, and tracing of the automated workflow.

C. Impact of Legacy ERP on Innovation

The legacy ERP systems were stable and integrated fundamental enterprise functionalities, yet monolithic and inflexible architecture frequently prevents innovation. Customization is both expensive and time consuming and limits the dynamism of organizations to modify processes or to embrace new technology. They cannot be easily agile and scalable due to their inability to interoperate with modern platforms and middleware [13]. By comparison, cloud-native middleware provides flexible, modular architectures that are easier to deploy, integrate and innovate across the enterprise systems. With an enterprise moving more towards a digital transformation, it becomes necessary to go beyond the legacy ERP in order to stay relevant and maintain constant innovation.

III. SECURITY CHALLENGES IN CLOUD-NATIVE ENVIRONMENTS

The issue of security in cloud-native environments (CNE) is associated with concerns about data protection, user access control, and reducing the impact of developing threats [14]. The main issues involve the security and data integrity of data during the migration process via the use of encryption, deploying a well-developed Identity and Access Management (IAM) system to regulate the user privileges, and implementing the Zero-Trust Architecture (ZTA) to authenticate each access request. All these plans enhance the confidentiality, integrity, and resilience of dynamic cloud-native systems.

A. Data Security And Encryption In CNE

The security need of data security is essential because operations of the company can be severely affected by the breach or leakage of data during migration. In migration, data is literally on the move and prone to numerous kinds of attack vectors, such as Man-in-the-Middle (MitM) attacks. One possible database migration technique is a phased approach, in which databases are migrated in numerous phases. The two main database models in CNA are the one-database-per-service model, which refers to the case where each microservice instance has its database and the shared database model, which refers to the case where multiple microservices share a database [15]. The latter model will require more sophisticated security work as it is more advanced. In order to reduce security issues, however, appropriate measures such as encryption of data could be done irrespective of the approach. Figure 1 demonstrates the data confidentiality.

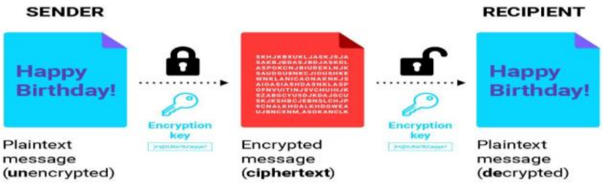
SENDER
RECIPIENT
Happy Birthday!
Encryption key
Happy Birthday!
Encryption key
Plaintext message (unencrypted)
Encrypted message (ciphertext)
Plaintext message (decrypted)

Fig. 1.Data Security through Encryption

B. Role of Identify and Access Managemt In CNS

A set of procedures, tools, and regulations known as Identity and Access Management (IAM) makes ensuring that the proper people have the right access to resources in a company or cloud environment. To ensure security, mitigate the threat of unauthorised access, and track the identities of users, IAM systems are essential [16]. The key components of IAM are identity governance, authentication, authorization, and auditing. The rules and policies governing user identities in order to ensure that they abide by security and rules are referred to as identity governance. Authentication is the process of determining the authenticity of who the person is claiming to be through the use of passwords, biometrics, or multi-factor authentication (MFA) [17]. The authorization provides the level of access a verified user is allowed to have by implementing the restriction on the basis of already established rules. Monitoring and Auditing are kept on the lookout on who is accessing what and what is done to ensure that rules are adhered to and any security vulnerabilities are discovered. The structure of the IAM (Identity and Access Management) is presented in the Figure. 2 It consists of three major elements, namely, Authentication, Authorization, and Accounting. These things work together to make sure that only the right people can access resources by checking identities, regulating permissions, and keeping track of users' activities.

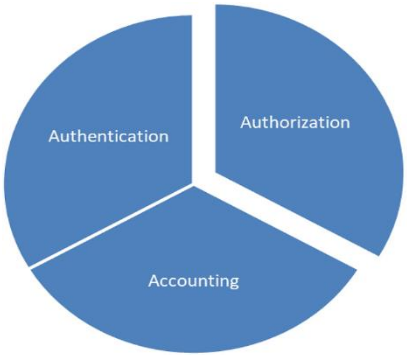

Fig. 2.IAM Framework

C. Zero -Trust Security Model

As a cybersecurity concept, Zero-Trust Architecture (ZTA) states that no device or person, whether within or outside the enterprise network, should be trusted by default. It operates on the fundamental tenet of "never trust, always verify," which is significantly different from earlier security systems that distinguished between trusted and untrusted areas using fixed network borders. Verification procedures are implemented at every level since every access request is seen as potentially hazardous. This concept encourages micro-segmentation, which divides networks into small sections to maintain access limits and reduce lateral movement in the event of a breach. ZTA puts a lot of emphasis on continuous authentication, least privilege access, policy-based enforcement, and decision-making based on telemetry. These concepts are not separate technologies; they are methods that combine identity management, endpoint security, access control, and behavioral analytics. Figure 3 compares the Zero Trust model to the Traditional approach, which believes that by default, people and devices inside the network perimeter may be trusted.

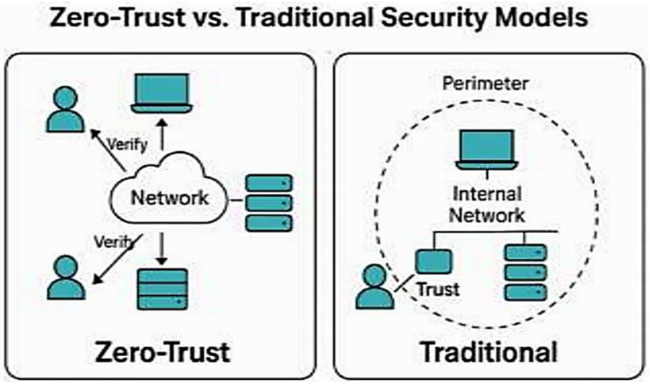

Fig. 3. Conceptual Representation of Zero-Trust vs. Traditional Security Models[18]

IV. GOVERNANCE AND COMPLIANCE CHALLENGES IN CLOUD NATIVE ENVIRONMENT

Governance and compliance problems in cloud-native settings primarily concern ensuring that policies are adhered to, that rules are followed, and that individuals are accountable for their actions. The most notable ones are the development of strong governance frameworks, the seamless nature of the implemented systems, standardization to avoid vendor lock-in, compliance with existing regulations, including the GDPR and HIPAA, as well as data sovereignty and cross-border legal issues. To distributed cloud systems, effective techniques enhance their openness, safety, and credibility.

A. Policy Enforcement and Governance Frameworks

The appropriate policies should be implemented, and best practices and frameworks should be followed in case the cloud-native systems are to be utilized on a safe and legal basis, and with accountability. Policies define how the resources are provided, accessed and monitored through the services, whilst governance structures present systematic rules of risk management [19], conformity to compliance and uniformity of operations. Automated enforcement tools and real-time audits, such as Policy-as-code, can allow businesses to have dynamic infrastructure in the cloud.

Good governance also includes ongoing monitoring and surveillance, reacting to events, and adherence to legal requirements, where new cloud-native applications can be executed within a certain level of security and compliance. Organizations can mitigate risks in their business operations through simple policies and well-designed governance structures [20], enhance transparency, and gain the trust of stakeholders in a place with so many stakeholders.

B. Standardization, Interoperability, and Vendor Lock-In

The elasticity and flexibility that are required to effect integration over cloud-native platform require a solid dedication to standardization and interoperability and lack of vendor lock-in. Cloud-native ecosystems can consist of numerous services, middleware components and layers of middleware that are required to interact and interact [21]. The absence of standard procedure, and interoperability of the systems can imply that interoperability with the other systems is intricate, and complexity of operation process and lock-in by the vendor can restrict innovation and responsiveness and make the process of implementing new technology more complicated and efficient scaling of services.

- **Standardization:** To facilitate the integration of diverse systems, use common standards, APIs, and design patterns.
- **Interoperability:** This is the capability of the diverse components, platforms and services in the cloud to be used in a multi-cloud or the hybrid environment.
- **Vendor Lock-In Mitigation:** Do not invest in proprietary technologies in order to reduce the migration costs and flexibility [22].
- **Portability:** The service designs and architecture are such that they can be easily cross-platformed and cross-provider.
- **Strategic Alignment:** To gain long term benefit, make sure that the cloud adoption plans, integration strategies and technologies decision that the organization adopts will be in tandem with long-term goals, governance trends, and organizational compliance needs.
- **Decision-making:** Technical and operational decision-making that complies with long-term corporate objectives and regulations.

C. Compliance Standards

The implementation of stringent policies that stop the efforts by unauthorized individuals to access and compromise patient data is necessary to comply. These are data security, privacy and auditability. The compliance procedures can also be implemented and made simpler using the enhanced security and governance capabilities of cloud-native technologies. Containerization can provide consistency and isolation, which in turn can decrease the likelihood of a data breach due to the differences between the corresponding environments. Cloud service providers help companies satisfy regulatory standards by offering a range of security solutions and compliance certifications [23]. Encryption is a basic need for regulatory compliance in cloud-native environments. Regulatory compliance helps monitor and ensure adherence to regulations such as GDPR and HIPAA. Additionally, AWS provides real-time conformance packs to assist with compliance.

- **General Data Protection Regulations (GDPR):** It sets strict guidelines for consent management and data processing [24], and international transfers, making it a vital component of worldwide compliance plans. Data security, consent control, deletion rights, and portability are necessary.
- **Health Insurance Portability and Accountability Act (HIPAA):** Healthcare providers and related cloud service providers are impacted by HIPAA's industry-specific regulations for protecting personal health information.
- **Network and Information Security Directive 2 (NIS2):** EU cybersecurity policy for digital and vital services. Concentrates on risk management, incident reporting and general security resilience.

D. Data sovereignty & cross-border challenges.

Data sovereignty is the legal principle, according to which digital data is subject to the legislature and control mechanisms of the country where it is stocked. This is an important principle in the cloud environment because information is usually copied and shared in different jurisdictions [25]. Companies are at increased risk when moving information across borders, particularly when the legal system of the hosting nation has limitations or is inconsistent with the home laws of the data owner. The proactive compliance methods, including the adoption of the localized storage solutions and the encryption controls, should be in place to make the auditing of the data comply with the local laws. There are also jurisdictional issues that affect the signing of contracts between cloud providers and customers, exposing them to operational and legal risks. The global cloud contracts should include provisions that specifically contain jurisdictional authority, applicable law and compliance provisions.

V. LITERATURE REVIEW

The reviewed literature explores cloud-native security frameworks, DevOps compliance, EMV integration, AI-driven anomaly detection, and microservice vulnerabilities, emphasizing advancements while exposing gaps in governance, compliance automation, and enterprise-wide adoption in hybrid and multi-cloud environments.

Srinivasan, Naga and Narukulla (2020) propose a multi-tier defence system for hybrid cloud applications, focusing on protecting cloud-native applications. The framework covers five layers: infrastructure protection, user access management, application-level security, data security, and privacy. It also ensures instant incident handling and network separation. The framework supports DevSecOps and monitoring compliance. By comparing various cases, the paper demonstrates how this strategy ensures secure, flexible, and well-performing hybrid cloud systems. The research concludes that layered, adaptive security architecture is essential for protecting cloud-native workloads and ensuring secure digital transformation in hybrid environments. [26]

Rompicharla and P. V (2020) highlight the importance of Cloud Computing for Application & Development teams, with the DevOps model being a key tenet of success. As the trend towards Hybrid Multi-Cloud continues, the DevOps approach of the security team, especially the Self-Service principle, has to be reviewed right away. According to a 2019 poll, 50% of businesses have used hybrid multi-cloud, while 90% of businesses utilize cloud services of some kind. Nevertheless, 67% of security teams lack insight into their compliance, security, and cloud infrastructure. The goal of the article is to offer a self-service solution for hybrid multi-cloud setups that is continuous and consistent with pre-deployment [27].

Ahuja et al.(2019) review paper examines the integration of EMV standards with modern cloud-native architectures, focusing on the challenges organizations face in implementing EMV in distributed environments. The paper examines emerging deployment patterns, security frameworks, and real-world integration strategies, highlighting both limitations and potential for innovation. The review also outlines areas for future research, such as secure tokenization approaches, hybrid deployment models, and containerized EMV middleware services, to help enterprises navigate the evolving landscape of digital transactions[28].

Torkura et al. (2018) explore the application-layer vulnerabilities of Microservice Architectures (MSA) such as Cloud Native Environments (CNE), paying attention to the security concerns of container technologies, such as Docker and Kubernetes. They apply vulnerability correlation in understanding the interdependencies among vulnerabilities in different levels to give information to microservices security hardening and risk management. The prototype implementation extends the Cloud Aware Vulnerability Assessment System (CAVAS) that is capable of a 31.4% vulnerability discovery rate compared to the traditional testing methods [29].

Torkura, Sukmana and Meinel (2017) explore the security challenges faced by Cloud Native Applications (CNA), which are complex distributed applications with varying technologies and fast development cycles. To solve these problems, they come up with a new idea for a Security Control dubbed the Security Gateway. This idea is backed by dynamic document storage and security health endpoints. It use cloud-native design principles to put these ideas into action and add them to the CNA process. Experimental assessments confirm the efficacy, temporal overhead, and vulnerability detection rate of suggested methodologies, rendering them appropriate for secure CNA and microservice-oriented implementations [30].

To determine the gaps in the research, the Table I shows a comparative overview of the available researches on cloud-native security, compliance, and governance, featuring the important methods, discoveries, weaknesses, and directions of future research

TABLE I. LITERATURE REVIEW ON SECURITY, COMPLIANCE, AND GOVERNANCE OF CLOUD-NATIVE MIDDLEWARE AND ENTERPRISE SYSTEMS

Reference	Study On	Approach	Key Findings	Challenges / Limitations	Future Directions
Srinivasan, Naga & Narukulla (2020)	Multi-tier defense framework for hybrid cloud-native applications	Proposed layered security architecture covering infrastructure, access, applications, data, and monitoring	Improved threat detection, automated compliance, and enhanced risk management in hybrid cloud workloads	Primarily conceptual; lacks large-scale empirical validation	Extend framework with real-world case studies; integrate adaptive AI-driven monitoring and compliance automation
Rompicharla & P. V (2020)	Security in Hybrid Multi-Cloud within DevOps	Emphasized continuous, pre-deployment compliance checks and self-service security models	Highlighted misconfiguration as leading cause of cloud breaches; proposed compliant self-service models	No practical implementation; imited focus on governance policies	Develop automated compliance verification pipelines; address multi-tenant security governance
Ahuja et al. (2019)	EMV compliance in cloud-native digital financial systems	Reviewed architectural and regulatory challenges in EMV adoption with cloud-native models	Identified conflicts between EMV standards and distributed cloud systems; discussed PCI DSS and localization pressures	Limited practical frameworks for hybrid EMV-cloud deployments	Explore secure tokenization, containerized middleware for EMV, and hybrid deployment compliance models
Torkura et al. (2018)	Security of containers and microservices in cloud-	Proposed Cloud Aware Vulnerability Assessment	Achieved 31.4% better detection rates than traditional tools; identified	Focused on technical vulnerabilities, less on compliance/governance	Enhance continuous monitoring; integrate with enterprise

	native environments	System (CAVAS) with vulnerability correlation	inaccuracies in severity metrics		governance frameworks
Torkura, Sukmana & Meinel (2017)	Security assessment for Cloud-Native Applications (CNA) using microservices	Introduced Security Gateway with dynamic document store & security health endpoints	Improved vulnerability detection with minimal overhead; integrated into CNA workflows	Mainly technical validation; governance and compliance aspects missing	Broaden adoption in enterprise CNA governance; combine with policy-driven compliance monitoring

VI. CONCLUSION AND FUTURE WORK

Enterprises navigating cloud-native adoption must balance the promise of innovation with the realities of risk management. The transformation of old ERP to the new modular middleware platforms is unmistakably advantageous in the realms of scalability, automation and flexibility, but also introduces new vulnerabilities. The protection against such security risks as the exposure of a database, unauthorized access, and insider threats should be of high quality, and the use of encryption tools, identity governance, and zero-trust architecture should be provided. High priority is also given to the governance as it must be automatically enforced, monitored easily, and the compliance proven in real-time. Continuous auditing of activities in cloud environment and accountability is also important due to such compliance as GDPR, HIPAA, and NIS2. Complexity of compliance is also augmented by barrier to interoperability, dependency and cross-border conflicts of sovereignty on data between vendors. The imperative to overcome these barriers is the need to adopt a collaborative approach, cross industry standards, and malleable governance frameworks which keep on adapting to the ever changing technologies. The future of AI-based compliance checking, intelligent aids interchangeable to coordinate the security policies in a seamless way, and the models of balancing the data legislations across the borders should be focused on employment. Moreover, the cross-cloud interoperability and universal government research may also help to reduce the level of fragmentation, not to mention the improvement of the enterprise confidence. The progress in these directions will ensure that the cloud-native middleware is becoming more secure and resilient and conforms globally to the foundation of enterprise digital transformation.

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