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Chapter 3: Cloud-Native Architectures: Scalability, Resilience, and the New Financial Stack

3.1. Introduction

Major cloud service providers support cloud-native architectures for many financial services. Demand-driven load patterns can cause oversizing underutilization of monolithic setups, resulting in spiralling support costs. Massively scalable cloud services supporting management, reporting, settlement, and clearing systems can improve capital efficiency. Cloud-native core financial services allow layer-delayer banking models employing state-of-the-art cybersecurity, especially with supervised digital currencies.

The modern development, maintenance, support, and expansion of cloud services have created numerous independent components that can accessed independently through APIs. Resilience is a core requirement of mission-critical systems, yet cannot be guaranteed. Chaos engineering complements robust design by breaking working systems to validate operational and support concepts. Error budgets clearly define the trade-off between risk, cost, and customer experience. Cloud-native architectures apply the core principles of cloud-native systems and various patterns—service mesh, API gateways, zero trust, cloud bursting, and active–active setups—to highly regulated environments. Cloud-native principles enable and streamline the redesign and modernization of legacy business-critical systems.

3.1.1. Overview of Cloud-Native Transformations

Cloud-native architectures are relevant not only for new systems and services but also for the significant modernization and transformation of legacy application environments. Partly, such environments can be considered in terms of their shared infrastructure goods, which are being further developed and migrated into clouds and cloud-like resource environments. These environments contain the non-functional infrastructure services, such as data storage and exchange, identity management, access control, fraud scanning, timeout sessions, communication, and observability. On top, innovations are underway for some of the core financial services, such as payments, and for services providing financial ecosystem fulfillment, such as checkout, settlement, clearing, and real-time gross settlement. These services can be made sufficiently modular to integrate with individual service-based architectures aligned with specific enterprise, marketplace, and ecosystem business strategies, through API gateways. The substantial part of the core financial services not undergoing rapid innovation is best viewed as a set of legacy financial components that still support the current business models and operations. These are now being approached with a risk-driven security and resilience mindset. Modernization entails resilient replication and associating automated testing and automated repair as sympathetically and operationally appropriate practices.

Any on-premise-cloud hybrid setup obviously must be "in account" with respect to cloud-based services and be seen by them as real present users. Any solution still being used for a financial daily business as a risk-and-cost trade-off should operate with a maximum degree of control. Eighty or more percent of users log onto their banks remotely through mobile and web channels. By far the greatest part of primary transactions and behaviors occurs when users only want to check account balances, prepaid transaction statuses, or the latest few transactions (though fraud checks should also occur at such times in real time). These activities must therefore be scaled elastically to be very available and supported by stateful elastically scalable session services and strongly secured communication channels. State should be observed, controlled, and supervised as a separate exercise using an increasingly in-disguise approach.

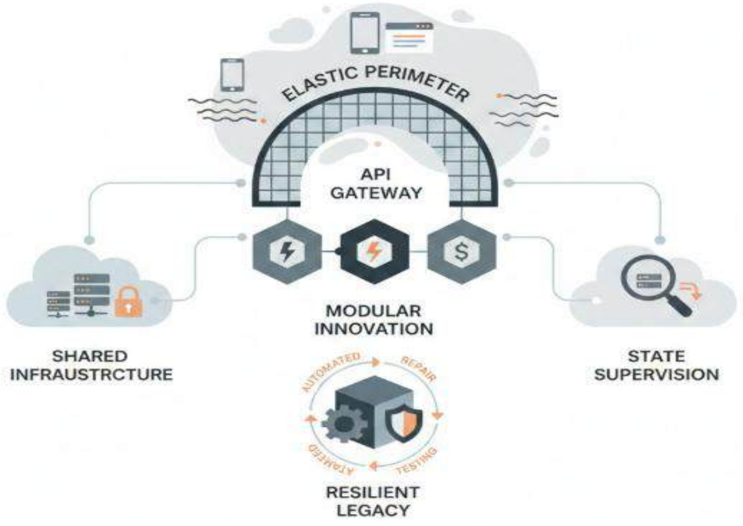

Fig 3.1: Architecting Resilience: Adaptive Cloud-Native Modernization and Elastic Scaling Frameworks for Hybrid Financial Ecosystems

3.2. Foundations of Cloud-Native Architectures

Cloud-native architectures have experienced steep adoption rates as organizations seek improved responsiveness and faster delivery of new capabilities. Cloud-native means building and running applications that exploit the advantages of the cloud computing delivery model. Core principles associated with cloud-native architectures include independence and loose coupling, and these principles are supported by several architectural patterns. To achieve cloud-native benefits, organizations must embrace observability, automation of infrastructure and deployment, and DevOps practices.

Cloud-native architectures support scalable and resilient solutions, as well as the replacement of a monolithic application or legacy COTS products with a portfolio of smaller services such as microservices and serverless functions. However, the full realization of cloud-native benefits is not always present and must be carefully considered in the design of the new architecture. Scalability is assured by demand modeling and the placement of elastically scalable components in the architecture, while resilience is guaranteed through appropriate patterns and mechanisms. Business processes can fall naturally into a cloud-native architecture and data-driven workflows appreciably raise the potential for automation.

3.2.1. Core Principles and Patterns

Most definitions of cloud-native architectures mention containers, microservices, serverless, and declarative APIs. These technologies, while popular in the industry, are not the core principles of cloud-native architectures. Together, they form a set of tactical patterns, often erroneously understood as strategic goals. The foundation of cloud-native architectures, flavoring the core patterns that enable those tactics, lies in the architect's use of the principle of the separation of concerns.

The first tactical direction, separation of concerns, raises the question of whether to deploy a part of the overall application stack as an elastically scalable service: will there be enough churn, such that the system optimizes cloud resources? Beyond the traditional cost calculus, however, decisions must also consider user-facing services that process requests for a rental service. Such components can be elastically scaled and are better decomposed into separate services. Cloud-native patterns correctly identify these services as stateless and advise grouping them by horizontal functionality. Face services must remain vertical, stitching together third-party services and vertical functionalities implemented as microservices.

The second tactical direction, resilience, raises the opposite question. Have engineers sufficiently understood the failure patterns of a service that they can explicitly anticipate, test, and mitigate them? If so, stateful components are given the same focus as user-facing services, making fault tolerance a primary use case for a service. Components such as databases or transactions are better understood as stateful and are increasingly monitored by chaos events that induce faults to test dependability.

3.2.2. Observability, Automation, and DevOps Practices

Given that complex systems are invariably built by poorly compensated, undervalued human labor, resilient cloud-native architectures facilitate a reliable, observable, self-healing, and automatically tested execution environment. Consequently, noise within large-scale systems can be continuously filtered, and responses to undesirable errors automated through software instrumentation. Cloud systems are appropriately detached, making Fort Knox-style security unrealistic.

Observability is distinct from logging and instrumentation, and embraces such seamless mechanisms as **black-box monitoring**, **application performance monitoring**, and **distributed tracing**. While logging, tracing, and profiling are earlier forms of observability that describe external behaviour, monitoring is an attempt to understand internal state; Ken Thompson's converse saying, "Your message will find some block hole in the net," therefore remains valid. External response time remains undiagnosed because the error may not be detected; black-box diagnostics mask the overhead of timers; databases appear healthy while the bottleneck is incurred at a nearby data source.

The scale of cloud environments demands pervasive **automation**. Building the system is achieved within an emerging **infrastructure-as-code** discipline, and **continuous deployment** with **loading tests** replaces traditional pre-release testing. Following multiple failures when automated failover was introduced in a single geographic region, continuity exercises are integrated into scheduled operations. Chiefly, maintaining inputs automates large-scale resilience testing, as in patterns of **chaos engineering**.

3.3. Scalability in the Financial Stack

To achieve scalability, the financial stack must be capable of scaling up and down in response to demand. Each of its core services should be turned into cloud-native services, with native support for elasticity through backend infrastructure that can be scaled in a cost-effective way. Demand models can help determine which components to make elastically scalable, while stateful services should be carefully considered. Demand-modeling techniques based on queuing theory or agent-based modeling can provide insights into demand patterns for a given bank or payment service.

Cloud-native supports for elastically scalable demand are well established for stateless services. Cloud providers and platforms offer backend services that can be elastically deployed, scaled, and charged according to actual demand. Services such as credit card checkout, card payments, and fraud detection are well suited for using these elastic facilities. Demand at each of these services typically follows a daily pattern, with peaks on working days and at particular times of day. By scaling to zero during off-peak periods and then elastically scaling up during the peak periods, cost-effective provisioning can be achieved.

3.3.1. Demand Modeling and Elastically Scalable Components

Elastic scalability—diffusion of demand to many instances that together carry load—fulfills the overprovisioning of capacity that is endemic to businesses with tax-like demand profiles. To maintain low latency for end-users, however, a cloud-native architecture must also offer demand models that characterize and understand anticipated peaks or time-varying demand profiles. For horizontally scaled components, such demand models are used to inform dynamic mechanisms that selectively coalesce many elastic instances into optimal fewer instance operators over demand valleys. The ability to provision elasticity with lower monetary cost over time is a natural aspect of modern cloud computing, as these service charges often depend on CPU-time consumption rather than mere presence of capacity.

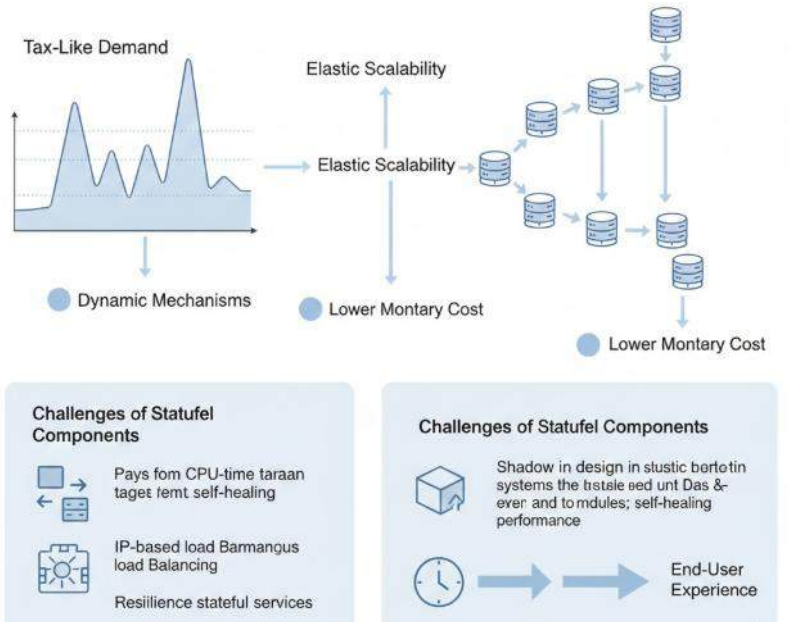
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Fig 3.2: The Elasticity Paradox: Orchestrating Demand-Modeling and Stateful Persistence in Cloud-Native Financial Architectures

Yet not all components of a modern financial stack are easily made elastically scalable. Some components are stateful and require a certain level of active presence or elastic demand. State-management considerations introduce complications such as data placement and consistency, while IP-based load-balancing considerations add complexity to self-healing design approaches. These considerations are often ignored during early prototyping phases, yet they quickly become shadows in production systems that appear years later demanding scrutiny.

3.3.2. Stateful versus Stateless Considerations

Asynchronous messaging technologies offer an excellent solution for managing temporarily imbalanced load when exposing elastically scalable components. In Cloud-Native Architectures for the Financial Stack, one pattern for solving demand flexibility is to let the consumer buffer excess demand for later and smooth the processing load with massive processing technologies, such as batch or parallelization over massively replicated services. However, it may be desirable to use auto-scaling at the backend service side, potentially incurring state overhead. Further, data flow links between the demand and supply component must be carefully monitored to avoid overflow on either side; otherwise, high peaks could still lead to overflow or underflow errors.

Stateful services, such as a Redis cluster, can lead to load imbalance when the service is exposed through an API, and stateless services must carefully analyze whether all state information can be embedded in the API call. This requirement can also lead to underuse of superposition when modifying a shopping cart because the state would be temporary on the user side, typically making resource-efficient design tedious.

3.4. Resilience and Reliability Mechanisms

Pragmatic focus on deployment and operational aspects leads to orthogonal mechanisms, scattered throughout architectures, instead of being consciously designed and integrated. Even so, they improve resilience—e.g., fault-tolerant system designs whose units can be replicated in active-active or active-passive configurations, self-healing based on health checks. Also part of pragmatic approaches are event simulation dedicated to non-production environments, chaos engineering, and testing for resilience. The latter, however, must be conducted holistically, meaning all components should be tested, not just the individual ones.

Chaos engineering seeks to discover weaknesses and improve response to real failures by injecting failures in production-like environments. It expands resilience patterns, e.g., routing requests to unavailable components, running desynchronized, injecting delays in processing, etc. It can be tedious and dangerous in traditional stacks, but it is more controlled and frequent in cloud-native environments, being facilitated by infrastructure automation and observability.

3.4.1. Fault Tolerance and Self-Healing

For cloud-native applications, below-component reliability is not a requirement; cloud providers sell virtual machines with an SLA of 99.99% or higher. Yet the cloud-native application often serves millions of users and business-critical needs, and so it is important to architect for reliability. The reliability solution is that the architecture tolerates failure for all components below a certain level in the reliability hierarchy. If an elastic AWS Aurora RDS-mysql database with an SLA > 99.99% fails, 250,000 orders in today's environment will likely be lost. If Chaos Monkey shuts down one of the 360 instances of an Asian bank's Internet banking, that is hardly noticeable. Such hardening and fault-tolerance approaches need to be systematically applied to cloud-native applications.

Applications need to self-heal; this is supported in the cloud ecosystem with elasticity and infrastructure elasticity. When there is not enough capacity to meet demand, typically an autoscaling group detects that situations worsen or thresholds are reached, and instances are added to the pool. The dashboards often display the number of instances or Virtual Machines available and that have scripts to re-deploy or re-start upon failure. Processes need to be built and reliably executed to build such automatic re-deployment to correct process states as quickly as possible. For instance, Facebook's engineers described how during an issue with the core system, 'we were able to stop a couple of bad bots on the services that use this core service, and then deploy a new version to all the services referencing the core service. Given the state of, and pressure on, the affected system, both the creation of the shutdown and the deployment to fix the problem relied heavily on our continuous deployment model.

3.4.2. Chaos Engineering and Testing

To obtain resilience and reliability, appropriate implicit and explicit testing should be considered. The Fault Tree Analysis (FTA) method can be beneficial to discover the relevant fault conditions allowing detection before affecting the normal operation of the system.

The Chaos Engineering discipline can be instrumental for this purpose by proposing real abnormal conditions to check the proper response of the involved components and the stack as a whole. In a cloud-native perspective, random faults and destabilizing situations should be intentionally created, allowing the system and its self-healing functionalities react and recover. Validated and persistent tests can be defined to enforce the proposed behavior. Monitoring and observability tools—together with altitude and radar procedures—can be used to verify that SLA are respected for the normal operation and that, when there are failures, the recovery is accomplished within the allowed limits with no obvious impact on the users.

3.5. The New Financial Stack in Cloud-Native Environments

Cloud-native concepts can be applied to the entire financial stack, allowing it to benefit from elasticity, failover, and scalability. The core financial services such as authentication, fraud detection, and money transfer can be expressed as cloud-native services. Demand models can then help to understand how traffic to services such as checkout and settlement evolves and whether an elastic component is needed. Each component can be designed in isolation, possibly with different technology stacks or cloud providers, and assembled by the cloud provider, for example by using service discovery.

Cloud-native architectures permit Cloud Computing providers to offer managed checkout, settlement, and clearing microservices. The checkout process receives all needed data, including the detailed basket of goods that needs to be purchased. The primary consequence of Cloud-native transformations in these financial activities is the increase of scaling elasticity offered by Cloud Computing providers. The settlement process is a typical transaction workflow, while clearing is a broadcast that can affect a large part of the user base. These properties open the door to routing payments and setting foreign exchange operations in an elastic way.

3.5.1. Core Financial Services as Cloud-Native Services

The Core Financial Services within the Financial Stack (e.g., Payment, Liquidity Management) manage centralized resources flowing inside the system and are often built as Cloud-Native Services. Modern Cloud-Native architectures offer scaling solutions to Face the On-Off Behavior of these Services, but they introduce new requirements mainly related to their Criticality.

Changes in the frequency flows of these Core Bank Services (Delivery vs. Payment, Sacco Service) have a severe impact on the Cloud costing of banks. Indeed, modern Service-Based Architectures, supported by Cloud pricing models, allow Banks to accurately manage the Service Of and On behavior of non-Critical Microservices. The same cannot be stated for the essential Core Bank Services, which remain up and costintensive, but, if designed with a proper level of granularity, their builds can be Electronically Managed in size and resource allocation. These Services can also be architected in a Cloud-Native way, in compliance with modern architectural patterns, can exploit Cloud features and APIs and are mainly subject to scaling concerns. Power and dependency on Third-Party infrastructures (for example Liquidity Requirements) are the main Criticalities of Core Bank Services.

Considering that the Financial Stack is the runtime in which these Services operate, the associated Slos must be respected. Complex Routing Behaviors strongly support composability, with little ownership of the Microservices involved. Security, at different levels, is also a major concern, done away from the Business Logic and duly implemented.

3.5.2. Checkout, Settlement, and Clearing Through Microservices

Cloud-native environments introduce many new patterns and tools for building services. Some of these tools are relevant to financial components such as checkout, settlement, and clearing, which combine latency sensitivity with demand peaks. Base functionality should be made available through cloud-native services. This approach enables clients to optimize their solution architecture for their own requirements, and potentially improves cost characteristics by redistributing excess load away from the core.

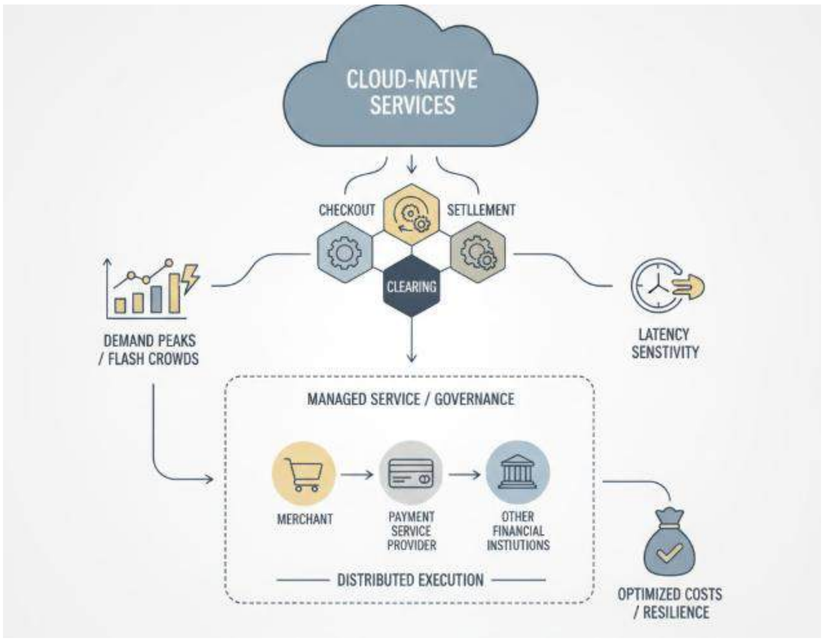

Fig 3.3: Distributed Resiliency: Leveraging Cloud-Native Microservices for Elasticity and Governance in High-Frequency Settlement Architectures

Microservices can be used to expose these capabilities while hiding the actual dependencies and informing the participants about fees, cut-off times, and so on. Components providing these services are generally back-end-facing, with their APIs consumed by checkout services operated by merchants, payment service providers, or other financial institutions, and providing access to multiple networks.

3.6. Architecture Patterns for Modern Finance

Cloud-native transformations of applications and services follow a common set of patterns, heavily influenced by microservices and event-driven architectures. The principle of adopting cloud-native styles of design and implementation extends beyond the core foundational services that make up the financial layer. The enhanced resiliency and scalability that cloud-native architectures bring also enable components of the checkout and clearing layers to be implemented as cloud-native applications. Such components utilize cloud-native feature sets and deploy on .net platforms. The resulting highly decoupled designs with well-defined boundaries are key enablers for extending the bank's capabilities through partnerships and ecosystem collaboration.

Of particular interest to institutional organizations is how their lifecycle management, risk, and finance processes can be mapped to cloud-native designs and deployed in a cloud-native manner. These components are typically complex financial workflows, often spanning multiple organizations, and integrating risk, and finance functions through complex model gymnastics. Because these components usually involve rich transaction flows, they do not lend themselves to a simple microservices architecture. Instead, they require integration across actors, and outside in decision-making support. Structures that bring the benefits of cloud-native architectures, but respect these unique process characteristics, are therefore required. Such characteristics typically point toward data-driven design patterns. Data-driven designs focus on the data first, aligning the lifecycle management with the data, and letting the data drive the supporting activities.

3.6.1. Event-Driven Architectures and Data-Driven Workflows

Event-driven architectures augment modern applications by decoupling services through event publishing and subscribing. These patterns enable many-to-many interactions between services and parts of a solution. Workflows can assemble and orchestrate services and tasks that are deployed to accommodate varying workflows or data flows. Data-driven workflows automate the construction and execution of user- or system-defined workflows, possibly drawing upon machine-learning models to assist with dynamic behavior.

Cloud-native transformations across the financial stack are subject to many of the same forces driving modern applications in other areas. Event-driven architectures provide an effective pattern for enabling services and parts of solutions developed and operated by separate teams to interact seamlessly. The architectural principles of event-driven applications support many-to-many communication between components using asynchronous messaging within a loosely coupled structure. Events capture time-stamped changes in a system state, which can include be business-related transactions or informa-tion of interest to an HTTP-based application born in the cloud. Applications can publish events to a messaging system, other ser- vices can subscribe to retrieve them and distribute them further, or they can be stored to enable future processing.

Complex data flows frequently involve work orchestrated across many automated tasks, through either formal workflows with well-defined control flow or other interactions between distributed systems. Orchestrators can enable parts of the flow to be separated into hosted services consuming inputs and streaming as outputs. Data-driven workflows permit expert users or systems to augment development and deployment as well as execution, providing continual improvement of business processes.

3.6.2. Service Meshes, API Gateways, and Zero-Trust Security

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Architecture Pattern 3: Service Meshes, API Gateways, and Zero-Trust Security

Service meshes are established to create a distributed communication and observability fabric between a multitude of microservices. Given the rapidly growing number of payments-related services required to support checkout, settlement, reconciliation, and clearing, finance services are prime candidates for deployment within a service mesh. Canva has successfully employed a service mesh for its event-driven architecture.

Leading financial institutions have deployed API gateways to enable secure communication across financial services. The API gateway serves as the single point of access for external parties to request payment services and has distinct implementations for each financial service between different financial institutions and between third-party service providers and financial institutions. The API gateway provides trusted security zones for consumers of API services and is aligned with the principle of least privilege. Wording as implemented by PSR-3 for the financial sector in Australia emphasizes a "never trust, always verify" principle across all external-facing APIs as part of a zero-trust security strategy.

API management capabilities, such as OAuth token management, throttling, and the generation of API usage statistics and alerts, are built into the API gateways. Zero-trust security flows between financial services within service meshes that handle growth, degradation, or Yang traffic patterns are automatically and credibly validated by the service mesh itself.

3.7. Conclusion

A cloud-native transformation of the financial stack in support of a completely new mode of delivery is underway. Along with established players, financial technology firms are leading this transformation by leveraging a modern, cloud-native architecture that provides the levels of scalability and resilience required in the cloud environment. Other participants are adopting cloud-native architectures for selected parts of the financial stack or for their entire operations to compete with the new players. Microservice-based architectures, event-driven designs, and data-driven workflow engine patterns are common. Zero-trust frameworks are increasingly implemented for security. Modern resilience techniques, especially monitoring, chaos engineering, portfolio defenses, and related test designs, are important aspects of these architectures.

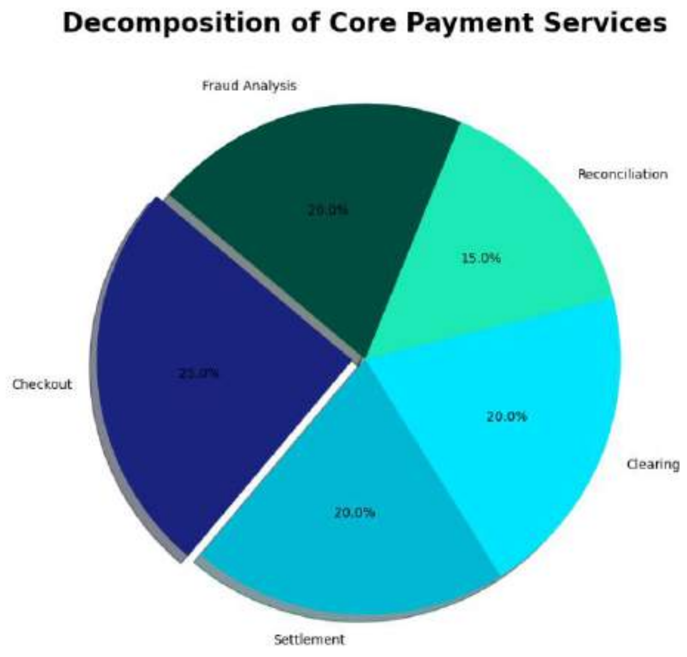

Fig 3.4: Decomposition of Core Payment Services

Three principal Likert items, when used to survey industry practitioners, underscore the requirement for a cloud-native transformation of the financial stack. Cloud-native architectures should provide true elasticity, with component sizing being driven by demand; offer proactive fault tolerance at design time rather than reactively at runtime; and accommodate dynamic interconnectivity among different components of the stack as new services emerge and more players seek to participate in offering financial services. When assessing the new direction within core financial services—in particular, payments—practitioners believe they should also follow a cloud-native approach. Primary financial services such as checkout, payment settlement and clearing are evolving as discrete microservices, supporting a growing ecosystem of fintech players in fulfilment of their own financial services journeys.

3.7.1. Final Thoughts and Future Directions

Many organizations are adopting cloud-native principles to scale and modernize their systems, building applications and infrastructure in ways that exploit the advantages provided by the cloud. These principles justify substantial investment in cloud capability and are key to winning the cloud race. For the financial sector, the presented cloud-native principles for scalability and resilience, along with supporting architectural patterns, enable an analysis of how the financial stack can be transformed and modernized.

Using cloud-native technologies, financial services such as active wallets for send/receive payments and checkouts can be built as cloud-native services. These services can then be combined with specialized elastic components and other microservices to recreate major financial processes such as settlement and clearing. By applying cloud-native principles to the design of the key financial processes across the financial stack, the research provides the foundations for a new cloud-native financial stack that delivers the scalability and resilience required for competitive advantage. At the same time, it lays the groundwork for modernizing the financial processes that constitute these services.

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