Week 7: Improving Availability and Performance of Cloud Systems

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**Improving Availability and Performance of Cloud Systems**

Applications move to the cloud to gain access to elasticity, instantaneous provisioning, sophisticated security, and cost controls, among other reasons. These new capabilities shift the modern architecture away from monolithic designs toward micro-service systems. While many applications are modernizing, their high-availability approach is not evolving (Verbitski, et al., 2018). These traditional strategies include several tried-and-true methodologies, such as state checkpointing and fail-over clustering (Zhao, 2014). Fundamentally, these strategies make assumptions regarding the physical hardware constraints. However, the cloud’s virtualization enables bending some of these rules. Engineering teams need to reassess cloud-native patterns as a mechanism to improve their systems’ performance, reliability, and economics.

# Background

Distributed systems are the most complicated computing environments because of their parallel and asynchronous nature. Many implementations also make false assumptions regarding the network’s reliability, security, homogeneousness, latency, bandwidth, and transport costs (van Steen & Tanenbaum, 2019, p. 986). When systems introduce one of those fallacies into the design, it produces subtle defects under production loads. Businesses combat these risks through high-availability architectural patterns that promote self-healing (Yang, Min, Yang, & Li, 2014). These strategies follow combinations of reactive (e.g., heart-beating) and proactive solutions (e.g., rejuvenation tactics).

There are inherent challenges with every high-availability solution. For instance, state checkpointing requires periodically writing memory to disk. This operation is exceptionally I/O intensive and significantly degrades performance, despite only a few of these snapshots ever used (Cheng, Huang, & Lee, 2019; Wu, Shang, Peng, & Wolter, 2020). Organizations that can remove these performance penalties could reduce resource requirements, improve Quality of Service (QoS), and become more competitive through cost reductions.

Another standard approach is through fail-over clustering and disaster recovery technics. This requirement translates into resource over-allocation and accepting wastefulness (Yan & Wang, 2020). Meanwhile, cloud-native systems support instantaneous provisioning, elasticity and can go global in minutes. These capabilities promote more efficient scheduling and allocation methodologies. However, even mature businesses limit their cloud exploitation to stateless, not stateful, services. Architects need to define frugal patterns that lead to reliable systems operating above unreliable and dynamic hardware.

# Problem Statement

           Traditional monolithic systems implement high availability within the finite constraints of private data centers. In contrast, cloud-native solutions exploit virtually infinite scalability across multiple global regions. Despite this additional flexibility, most businesses do not fully use the performant high availability potential of operating on public cloud platforms. Researchers must define new architectural tactics that leverage the cloud’s unique characteristics.

The dichotomy of traditional and the potential for cloud-native high availability is most apparent with stateful services. Unlike stateless services, it is challenging to handle stop-faults elegantly. Platforms like Apache Spark, Flink, and Storm mitigate these concerns through checkpointing. However, this solution decreases overall throughput by 35-40% (455-570MB/s versus 755-900MB/s) (Cheng, Huang, & Lee, 2019, p. 12). Businesses must provide extra resources to offset this degradation. Increasing the cluster size also means higher failure rates due to more significant cross-component communication needs and higher I/O requirements.

More ideally, software platforms decompose the processing nodes into a collection of micro-services. These components can execute across dedicated hardware that does not impact the performance-critical path. Cloud providers also expose features that replicate and multicast information across distinct nodes. While these technologies are not unique to the cloud, they are historically cost-prohibitive and only available within enterprise topologies. In contrast, public cloud providers have democratic access to sophisticated technologies.

# Goal

Architecture teams must define modern high-availability mechanisms that exploit the cloud’s capabilities. This constructive research core deliverable implements a benchmark of streaming applications that follow cloud-native patterns. The model will cover several standard use-cases (e.g., WordCount and StreamGrep) while minimizing overhead through high-availability micro-structures. Second, an assessment will confirm that these micro-structures are generalizable by examining an open-source platform’s internal requirements, such as Apache Spark or PostgreSQL.

# Relevance and Significance

Modern applications are moving toward micro-service architectures that require zero downtime (Rudrabhatla, 2020). Businesses meet these requirements through mechanisms that use excessive resources. Alternatively, cloud-native solutions would reduce costs and complexity. When organizations become more efficient, it increases their competitiveness. This characteristic makes these optimizations broadly applicable.

# Literature Review

The current academic literature presents several themes toward building performant applications with high-availability capabilities.

## Disaster Recovery Techniques in Cloud Computing

Distributed systems are complex environments that must defend against a litany of sources. Tamimi et al. (2019) provide a taxonomy with top-level origins, including natural disasters, network failures, network intrusions, system failures, malicious code, and human errors. Unsurprisingly, human error accounts for nearly 60% of all issues.

When a service outage occurs, the business needs to restore operations through a remediation strategy. “Broadly speaking, all those [recovery] techniques focus on three different aspects, such as cost control, data duplication and security issues (Tamimi, Dawood, & Sadaqa, 2019, p. 847).” Each workload within an organization comes with unique characteristics that dictate the Recovery Time/Point Objective (RTO/RPO) requires. Consider a FinTech company that hosts both an internal payroll portal and a real-time trading application. If the trading system is offline, the business risks significant losses relative to the human resource app. Mitigating that financial loss justifies higher costs and complexity.

## Deployment Challenges

Modern businesses use Continuous Integration and Deployment (CI/CD) pipelines to release production updates multiple times per day. This requirement introduces complexity for high-availability systems that seek to maintain zero downtime. Rudrabhatla (2020) presents constructive research into rolling, blue-green, and canary methodologies, stating the core difference is the cost, duplication, and security. These observations directly overlap with Tamimi et al. (2020). Blue-Green deployments refer to duplicating the environment and using load-balancer or DNS (Domain Name Service) magic to toggle between them. This strategy has the most safety but also the highest cost.

## Evolution of Clustering Strategies

           Cheng et al. (2005) describe a case study with International Technology Roadmap for Semiconductor’s Factory Information and Control Systems (FIC). This mission-critical system cannot exceed 240 minutes of downtime annually (99.95% uptime).

Similar to other companies, FICS relies on clustering services. Under the covers, these solutions employ a heart beating mechanism to discover compute-node failures. Additional custom client middleware also transparently retries failures. Despite these architectural protections, the operations team still found it challenging to meet this aggressive Service Level Objective (SLO).

           The engineers began collecting metrics, leading to the discovery that node failure is proportional to service instance age (total runtime). This revelation makes logical sense, as long-running processes have more opportunities to become corrupt or leak resources. They began collecting data to predict Mean Time To Failure (MTTR) per service. Today, FCIS experiences than 120 minutes of annual downtime (99.98% availability).

Wen et al. (2020) presents research into Kubernetes container task placement strategies.  Kubernetes is a container orchestration system that supports policies for physically distributing workloads. For instance, they span Elastic Search across four physical nodes, demonstrating that rebooting hosts does not impact system availability. Finally, the authors present a series of equations that maximize resiliency and minimize hardware requirements.

Dedicated fail-over clusters increase availability and operational costs by prematurely provisioning idle resources. Yan & Wang (2020) propose upgrading traditional active & passive models (1+1) for H+K configurations. Essentially, administrators deploy H-service instances plus K-extra nodes. Then the environment can maintain full availability until K-concurrent failures.

## Reliability Constructs

Zhao (2014) documents multiple strategies for building dependable distributed systems. Their patterns cluster into partitioning, checkpointing, and consensus constructs (see Table 1). Engineers can freely mix and match elements to form defense-in-depth architectural designs. Consider a resource-intensive application that spans multiple server racks. Administrators could use partitioning schemes to constrain the blast radius of the rack’s edge router. Programs with smaller logical units are simpler to backup and operate because of reduced internal state size and cross-component communication of requirements.

Table 1: Reliability Patterns

|  |  |
| --- | --- |
| Construct Method | Unique Characteristics |
| Partitioning | 1. Failure domain that is constraining impact of error 2. Serve as a logical horizontal scaling unit |
| Checkpointing | 1. It follows a fetch-do-persist-acknowledge loop 2. State is Write-Many-Read-Maybe |
| Consensus | 1. Decentralized event processing 2. Eventually consistent reconciliation |

Wu et al. (2020) examine Apache Kafka-based streaming applications’ performance metrics under different checkpointing and batch-sizing configurations. They demonstrate that adjusting the frequency and sizing influences dequeuing speeds by 10x (102 to 103 ms). After collecting a timeliness custom-metric, the authors construct an Artificial Neural Network (ANN) that optimistically issues the checkpoints.

Instead of reducing the checkpointing frequency, Cheng et al. (2019) seek to remove it entirely. Their empirical study compares the performance of removing event durability entirely from standard open-source products (e.g., Apache Storm, Flink, Spark). Next, replaying open-source data sets (14 to 45GiB each) enables measuring several streaming use-cases' reliability (e.g., online learning and event joining). Their results show that even the non-checkpointed stress tests asymptote at 92.5% accuracy.

Verbitski et al. (2018) present the Amazon Aurora database, a cloud-native database that avoids distributed consensus. They improve write performance by supporting per node append-only transaction logs. This approach avoids write-contention and the need to update previous blocks. When a consistent system view is necessary, then the storage layer projects a virtual point-in-time view. The view reassembles the individual transaction logs without requiring any locking. Their elegant solution is generalizable and applicable to other database technologies.

The literature review encapsulates several themes that must appear in future constructive research. First, high-availability systems must defend against numerous operational risks, such as deployment management, operator error, and acts of God. However, mitigating those risks adds significant overhead, especially when considering they rarely factor into operations. This situation requires businesses to balance protections through ‘art-not-science.’ Second, there are combinations of traditional architecture technics that likely need modernization. For example, cloud databases can access arbitrarily large disk volumes, simplifying immutable storage patterns.

# Approach

The research applies themes from the literature review across real-time stream processing applications and quantifies any gains to reliability, availability, throughput, and response time.

## Delivery Format

This constructive research delivers a collection of scenario-specific stream processing applications that minimize resource waste. Quality research must be complex, elegant, and valuable (Zeller, 2014). Meeting that expectation means that the results must be broadly applicable to many modern applications, ideally as Quality of Service (QoS) and costing models. That format enables engineering and operations teams to assess value quickly.

## Proposed Timeline

Northcentral University allocates research into eight-week blocks. Given the limited budget, the project cannot spend more than six weeks experimenting and two weeks authoring results (see Table 2).

|  |  |  |
| --- | --- | --- |
| Week# | Title | Success Criteria |
| 1 | Setup developer environment | Automation deploys and executes a hello-world benchmark |
| 2 | Identify and include additional use-cases and benchmark data | Document selected scenarios and decision rationale |
| 3 | Identification of architectural costs | Instrument and assess the distribution of runtime costs |
| 4 | Propose design modifications | Document recommendations and potential system changes |
| 5 | Implement recommendations | Document status update and link to pull request |
| 6 | Implement recommendations | Complete changes and briefly document progress |
| 7 | Measure the influence of changes | Document the procedure and results |
| 8 | Document research findings | Construct a 5-page journal article that covers progress, results, and observations |

## Assessment Structure

Similar to Cheng et al. (2019) and Wu et al. (2020), predefined open-source datasets will flow through stream processing applications that operate across one (or two) different runtime platforms (e.g., Apache Spark or custom implementation). While events stream across the topology, telemetry will measure the runtime statistics of the individual components. The metrics will confirm or deny the literature review’s assessment that storage architecture is the most performance-critical subsystems. Next, different cloud-native architectural patterns will improve those areas’ reliability, availability, throughput, and response time.

While previous efforts must constrain solutions to finite resources, these architectural patterns can assume elasticity, intelligent data replication, and additional sophisticated cloud services. This agility and freedom enable experimentation, such as reducing traffic via multicasting networks or incorporating shared memory blocks. Each experiment needs to be minimally invasive to the existing codebases. Finally, rerunning the relevant benchmarks will measure the modification’s utility.

# Conclusions

Public Cloud Providers offer applications the ability to scale, replicate data, and consume higher-level services elastically. These dynamic properties lessen constraints that exist for traditional applications that operate within private datacenters. Historically, businesses address high availability through methodologies that are wasteful and impactful toward performance. Now, research must evolve these architectural patterns that leverage cloud-native environments. For instance, monolithic worker nodes become swarms of micro-services that operate across role-specific hardware (e.g., memory-optimized) and employ sophisticated replication solutions. After decomposing components, the cluster management system can enact a more granular auto-scaling policy.

The upcoming constructive research will assess different cloud optimizations, then define QoS and costing models. Calculating the model requires streaming benchmarks through open-source frameworks and measuring the total costing. Likely the bottlenecks exist with the storage layer and necessitate modernization. Finally, those changes will be quantified and ideally prove generalizable.

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