Section 3: Week 7: Reliable Cloud Data Ingestion

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# Reliable Cloud Data Ingestion

Contoso is a provider of online student analytic services with a vast collection of microservices hosted in their private data centers. A tenant of micro-service design states that each component should ‘share-nothing,’ including data stores. This reduces the blast radius and improves the resiliency of the overall system. They need a mechanism to efficiently transition their product lines from private data centers into the public cloud. These heterogeneous private data stores can introduce challenges for that migration as they need to become hydrated afterward. Substantial amounts of literature exist for trivial ‘lift and shift’ paradigms upon an individual store. However, less research has taken place on reliably hydrating networks of integrated data stores.

# Background

Many businesses like Contoso are actively working to transition their proprietary systems into the public cloud. This reduces infrastructure costs and improves the agility to create new features for their customer base. These strengths are well documented through highly optimized ‘pay per use’ pricing models and instant access to virtually unlimited resources. For many enterprise businesses, the journey to the cloud can be complicated, as it requires moving their proprietary systems into new environments. There are two supersets of issues (1) getting the infrastructure to the cloud; and (2) migrating the customer data into the new cloud stores.

Business stakeholders often take a conservative position during cloud migrations and are hesitant to ‘flip the switch’ across all customers. This leads to deployment decisions such as creating a (1) dedicated deployment instance in the cloud; and (2) then hydrating the history of select customers across multiple migration iterations. Transitioning a handful of customers per iteration reduces the blast radius and simplifies the communication across stakeholders in exchange for more time to complete the project (Ferdiana & Putra, 2018).

Due to the longevity of the migration project, the system state can end up in an ‘arbitrary flux.’ This occurs from (1) new features being added, (2) internal implementation details changing, and (3) unused features being removed. The data migration process has three choices to mitigate these issues: (a) create and maintain bulk load interface for each data store; (b) replay the historic traffic through the steady-state interface, or (c) a combination of (a) and (b). If the system has (1) many heterogenous private data stores; and (2) a high degree of data connectivity between them; then it could be prohibitively expensive to choose option (a). Consider the scenario where events cascade such as ‘service A’ emits N events to ‘service B,’ which in turn emits M events to ‘service C.’ To externally model this could duplicate large amounts of business logic and be error-prone over time. Another reason for businesses to desire (b) is that improvements to the data migration scenario are improvements shared by the general customer. Shared fixes can include general correctness, backward compatibility assurances, performance and scalability scenarios.

There are micro-services where scenario (a) is desired in combination with (b). A business might have archives of physics simulations, where each required several days to render. In this example, they might choose to maintain an out of band process for moving the models while replaying the metadata through a steady-state ingestion pipeline. Within the context of this proposal, it is assumed that the business chose option (b) or (c) due to option (a) being prohibitively expensive to build and maintain. Another key advantage of selecting the scenario (b) is that it makes both data migration and data ingestion identical. This can reduce the maintenance overhead while increasing consistency.

# Problem Statement

Cloud Migration Strategies tend to center around (1) getting the infrastructure; and (2) populating the data into the new environment. For enterprise customers with large numbers of micro-services there are challenges to accomplishing both. Patterns regarding the movement of infrastructure into the cloud are a well-studied problem, thanks in part to virtualization and containerization technologies (Cefaratti & Lin, 2018) (Ahmad, Naveed, & Noda, 2018). A lesser studied scenario is data migration and methods for overcoming their inherent challenges.

Consider the scenario where a bulk migration of 10 million records traverses a component with a 0.01% failure rate. This will produce 1,000 instances of the defect, which can impact results across several customers. If all issues within the product code can be resolved, there will still be issues due to the underlying system being built on commoditized hardware. An expectation of failure needs to exist within the data migration and ingestion scenarios.

Another challenge is optimizing the throughput rates that ingestions should target. If the pace is too slow it will never complete, yet too fast, and it causes scalability issues across the infrastructure. These scalability issues will increase the failure rates and create a rippling effect. If the system were set to scale infinitely then it would become too costly to operate. This would lessen the competitive gain from moving to the cloud and place an unjust financial burden on the business. While that might be acceptable for a short period it has already been stated that an entire enterprise migration could last years.

# Goals

## Max Flow Model

These challenges could be restated as there is a need to solve the ‘min-cost max-flow’ (MCMF) across the distributed architecture. There is also a need to model which junctions lead to bottlenecks or are over-provisioned. For instance, if ‘service X’ is bound by the scale of ‘service Y,’ then either X needs to be reduced for cost savings purposes.

The primary goal of this study would be to identify the features which are most critical to the maximum flow model. Consider a component that can only process ‘N records per second.’ In cloud environments, the ability to add or remove unlimited resources changes the dimensionality into ‘N records per V virtual cores per M gigabytes of memory.’ Once these optimization points are identified, then a system can be created to provide recommendations to the operations team or apply them automatically. This would result in economic gains in terms of reduced labor overhead and fewer billable cloud resources.

## Min Error Rate

Another objective is to maximize the flow of records while minimizing the number of failures. Writing error-free distributed source code is an extremely complex problem. A domain-specific language (DSL) could be created to describe the distributed compensation policy. This would ensure consistency of remediation rules.

If the system is capable of self-healing, then fewer concerns would exist regarding availability, and the net ingestion rate can be increased. It would also reduce the number of customers reported support requests as the holistic system becomes more resilient.

## Define New Patterns

Multi-casting data to several unreliable receivers is not a unique problem and is shared by several sciences. These challenges are well-studied in specific electrical and consumer broadcast communication systems. A more in-depth investigation needs to exist to determine how those learnings can be applied to this use case.

# Relevance and Significance

Businesses of all shapes and sizes are actively migrating their workloads onto the public cloud. If they can determine bottlenecks in the hydration process, then it is possible to prioritize changes that lead to the maximum return. This can expedite their journey and begin reaping the benefits of that transformation.

Reliably ingesting large quantities of data is not the only scenario that would benefit from this research. For example, auto-scaling legacy services can introduce its own set of challenges. Today businesses often rely on simple metrics such as CPU rates to signal a change to service instance counts. This can be inefficient as it *reacts* to the degradation of *individual* service. Instead, a holistic flow model could *preemptively* determinethe increase in load requires *multiple* services needing to scale in unison. When services are expanding in harmony, there is less risk that the throughput of one system overruns its dependencies. All distributed micro-services rely on notifications to be reliably transmitted between one another. For many scenarios, the cost of processing duplicate messages is less than the price of missing the event entirely. That is not to say that all traffic should be redundantly sent. However, there are potentially encoding schemes that allow for the introduction of parity bits and auto-remediation. These self-healing solutions would increase the fault tolerance of the entire system and provide a more positive user experience to all consumers of the service.

# Literature Review

There are four core literature scenarios that were reviewed (1) cloud migration challenges and strategies; (2) maximum flow and graph analysis; (3); reliable distributed systems; and (4) distributed transactional management.

## Cloud Migration Challenges and Strategies

In *A Review of Cloud Migration Strategies in the Developing Countries*, Ferdiana and Putra performed an extensive survey of challenges that face cloud adoption. The issues facing developing countries can also be a proxy for smaller enterprise environments (<=1B$). This is due to their limited access to funding and resources. Two of the most frequent challenges identified were (1) data migration issues; and (2) conservative business cultures.

In *Strategy and procedures for Migration to the Cloud Computing*; Ahmad, Naveed, and Hoda define the six R’s of migration as Re-host, Re-platform, Re-purchase, Re-factor, Retain, and Retire. They continued with an investigation into the ‘state-of-art’ implementations for these ideas. The journal also defines levels of cloud maturity, which businesses transcend across their journey. While significant attention is provided to the infrastructure, little was stated around data migration strategies.

In *Exploring Data Center Migration: A Case Study*, Cefaratti, and Lin provide a postmortem for a successful enterprise migration. Their use case impacted 80,000 users as the workload transitioned from a private data center to the public cloud. Thematically planning and effective communication were provided as primary drivers of success. A strong focus on infrastructure was also presented with little attention to data migration. It appears they used a relied on a standard ‘lift and shift’ approach into IaaS.

## Maximum Flow and Graph Algorithms

In *Efficient Maximum Flow Algorithms*, Goldberg and Tarjan provide a broad overview of scenarios that can be addressed with ‘max flow’ algorithms. They describe optimizations that exist in various concrete examples. Many of these examples resonated with the challenges of the data hydration scenarios.

In *Modeling and Optimizing of Renewable-Energy Sharing*, Benda, Chu, Quek, and Buckley describe the challenges of harvesting and distributing power between a mesh of base stations. Their analysis showed that using a ‘min-cost max-flow’ (MCMF) over ‘max-flow’ (MF) model resulted in a 30% savings with equivalent output. The structure of the problem is like the hydration scenarios, which suggests it could be advantageous to use a similar solution.

In *A Study on Rapid Incremental Max Flow in Dynamic Networks*, Wang and Ling provide algorithms on top of classical ‘max-flow’ (MF), which efficiently accepts partial updates across the dynamic network. If the MF can be cheaply recalculated, then it allows for auto scalers to be more responsive.

## Reliability Patterns

In *Reliability of Multicast under Random Linear Network Coding*, Tsimbalo, Tassi, and Piechocki describe the challenges encountered with transmitting television signals. They provide an enhancement over traditional Application Level Correction (AL-FEC), through a notion of parity encoding. Consider the scenario where a sender has access to 3 channels and needs to post messages A and B. If they send one message per channel encoded as (A), (A+B), (B); then a consumer subscribed to all three channels could miss 1/3rd of the messages without data loss.

In *Reliability and Availability Issues in Distributed Component Object Model*; Wang, Damani, and Lee propose a collection of aspects that can be injected into existing DCOM services. This adds capabilities such as automated state checkpointing, which enables stateful objects to periodically die without impacting the broader system. This idea aligns with the objective of the system to self-heal.

In *Scalable Eventually Consistent Counters Over Unreliable Networks*, Almedia and Baquero propose a scheme for incrementing a distributed counter such that no numbers are skipped or repeated twice. This is accomplished through Conflict-free Replicated Data Types (CRDT) and can be expanded to any scenario that needs assurances all elements in a set are processed exactly once. The capability could be leveraged by a Distributed Transaction Manager (DTM) to be guaranteed a transaction has not already been compensated.

In *A Comprehensive Survey on Distributed Transactions*, Bharati and Attar performed an extensive review of methods available for ensuring consistency across a replicated record-set. Their survey includes techniques for heterogeneous data stores, which is directly applicable to the data ingestion and self-healing scenarios.

## Distributed Transactional Management

In *SagaMAS: a framework for distributed transactions in microservice architecture*; Limon et al. combine the ideas of the Saga Pattern with Multi-Agent Systems. A Saga is defined as a sequence of local operations that become eventually consistent. This occurs through either an orchestrator (e.g. central service) or choreographer (e.g. log monitor). Saga MAS constructs a tree structure with each node containing the tuple (id, name, data, action name, compensation action). The tree is continuously pruned by invoking either action on a leaf node until the operation is successful.

In *the Prometheus Methodology*, Winikoff and Padgham provide design requirements for the co-existence of the multi-agent system. The lectures suggest best results are achieved by (1) building the system in terms of goals and (2) aligning the agent’s functionality with the objectives. This is the approach that *SagaMAS* referenced extensively and proposed in their work.

# Approach

## Summary of Approach

Based on the guidance of the literature review, there are two systems that need to co-exist. The first is an auto-scaling solution that uses an MCMF model to ensure that the resources are efficiently sized based on a collection of dimensions. The second needs the ability to detect hydration failures and apply to compensate actions as a mechanism for self-healing. If the system can dynamically scale based on a set of metrics, then it would process the records in the most resource-efficient manner. From the model, it should also be possible to identify bottlenecks in the distributed call graph of micro-services. This can lead to prioritized improvements that provide the maximum return on investment. Even with an entirely error-free system, there will still be failures that the application must be able to correct without manual intervention.

## Max Flow Model

The first objective is to build a model that encompasses the required information to determine the MCMF flow. Using an MCMF function instead of MF has the potential to provide a more efficient solution (Benda, Chu, Sun, Quek, & Buckley, 2018). The optimization target would be increasing the number of records per second through the entire system. There are several potential system aspects to minimize such as (1) total billable cost; (2) total faults; or (3) a domain-specific metric. After the model can reliably tell the desired state of the system, it needs to compare against the actual state. If the deviation exceeds a threshold, then the system needs to compensate through initiating auto-scale requests. As the scale requests are invoked callbacks can notify the model of incremental changes without recomputing the entire graph (Wang, Y; Ling, J, 2018). For large enterprise environments, this will become critical as there can be thousands of highly connected components.

It would also be beneficial to expose a domain-specific language (DSL) to express service connectivity, configuration, and thresholds. This would simplify the end-user experience and limit their direct interaction with the system. Many enterprises already have this information described through Infrastructure as Code (IaC) languages. It could be advantageous to include a translator for 1 or 2 of the most common IaC languages (e.g. Terraform and Puppet). The final deliverable for this goal would be to deliver a dashboard that shows the operations team how much the auto scale system has reduced its cloud bill. It would also be beneficial to surface how many additional events were processed due to the modifications. Any other measurements of success could also be rendered in simple graphical form.

## Min Error Rate

Implementing a Distributed Transaction Management (DTM) protocol based on Sagas could improve the reliability of the broader system. This can be accomplished by having components emitting schematized intents into log files. Those logs could then be mined by a decoupled service that constructs a tree of desired actions and compensations (Limon, et al, 2018).

If the system discovers success confirmation messages are missing, then it can automatically apply the compensations to self-heal failures to the system. An investigation is required to determine the correct pattern to acknowledge a transaction completed. As reported by Bharati and Attar, there are numerous variations with slight performance and consistency considerations. There could be challenges with expressing the distributed transaction semantics within the micro-service code itself. It is also undesirable to make modifications each time the configuration changes. To mitigate these issues, a DSL could be defined for instrumenting common scenarios, at build time and express distributed component dependencies. Based on the configuration of the transaction, compensation could have ‘at-least-once or at-most-once’ semantics. Using a CRDT structure would allow the DTM to honor those requirements even though it is also a distributed asynchronous entity. (Almeida & Baquero, 2013)

The success of this deliverable could be measured through a simple KPI that states the number of self-healed operations. Based on the intent tree structure other metrics could be extracted, such as failures that were not correctly recovered.

## Define New Patterns

Introducing parity information into redundant messages is a unique idea that could be very helpful in specific lossy scenarios (Tsimbalo, Tassi, & Piechocki, 2017). This could be implemented as an extension to the Http Client, which keeps a sliding window of recent messages. These messages could be sent first in their original form and then later in a RAID-like combination. Services that support the encoding could then decode the words and process only those that were missed. To determine if the word was not present Almedia and Baquero’s CRDT solution could be used here as well.

Another deliverable of this objective is to determine what additional ideas are present in global communication systems and are applicable to these data ingestion scenarios. To measure the success of this feature, performance metrics should be published to identify the number of times this helped verses became a no-op.

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