Department of Electrical and Computer Engineering
University of Victoria
SENG 462 — Distributed Systems and the Internet

Project Report

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Overview

The goal of the project was to build a distributed day trading system, with a focus on performance. The client original stated the following actions as business requirements:

- View their account
- Add money to their account
- Get a stock Quote
- Buy a number of shares in a stock
- Sell a number of shares in a stock they own
- Set an automated sell point for a stock
- Set a automated but point for a stock
- Review their complete list of transactions
- Cancel a specified transaction prior to its being committed
- Commit a transaction

Additionally, the overall architectural goals of the system were:

- Minimum transaction processing times.
- Full support for required features.
- Reliability and maintainability of the system.
- High availability and fault recoverability (i.e. proper use of fault tolerance)
- Minimal costs (development, hardware, maintenance, etc.)
- Clean design that is easily understandable and maintainable.
- Appropriate security
- A clean web-client interface.

These requirements form the basis for the distributed daytrading system commissioned by DayTrading Inc.

Chapter 1

Architecture

1.1 Original architecture

Can steal most of this from the first report.

1.2 Technology

1.2.1 Golang

1.2.2 RabbitMQ

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1.2.5 Websockets

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1.4.3 Audit logger

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Chapter 2

Security

lol. just lol.

Chapter 3

Test plan

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Validate command pre/post conditions. Tested through FE?

Chapter 4

Fault tolerance

Chapter 5

Performance analysis

5.1 Decreasing quote retrieval time

5.1.1 Statistical analysis of legacy quote server

5.1.2 Using timeouts to ensure fast quote retrieval

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Chapter 6

Capacity planning

Progressing through the series of workload files stresses different parts of the trading system architecture. Workload files differ by the number of unique users, quotes and total transactions. Early workload files have few unique users and quotes but rapidly increase the number of transactions. The primary design goal becomes minimizing individual transaction times. Later workloads rapidly increase the number of unique users and quotes, exposing inefficiencies in different parts of the system that were often the result of optimizing a design for high transaction throughput for early workloads.

This chapter outlines the often surprising manner in which our system failed as we progressed through the workloads, and the design changes that followed. Most often, the manner of failure was the result of an assumption that would be true at smaller scales but became invalid at a later point.

6.1 Logging throughput

The 1000 user workload was the first occasion for our system to operate at nominal TPS for a significant portion of its runtime. Since each transaction needed to write at least one entry to the audit log the volume of log messages was unprecedented. Controlling the "firehose" of log messages was the most significant architectural redesign. It included several false starts and, ultimately, reached a workable but flawed solution.

link to image with 100 v 1000 tps

6.1.1 Limits of logging to a flat file

From the initial prototype through the 100 user workload, the audit service wrote directly to an `.xml` file that could be submitted for validation. Log messages were removed from RMQ and stored in memory for writing by separate threads. However, running the 1000 user workload exceeded the rate that the audit service could clear messages from RMQ, causing a significant backlog of messages to develop. As the total message backlog size approached 700k the rate that messages could be exchanged slowed, causing a slowdown in the rest of the system as execution was blocked on message exchange. Soon after, services would fail as they lost their connection to the RMQ server.

As noted in the "Production Checklist" section of the RMQ user guide[1], performance is heavily tied to available RAM. As the backlog increases RMQ will begin swapping RAM to disk to ensure persistence. The IO penalty for writing to disk causes an intense slowdown. Since the worker services generating the logs are not capable of throttling they eventually push RMQ into resource exhaustion and failure.

Direct to file logging was never intended for production use. Creating per-user dumplogs would be onerous since there was no direct method for searching or sorting the log file. Leaving

[1] https://www.rabbitmq.com/production-checklist.html

the log file implementation in place for most of the project allowed us to focus development efforts on optimizing the quote manager and implementing the auto transaction service. Letting RMQ fail illuminated the "danger zone" for RMQ on the lab machines. Different audit logger refactors could be compared for effectiveness by monitoring the RMQ backlog.

6.1.2 Logging directly to an RDBMS

The first refactor involved inserting logs into Postgres and writing to a file on an as-requested basis. This solved the problem of creating per-user log files but throughput was significantly worse than writing direct to a file. With direct to file, the 100 user workload with 100k transactions generated 2k backlogged messages on RMQ. With the Postgres refactor, the 100 user workload resulted in a 20k message backlog. No attempts at larger workloads were made after this poor result.

This performance slowdown is not surprising. The flat file and RDBMS both store the preformatted `.xml` entry for the event. In addition, the RDBMS stores extra data about the user name, transaction type and creation time to enable queries. The RDBMS is storing more data than the flat file. In addition, the RDBMS suffers a performance penalty from indexing data on insertion. While there are methods to mitigate these problems, such as connection pooling, the performance degredation was extreme enough to justify larger service refactors.

6.1.3 Processing logs with ELK

An RDBMS enables rich querying and enforces data integrity — useful features that are not relevant for storing an append-only log. Moreover, the indexing that provides those useful features introduces a performance penalty that limits throughput. Specialized log storage solutions forgo rich indexing in order to maximize write throughput.

The Elasticsearch - Logstash - Kibana (ELK) suite of applications from elastic.co[2] is a popular distributed log storage method. Logstash consumes and transforms data for indexing and storage in Elasticsearch. Kibana is a graphical monitoring suite that provides information about the logging rate and health of the logstash and elasticsearch services.

A prototype was created that deployed the ELK stack in separate Docker containers collocated with the audit logger. Logstash consumed messages directly from RMQ and sent them to Elasticsearch for indexing and storage. The prototype had abysmal performance. With the 45 user workload there was a 7k (out of 10k total) backlog. Development was abandoned at this point.

The poor performance of the ELK stack was directly related to its resource limitations. Each part of the ELK stack performs better with more available RAM. Collocating all services severely limited the available RAM. Also, ELK requires a non-trivial amount of JVM and OS tuning to provide optimal resource availability. Although there are guides for this process it was unclear how to apply their recommendations on the tower of abstractions in the production environment: a docker OS on a VM OS on a host OS, each needing their own tuning.

The Elasticsearch scaling guide[3] recommends adding more shards (i.e. independent instances which maintain a partition of the data) to increase write throughput. This throughput solution — a distributed system within a distributed system — directly links scaling to resource demand. Scaling Elasticsearch would likely reduce the number of systems available to host workers and limit the maximum TPS. The problem of high log throughput would be solved by removing the ability to create logs at a high rate.

[2] https://www.elastic.co

[3] https://www.elastic.co/guide/en/elasticsearch/guide/current/scale.html

6.1.4 Buffered logging

The problem with the RDBMS solution in 6.1.2 is fundamentally a mismatch between the production and consumption rate of log messages. The solution to this problem is to place a buffer between the producer and consumer.

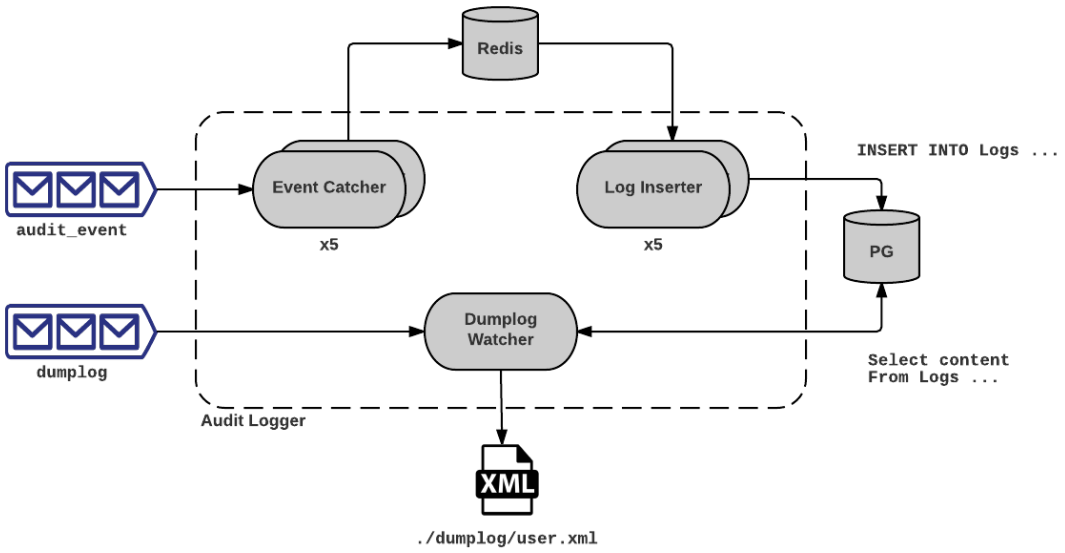

Figure 6.1: Buffered audit logger

Figure 6.1 shows how multiple `Event Catcher` workers remove incoming log messages from RMQ and place them in Redis. `Log Inserter` workers remove items from Redis and store them in Postgres. With this design, the 1000 user workload only reached a 20k backlog of messages and had no observed performance degradation. Although a run would finish in around 45 s it would be upwards of 6 min to finish insertion into Postgres. When a message for a dumplog was processed it would display messages had successfully migrated to Postgres but was unaware of those still in Redis. This is a soft violation of the business requirement that a dumplog should show all transactions proceeding itself. We believe this is acceptable since, in actual use, there is no clear "end of work" to capture. All log messages will make it into Postgres for querying so the requirement is *eventually* satisfied.

This method has an upper limit to its effectiveness since the Redis buffer could run out of storage space under periods of sustained high TPS. The boundary of the buffer memory was not encountered during any testing and we cannot speculate about its value. In order to determine the limits we would need a workload file larger than the final workload. Alternatively, we could induce a period of sustained high TPS by removing the requirement to re-fetch expired quotes and concatenate existing workloads.

6.1.5 Alternate solutions

When the buffer method in 6.1.4 reaches its limit there are several possible development paths for proceeding forward:

1. *Agglomerate messages*: Message traffic can be reduced by combining multiple log events into one message. Workers would only emit messages for logging at fixed intervals or after a certain number of events (whichever comes first) and reduce the overhead associated with creating, sending and processing RMQ messages. The optimal message size would have to be determined through experiment.

2. *RMQ scaling*: RMQ is capable of its own distributed deployment. Increasing resources available to the message bus would allow more messages to be stored before removal into the buffer.

3. *Robust message passing*: Apache's Kafka[4] provides functionality similar to RMQ but is optimized for message storage and large backlogs. This allows consumers to operate at different rates and removes the need to process log messages faster.

6.2 Quote manager scaling

The system's TPS grows almost 10× once a full set of quotes has been retrieved. further increases to average TPS could be gained by decreasing the time spent fetching quotes. The methods in 5.1 brought the quote server response time to its lower limit so further efficiency could only come from horizontally scaling the quote managers. Intuitively, doubling the number of quote managers should decrease the total time to retrieve all quotes by half, provided the workload is split evenly. If only it were so simple.

6.2.1 Building a "snoopy" quote manager

With one week until the final deadline we decided to refactor the quote manager to participate in a multi-quote manager environment. We ported the "snoopy caching" functionality from the worker and audit logger into the quote manager. The "snoopy" quote server could listen to quote broadcasts and update its local cache accordingly. With this functionality, multiple quote managers could act as workers servicing requests from a single RMQ queue.

A message header with the ID of the quote manager that serviced the request was added to all quote broadcasts. The quote manager cache updaters would discard messages that originated from its own quote manager. This is inefficient but necessary because RMQ does not allow an "anti-match" for message routing keys. That is, one cannot specify, "Capture all messages *except* ones that follow this pattern."

Total development effort was approximately one hour.

6.2.2 Performance analysis

Figure 6.2 shows that TPS correlates *negatively* with the number of snoopy quote managers. This is very counter-intuitive and deserves reflection.

Comparing the single quote manager deployment in multi and single architectures gives a sense of the overhead associated with discarding quote broadcasts. The relation becomes less clear when two and three quote managers are used: the system benefits from having to retrieve fewer quotes per quote manager but adding quotes to the cache also has a delay. The benefits from horizontal scaling start to manifest when three quote managers are used, but it takes the form of, "things stopped getting worse," instead of "performed better than a single quote manager."

The single architecture quote manager is very fast because it already functions like a multi machine quote manager. Each new request spawns a thread that handles communication with the legacy service. Most of the threads are blocking on a response from the legacy service making it very likely that a new thread will find the application in an idle state. Since workers block on the completion of a quote command the maximum number of simultaneous quote requests is equal to the number of workers. Hence, the number of threads requesting quotes in the quote manager is capped, thus preventing thread creation runaways and CPU starvation in the quote manager. Adding more quote managers doesn't increase the number of simultaneous quotes that can be requested by workers.

[4] https://kafka.apache.org

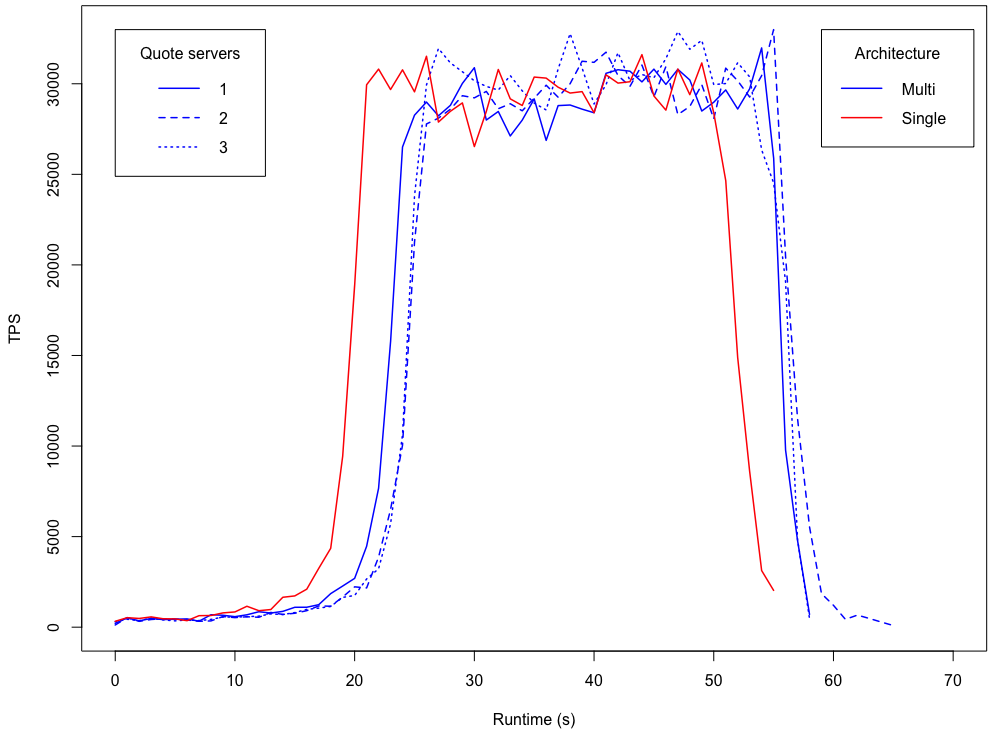

Figure 6.2: Performance of multi and single quote manager designs on 1000 user workload

6.2.3 Alternate solutions

The snoopy quote manager was implemented because it was a small amount of development effort for a large potential payoff. There is another way to implement multiple quote managers, although it is more complicated: quote symbols could be hashed to associate with unique quote managers. This prevents the need for quote managers to do snoopy caching. However, it introduces problems with scaling since the hash will depend on the number of available quote managers.

The snoopy quote manager can scale easier since failures would be independent. As the number of workers continues to grow, Figure 6.2 should be re-run to determine the break point between the communication overhead and the increased capacity for simultaneous quote requests.

6.3 Worker loading

Appendix A My appendix

Here is some text for my appendix.