

Building a Social Media Platform Capable of Scaling to a Million Users Overnight

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Abstract

The creation of Omni, a scalable social media platform made especially for junior software engineers to share personal projects and create professional portfolios, is examined in this dissertation. The project aims to develop a system that can support viral user growth to millions of users with little performance degradation, acknowledging the shortcomings of current platforms like LinkedIn in catering to this demographic. Omni uses a Kubernetes-enabled microservices architecture, with a GoLang-developed backend and a frontend that makes use of Go templates, HTMX, and TailwindCSS. The platform's data management approach is supported by a horizontally scalable MariaDB database that makes use of Snowflake IDs for effective sharding. The platform's capacity to adapt to growing demand was demonstrated by integrating observability through structured logging and metrics collection and validating scalability through load testing in a Kubernetes environment. User surveys were used to assess the platform's usability and suitability for the intended audience. In order to further improve platform performance and user experience, the project ends with a reflection on future work that includes the addition of recommendation algorithms, real-time event streaming, and caching mechanisms.

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Chapter 1

Introduction

1.1 Motivation

In today’s increasingly digital-centred landscape, social media can transform lives and connect us in ways our ancestors could never have imagined. Social media enables friends and family to share their lives, connects customers to businesses directly, allows fans to interact with their sports teams and players, and helps employees find new jobs. Social media has allowed us to connect more and “play a positive role in strengthening the relationship between friends” (Chen et al. 2016).

One such social network that has seen consistent growth is LinkedIn. This professional social network connects professionals across all industries with their peers and colleagues. Whilst it is the gold standard, it would be impossible for the network to cater to the needs of each industry individually. This project aims to create a new social media platform enabling computer science students and software engineers to show off their personal projects

to their network, giving them a single place to direct friends, colleagues and recruiters to display their skills and engineering and creative skills. In the software industry, personal projects and past achievements are more valuable than academic grades as they show a willingness to learn and interest in software outside of work, leading to a more overall picture of a candidate than just an assessment centre (Stepanova et al. 2021).

New social media platforms often start slow but eventually hit a critical mass where growth becomes exponential, as with BeReal. In just two years, this pandemic-born platform exploded to an active user base of over 70 million (Curry 2025). One of the key focuses of this project, then, should be to create a highly scalable social media platform that can cope with the demands of millions of users overnight.

1.2 Aims and Objectives

This project aims to build a highly scalable web application, Omni, which enables users to share their personal projects online in a single space, creating an online portfolio they can share with friends, family, colleagues, and recruiters. Formally:

- Create a highly rated (in user feedback) web application that is both easy to use and pleasant to view. This application should enable users to see projects that others have posted.
- To serve this web application, create a highly scalable backend using a microservices architecture capable of scaling from 0 to millions of

requests per minute.

- Create an API that enables third parties to interact with the platform, backed by scalable microservices.
- Create a database and schema allowing sharding to enable horizontal data storage scaling.
- Follow industry standards for microservices, system design, Kubernetes, and software engineering.

Two approaches can evaluate these goals. The first is user feedback surveys, which can be used to gather qualitative opinions of users. Surveys will allow the assessment of the first objective. To evaluate the scalability requirements, load tests on the finished platform will enable a view into how the platform responds to ‘viral’ moments and its ability to flex as the user base grows.

1.3 Scope and Limitations

As this project primarily focuses on creating a highly scalable backend for a web platform, the majority of the focus will be on this section of the project. The front-end website shown to users will contain the minimum viable product to display the backend features but will not have much front-end ‘magic’ to enhance the user experience. Additionally, the platform does not contain the attributes commonly associated with social media, such as likes, follows and comments. This is an effort to combat ‘fakeness’ on social networks: following someone to boost your social status, posting low-effort and topical content to receive vast numbers of likes. This social network intends to function closer

to an online blog or portfolio, allowing software engineers to show off the cool projects they are working on without the fear of ‘creators’ dominating the platform.

The platform will also not have any algorithmic recommendations, although this would be interesting to explore in the future. Much of the success of modern social media can be associated with the algorithmic suggestion of content for users to consume, as it “directly impacts user satisfaction, engagement, and retention” (Chen & Huang 2024). Despite the benefits, this machine learning algorithm could be a project within itself and falls outside the scope of building a scalable web platform.

1.4 Dissertation Structure

Chapter 1 introduces the problem and the platform that will be built. Chapter 2 includes some background information that will help you understand the platform’s intentions and some of its potential design aspects. The platform’s design is described in Chapter 3, covering all aspects from front to back. Chapter 4 goes into more detail about the implementation of each section, including any interesting details. Chapter 5 covers the verification through testing and a user feedback survey. Finally, Chapter 6 includes a reflection on what was learnt during the platform’s construction and a brief evaluation of the goals set in Section 1.2.

Chapter 2

Background

2.1 The Growth of Social Media

In recent years, social media has become a cornerstone of modern life with 2.19 billion active users on Facebook in 2018 (Saha & Guha 2019). Emerging adults spend approximately 6 hours using social media daily and frequently use multiple platforms simultaneously (Vannucci et al. 2019). In contemporary life, “we draw on the benefits of the ubiquitous networks which provide unparalleled opportunities of economic as well as cultural growth” (Hruska & Maresova 2020). Some social media platforms cater to specific demographics, such as LinkedIn, which targets professionals across every industry. Despite being a professional network, LinkedIn falls flat at serving the needs of unique demographics, such as young software engineers and computer science students. These demographics do not actively engage with professional social networks as their older counterparts do (Florenthal et al. 2012).

2.1.1 A New Professional Network for Junior Software Engineers

Junior software engineers should focus on growing their professional networks and their portfolio of personal projects to best position themselves in a competitive post-COVID job market, with open roles for software engineers down 34% in 2025 from 2020 (Federal Reserve Bank of St. Louis 2025)

LinkedIn is motivated to cater to its largest demographic, which, in turn, discourages younger demographics from engaging on the platform. While highly motivated to break into the software industry, this demographic does not engage with the traditional professional networking giant.

2.1.2 Scalability in Social Network

According to Chippa et al., scalable computing systems maintain consistent performance under an expanded workload. Social networks must maintain high performance in user experience while experiencing rapid growth in their user base (Pujol et al. 2010). For example, Twitter experienced a rapid growth in active users of over 1000% between 2008 and 2009, which resulted in significant downtime due to the architecture not being designed to scale efficiently at that rate (Sakaki et al. 2010). Scalability should be a fundamental philosophy from the inception of a design.

Chapter 3

Design

3.1 Architecture

Omni will use a microservices architecture. This enables a highly distributed and scalable system that can respond dynamically to changes in incoming requests. The approach should make use of common industry standards and technology as well as be portable across cloud providers. The aim is to build Omni cloud-natively so that it could scale exponentially in the case of a ‘viral’ moment. Omni will be primarily designed using the microservices architecture. This enables a highly distributed and scalable system, which is able to respond to changes in incoming requests dynamically.

3.1.1 Kubernetes and Containerisation

Kubernetes is an orchestration tool which enables the management of pods across clusters. A cluster is one or more nodes (physical machines) connected together, possibly across different data centres or even regions, which run

workloads. Figure 3.1 shows the architecture of a Kubernetes cluster¹.

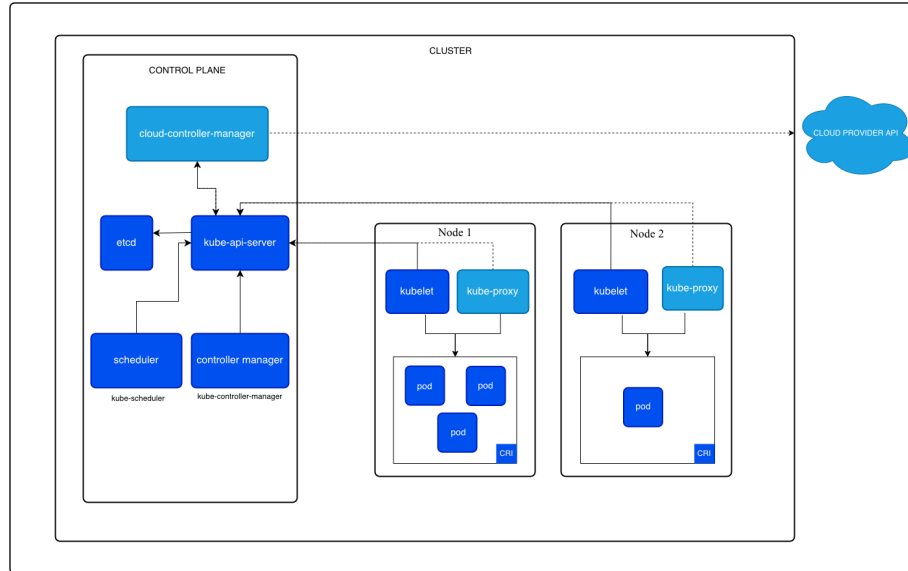


Figure 3.1: Kubernetes Architecture

Kubernetes manages the lifecycle of pods using the industry standard health check endpoints:

- `/healthz` - General health of the pod
- `/readyz` - Whether the pod is ready to receive requests
- `/livez` - Whether the pod is alive and should be running

Using these endpoints, Kubernetes deployments can monitor the pods (a pod is a running unit usually containing one but sometimes more containers) they have spawned and, if any of them die, for example, if they crash, auto-heal and spawn a replacement. Deployments can also be configured to scale up the number of pods they run when certain limits are reached. The possibilities

¹'Kubernetes cluster components' by The Kubernetes Authors, from <https://kubernetes.io/docs/concepts/architecture/>, licensed under CC BY 4.0.

are endless, but some common examples could be CPU usage on a particular node or the number of requests received per time period.

This is what makes Kubernetes super powerful. Combining auto-healing and management of ephemeral pods with autoscaling leads to solutions that are highly adaptable to any scenario. For this reason, Omni will be designed to run natively in Kubernetes, meaning that containerised applications will need to be created to run the platform.

Containerisation is the process of modifying an application to run within a container. A container is a self-contained module that can be run without needing to worry about its dependencies or setup. For example, if an application has a dependency on a particular version of Linux with a specific library installed, containerisation will mean that the user running the container can execute the application on any supported OS without needing to worry about the dependencies.

The other added benefit of containers is that the execution environment only needs to contain the compiled binary. Rather than the host machine needing to compile the binary or a CI/CD pipeline creating many binaries for various operating systems, we can use one container, which contains only the compiled binary for the container's OS.

So, for Omni, the application(s) should be containerised and ready for deployment to a Kubernetes cluster in any of the major cloud providers (as well as bare-metal solutions). Kubernetes is a perfect fit for the microservices architecture described in Section 1: It simplifies the management of individual containers and their lifecycles and provides auto-scaling, rollbacks, service discovery, security and portability. Because of this, Kubernetes is ideal for

maintaining scalable and reliable microservice-backed platforms.

3.2 Database

Omni’s database needs to scale horizontally across many machines to handle potentially hundreds of thousands or even millions of users. Database sharding will be needed to “build scalable, fault-tolerant, and efficient database architectures” (Shethiya 2025). In order to accomplish successful database sharding, one of the problems that needs to be solved is how to locate data. Formally:

Given N nodes (where N is sufficiently large), how can a backend locate a specific piece of data whilst preventing a worst case $O(N)$.

Ideally, we want data retrieval to be of the order $O(1)$, where a backend knows precisely where to look to find a piece of data that we want to retrieve.

3.2.1 Snowflake IDs

Luckily, this problem has been solved for us. Engineers at Twitter (now X) faced this same problem and came up with an intuitive solution: snowflake IDs. Snowflake IDs are a type of ID that not only uniquely describes a piece of data but also its locality: where it is stored (X 2010). This enables data to be sharded across many database instances whilst retaining a look-up time with a complexity of $O(1)$. Snowflake IDs are unique 64-bit integers with the following properties:

- The first bit is locked to 0, which ensures that all snowflake IDs are positive. Treating them as signed or unsigned does not matter.
- The following 41 bits are dedicated to be a timestamp. This is the time that the ID was created and is based on a custom epoch (rather than the UNIX epoch) to increase the range.
- Following the timestamp, each ID has a 10-bit Node ID. This represents the location where a piece of data has been stored.
- Finally, we have a 12-bit Sequence ID. This prevents collisions between IDs created for the same Node ID and Timestamp.

Table 3.1 shows the final structure of the 64-bit Snowflake ID.

| | | | |
|--------------|------------------|----------------|--------------------|
| 1 bit unused | 41 bit timestamp | 10 bit node id | 12 bit sequence id |
|--------------|------------------|----------------|--------------------|

Table 3.1: Snowflake ID Structure

Using these Snowflake IDs, it becomes obvious how to store data across many nodes while retaining an efficient retrieval mechanism. A backend only needs to inspect the bits representing the snowflake’s node to determine where to route its request. Using 10 bits for this value also allows us to scale up to 1024 nodes, which should be plenty for even the largest social media networks.

When using Snowflake IDs, the key concern is ensuring that only a single object in a given backend can create the IDs and that each backend is assigned a unique Node ID (even if multiple Node IDs are stored in the same database shard). This prevents ID collisions during generation, rather than using a 128-bit ID like the one specified in the RFC 4122 UUID specification (Leach et al. 2005).

3.2.2 Database Implementation

A classic SQL database will suit our needs since the data we will store in a social media network is structured, where the relationships between users, posts, and comments are known. The added flexibility of a NoSQL database, whilst attractive for sharding (Gupta et al. 2017), is not warranted for such a platform, and a more strict and structured schema should bring benefits in the long run when comparing developer experience and stability.

Given this directive, some natural choices are SQLite and MySQL/MariaDB. They are both robust and straightforward; however, MySQL/MariaDB is better suited for this particular application with a single (sharded) database. In lightweight/mobile applications, SQLite is the preferred option (Feiler 2015).

As mentioned above in Section 3.2.1, the database will be sharded so that the load of multiple backends accessing data from the database is balanced across multiple servers. This allows databases to be located in separate regions and balances the load across multiple servers. Another option to balance the load on the database is to use read replicas, where there is one primary node and many read replicas, which are a copy of the primary node. This setup is perfect for read-heavy applications, as read requests are distributed across the replicas. It also brings the benefit of higher availability, as all servers have the same database, so if the primary node fails, other nodes can be promoted to receive write requests. Replication does however bring a write bottleneck where only one server can process writes, in order to maintain ACID compliance.

Overall, sharding is the better option for the Omni platform due to the write bottleneck and the potentially massive amount of data that will be stored in the database. A future improvement would be to use a hybrid approach, where some things, like the user profile data, which is not expected to receive many writes, are stored in a replicated database, whereas post and comment data is stored in a sharded database to prevent a bottleneck when writing.

3.2.3 Resources

The core of the Omni platform revolves around the posts that users produce. Any user can create a post and comment on other users' posts. This brief description shows three clear resources: users, posts, and comments. Figure 3.2 shows the entity relationship diagram for the relationships between these three resources, where one user may create many posts and many comments, and one post may have many comments.

3.3 Backend

Omni has a couple of requirements for the backend:

- The backend needs to be able to service both users interacting with the frontend as well as via an API
- The backend must be able to scale to meet the needs of the incoming requests

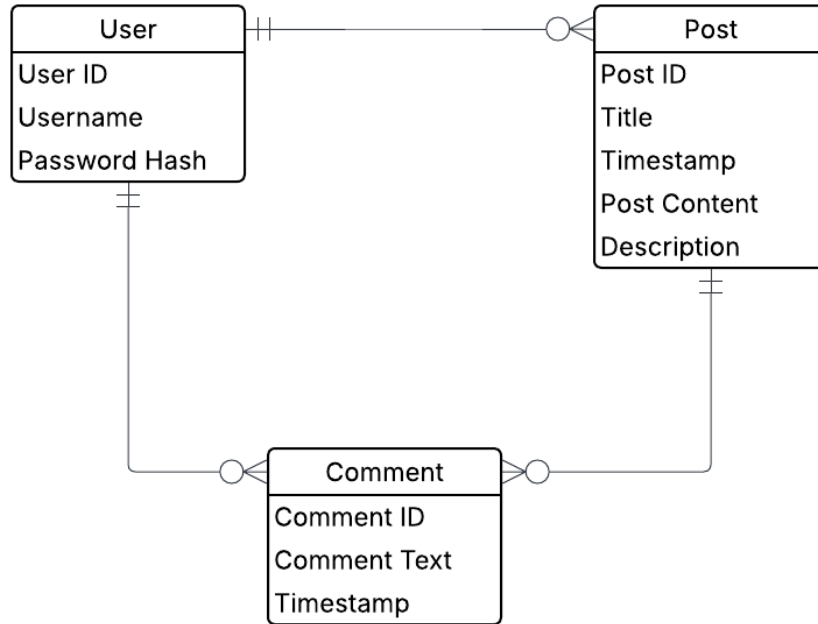


Figure 3.2: Entity Relationship Diagram of Omni Database

Considering these requirements, the backend must be designed to scale efficiently. A social media platform expects to receive a lot more read requests than write requests. Splitting the backend into multiple microservices that can scale to demands independently puts the platform in the best position to maintain availability and reliability. One way to achieve this is to use separate microservices for read and write requests. This allows us to scale the read service to use many more instances than the write service during periods of high usage.

By adopting this approach, we can also split other sections of the application into separate microservices. For example, we could use an authentication service that is only responsible for logging users in and providing them with a JWT token for future requests. There is no limit to the granularity of

the microservices used. However, there will likely be a limit of diminishing returns where further breaking down microservices does not lead to significant performance improvements compared to the effort spent creating them.

3.3.1 Omni Microservices

Based on the discussion in Section 3.3 above, Omni’s backend is split into three different microservices, built using GoLang:

- OmniRead, which will handle purely read API requests with no side effects
- OmniWrite, which will handle any API request that modifies the database
- OmniAuth, which will handle authenticating a user when they log in as well as provisioning JWT tokens

Figure 3.3 shows the architecture of the Omni platform, including the microservices and database.

We do not want separate API endpoints for each service. To route requests to the correct microservice, we will use a layer 4 load balancer. Because requests are balanced based on their HTTP method and path (GET requests are for OmniRead, /login requests are for OmniAuth, and everything else is for OmniWrite), a layer 4 load balancer, which operates at the application layer, is preferred over a lower-level layer 7 load balancer, which operates on TCP/UDP packets.

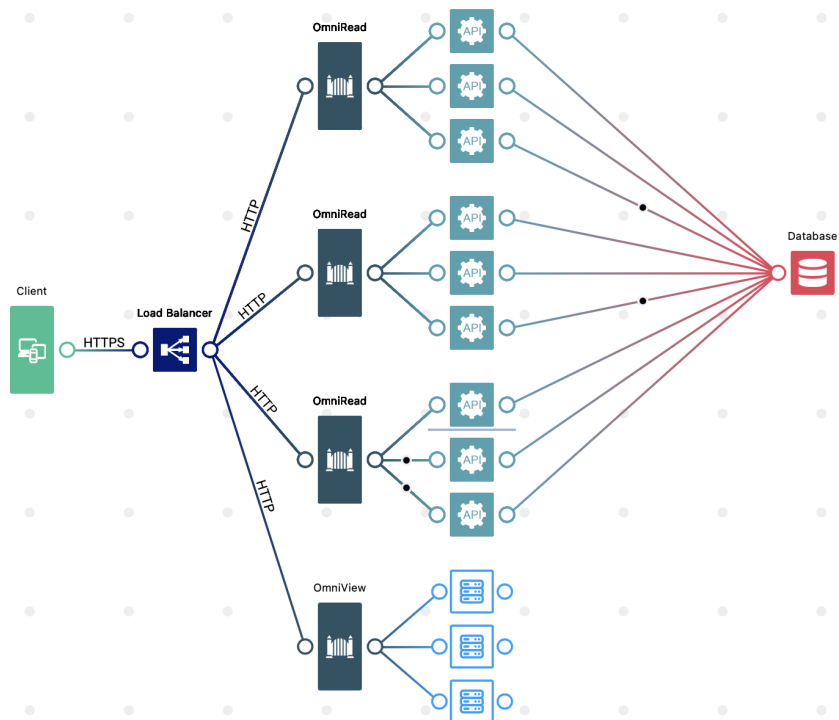


Figure 3.3: System Design of Omni Platform

3.4 Frontend

Similar to how multiple microservices serve the backend, the website will be served by a separate microservice that is only responsible for rendering page content. Any data the frontend service (OmniView) requires will be retrieved by calling the backend inside the Kubernetes cluster. Kubernetes allows pods inside the same cluster to communicate with each other via standard HTTP requests. As the website is not the main focus of this project, and a social media platform inherently does not have much onscreen interaction (instead, they are traditionally comprised of many pages linked together), the website will be built with a combination of HTMX (served via the GoLang microservice), TailWindCSS for styling, and AlpineJS for the limited amounts of more complex interaction that is required.

3.4.1 Posts

Omni's target audience is junior software engineers who want to showcase their latest projects and act as an online portfolio. It is commonplace for engineers to add a link to their GitHub page on CVs and applications to show hiring managers the projects they have built. However, GitHub can be confusing to navigate, and often, the project name is not enough to understand what an engineer has achieved in building something.

Omni looks to rethink how engineers show off their portfolio of projects. The key to this is to make posting new projects as simple as possible; rather than making engineers write a whole blog post about a project, Omni will utilise the README files they have already created for their projects as the

body content of a post. Users can add a more descriptive title and description to each post and then link their README file from elsewhere on the internet, such as GitHub or GitLab. Omni will parse the README files markdown and present it on each post page for users to read.

3.5 Tech Stack

The Omni microservices will be built using GoLang. This is a fast language with excellent concurrency features, making it ideal for web servers and APIs. The SQLc library will automatically generate the database layer from the SQL migrations and queries to connect to the database from within Go. Letting a code generation framework create this code automatically, ensures that the database and the microservices will always be in sync, and any errors caused by new migrations will be flagged as type errors when compiling.

As mentioned in Section 3.4, the website will use HTMX, TailwindCSS, and AlpineJS. HTMX is a lightweight JavaScript framework that can be used for client-side interactivity as an alternative to ReactJS or NextJS. Using HTMX, one can dynamically update portions of the page by serving partial HTML snippets from the webserver. This can be used, for example, to add a new post to a list of posts dynamically.

MariaDB is the database of choice for the reasons mentioned in Section 3.2.2, and Kubernetes will be used to orchestrate the workloads being run. I have built a custom Kubernetes cluster running across 3 Raspberry Pis which will be used for testing, but there is nothing stopping the same deployments to be used in a cloud-based Kubernetes environment like GKE, AKS or EKS

(from Google Cloud, Microsoft Azure and Amazon Web Services respectively).

Chapter 4

Implementation

This chapter will describe in detail the technical implementation of the Omni platform.

4.1 Configuration

Configuration is an important part of any production application. It is any data required by the application for it to run. Configuration may need to change, and it should be able to do so without requiring developers to rebuild the application. Allowing configuration to be ephemeral enables companies with separate teams that manage a platform's operations to make configuration changes without the need for intervention by a software developer.

Configuration items should be passed to the application via its environment rather than compiled into its binary (Wiggins 2017). One method for specifying configuration is through a configuration file. This file (normally JSON or YAML) contains key-value pairs of data for the application to

consume at start-up. Some frameworks even enable the file to be monitored for changes so that the most up-to-date values can be used without requiring a restart.

Another method preferred in Kubernetes and containerised environments is using environment variables. These are variables set in the environment that the application is executed from. The application can then read the values of these variables and use them for its own configuration.

Kubernetes allows environment variables to be specified in the workload manifests for each application. This means that if the configuration changes, a new manifest can be loaded to bring new pods online with the updated config. Once the new pods are available and responding to requests, the old pods are scaled down and removed.

```
1 func main() {  
2     ctx := context.Background()  
3     cfg, err := env.ParseAs[config.DatabaseConfig]()  
4     if err != nil {  
5         panic(err)  
6     }  
7  
8     // Start-Up Code...  
9 }
```

Listing 4.1: Example of Parsing Environment Variables

The second method will be used as Omni is designed for Kubernetes. To enable the use of environment variables for configuration, an open-source package called [Caarlos0/env](#) will automatically pull these values from the environment (shown in Listing 4.1). Defined in the applications are different

configuration objects with the required configuration items included, along with some special tags that indicate the name of the related environment variable. On start-up, a call to the package automatically creates the configuration objects based on the values from the environment. The config objects can then be passed around the application to the sections of code that require them.

4.2 Observability

Logging and observability are vital to the ongoing stability of any production system. “The distributed nature of microservices also introduces complexity, making it challenging to ensure the reliability, performance, and security of the system” (Chinamanagonda 2022). Clear and consistent logs are crucial for developers to be able to debug faulty platforms quickly.

Logging is not the only facet of observability. However, metrics and tracing are also key to building a holistic view of a platform’s health. Metrics are the key numerical data points representing a system’s health and behaviour over time. Metrics often include requests per second, latency and CPU usage. These can be easily aggregated, structured, and visualised in top-level dashboards to provide a glanceable overview of how a platform is performing. They are the first level of reporting an operations team will monitor.

Traces, on the other hand, record the path that requests take through a platform. They often capture the logs each system produces along the way and measure latencies across the system. Traces are ideal for identifying bottlenecks and pinpointing failures within a larger microservices architec-

ture. Tracing is often handled by a framework called Open Telemetry, a standardised way of collecting and exporting traces from many different applications.

Finally, logs are the lowest level of the three fundamental observability pillars. Logs are immutable, timestamped events that applications emit when processing incoming requests. Developers, with a fine-grained understanding of how the system functions, can best use logs, which are extremely useful for pinpointing the exact line where a system has failed.

4.2.1 Observability in Omni

In Omni, the Go standard library's structured logger emits logs, allowing each log to contain extra information, such as variables. The structured logger can output logs in various formats, the most common being text-based (for console logs) and JSON-based (for consumption into an observability pipeline).

```
1 if errors.Is(err, sql.ErrNoRows) {  
2     logger.InfoContext(  
3         ctx, "entity not found",  
4         slog.Any("id", id)  
5     )  
6     http.Error(  
7         w, "entity not found",  
8         http.StatusNotFound  
9     )  
10    return true
```


Listing 4.2: Example of Structured Logging

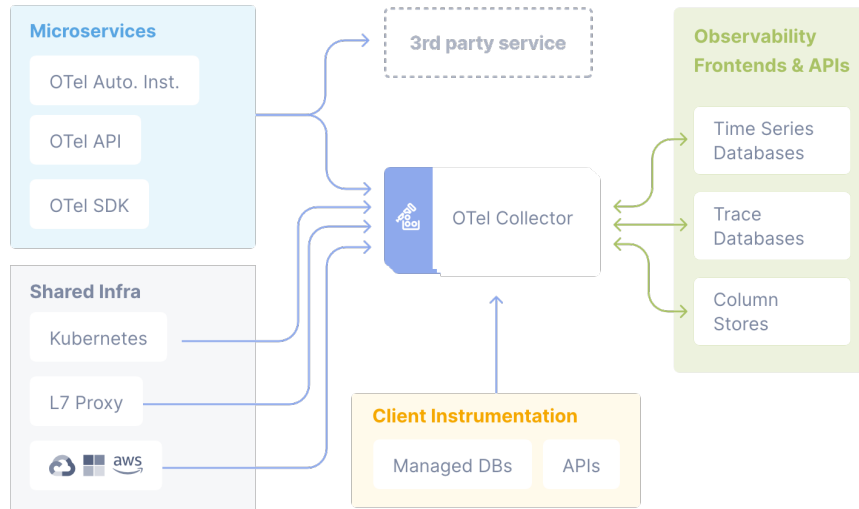


Figure 4.1: OpenTelemetry Reference Architecture.

Whilst tracing using a framework such as OpenTelemetry would be helpful in a larger production environment (Figure 4.1 shows the architecture of OpenTelemetry¹), Omni currently only has four microservices. Tracing has been ignored for the initial product but could easily be retrofitted around the existing logging infrastructure. An OpenTel Exporter would then consume these traces from many different applications and publish them to a single location, for example, Prometheus. The Kubernetes cluster provides top-level metrics covering basic needs, while load balancers provide more in-depth metrics, such as requests per second.

¹'OpenTelemetry Reference Architecture' by OpenTelemetry Authors, from <https://opentelemetry.io/docs/>, licensed under CC BY 4.0.

4.3 Database

Data is at the centre of every social media platform. The first step in creating Omni should be to build the database in which its data will be stored. To ensure the database is reproducible on multiple servers (for example, when creating a new database shard), database migrations must be written and applied iteratively on top of one another until the final database structure has been formed. There are many tools and libraries for applying database migrations to a database, but since the microservices will be written in GoLang, the GoMigrate tool is a natural fit.

4.3.1 Database Tables

Figure 4.2 shows the final design of the tables. The Omni platform has two main entities that are easy to see, and a third arises during the implementation.

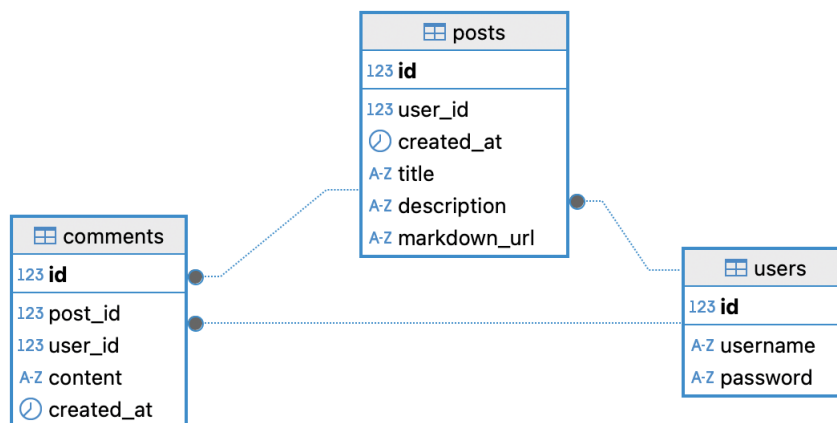


Figure 4.2: Database Entity Relationship Diagram

Information about each user needs to be stored, so a user table is naturally

required. This includes any information about the user, such as username and password hash. In the MVP of Omni, there is not much additional information stored about each user, but this could feasibly be expanded to store much more data for new features, such as storing a user's birthday. In the future, if a hybrid approach for database distribution is used, a separate table to hold authentication data may be better to store this on a replicated database cluster rather than a sharded one.

The second easy-to-see table holds information about each post. It must store the creator's ID, title, description, link to the markdown file, timestamp, and more. Posts will have a one-to-many relationship with users, where one user may create many posts, but each post is always associated with just one user.

The final table is not as obvious to spot but still crucial: a table to store comments in. Storing this in the posts table does not make sense in a structured SQL database. Adopting this approach could work in a NoSQL setup, but for popular posts, the document size would grow too big and slow down reading the post for everybody. By storing the comments in a separate table, we can use pagination in our SQL queries to limit the number of comments we return to a user simultaneously. This limits the load on the microservices, ensuring they are not overwhelmed by a very popular post with many comments.

4.3.2 Discussion on Sharding

As discussed in Section 3.2, the design of the database and Snowflake IDs enable easy sharding of the database, whilst maintaining fast access times by backend microservices. A single database has been used to maintain simplicity for the initial implementation and testing of the platform. The only difference this has in the code is that the logic for selecting which database node to retrieve data from is removed (as all the data is contained in only one node).

4.4 Backend Microservices

This section discusses how the backend microservices were created and how they interact with the broader environment. Some patterns have been shared across services to enable as much code reuse as possible.

4.4.1 Database Access

All three backend services require some level of database access. OmniAuth and OmniRead require only read access, whereas OmniWrite will read and write data.

All the applications (currently) interact with the same database, although, as mentioned in Section 3.2.2, future improvements could include using separate databases for things like authentication. Because the database is shared, we can utilise the same database layer in each application, reducing the amount of code we need to write.

The SQLc Library

SQLc has been used to generate the database layer automatically. This code generation library takes as input database migrations and all the queries to be run against the database. It then compiles these inputs into type-safe code. There are multiple benefits to this approach:

- Most of the code generated is boilerplate developers must write by hand or copy from documentation. It does not solve novel problems.
- The code generated is type-safe and handles embedding objects from joins for a more traditional object-orientated programming style.
- The compiler flags breaking changes to the database via migrations when the database layer has been regenerated, but the business logic has not yet been modified.

Using this approach, SQLc has generated objects for users, posts, and comments, as well as other objects used when retrieving smaller data sections from each table. Helpfully, the library generates an interface used within the code to access the database and an implementation of the interface for accessing the database. However, this interface enables developers to write custom implementations, for example, to be used during unit testing.

```
1 type Post struct {  
2     ID          int64      `json:"id"`  
3     UserID      int64      `json:"user_id"`  
4     CreatedAt   time.Time `json:"created_at"`  
5     Title       string     `json:"title"`  
6     MarkdownUrl string     `json:"markdown_url"`
```

```
7   Description string    `json:"description"`  
8 }
```

Listing 4.3: The Generated GoLang Post Struct

All the backend services share this database layer as there is no need to write the queries separately for each one, as operations like retrieving a user profile happen in all the services.

Managing Database URLs

In order for the services to make calls to the database, they need to know where to send requests. This is defined by a URL that is passed to each application through the environment, allowing for on-the-fly changes to the configuration without having to rebuild each application. The start-up function parses this URL and then creates a database connection using Go's built-in database/SQL package. Finally, a Querier object (generated by SQLc) is initialised from the database connection object. This is the object which will be passed to each service's business logic so that database requests can be made.

4.4.2 Authentication

Authentication is an important part of any platform. It ensures that users can only access data and perform tasks they are authorised to do. Rather than using an authentication library, Omni uses a simple, custom authentication implementation, where users log in using a username and password.

Sign Up

When a user signs up to Omni, they enter a unique username and a password of their choice. This information is sent to the backend, where the password is hashed using the bcrypt algorithm developed by Provos & Mazieres. The GoLang package `crypto/bcrypt` handles this. The password hash is then stored in the database along with the rest of the user's details.

Bcrypt

The Bcrypt algorithm stores all the information required to verify a password attempt in the hash.

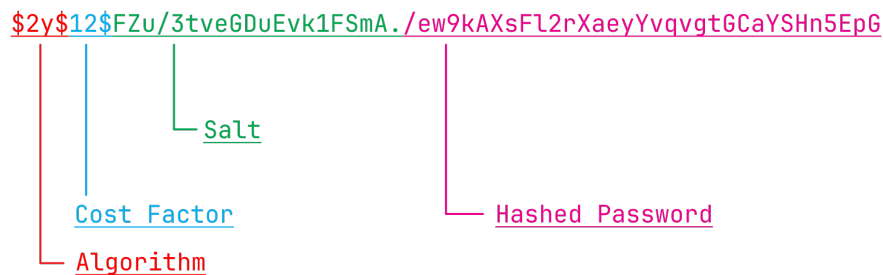


Figure 4.3: Sections of the Bcrypt Hash

The first section of the hash contains the algorithm used to create it. Bcrypt uses a version of the Blowfish cypher, denoted by the hash `$2b$`. The second section is the cost factor used in the algorithm. The default of 10 is used for Omni, but in production, this should be increased to 12 or higher. Generally, the larger the value of the cost factor, the slower it is to check a password. While counter-intuitive, this is the desired behaviour, as the slower it is to check a password, the harder it is for a brute-force algorithm to check

the most common passwords. The third section of the hash is the salt used; this is stored as plain text so that it can be used to derive the encryption key for later use. Finally, the encrypted password is stored as the last part of the hash, which is compared against a potential password.

Checking a password involves deriving the encryption key from the given algorithm, cost factor and salt, using that key to encrypt the given password and then comparing it against the valid password hash. If the hashes match, the password is valid.

JSON Web Tokens

JWTs are the industry standard for ongoing authentication (Ahmed & Mahmood 2019). They can contain many standard or custom ‘claims’, which the application uses to determine whether the JWT is valid. In particular, Omni uses the **exp** and **sub** claims (standing for expires at and subject, respectively).

After a JWT body is generated, applications hash it using a secret key, which is appended to the JWT to ensure that the body is not modified by anyone other than the authorised applications. Figure 4.4 shows the three sections of a JWT.

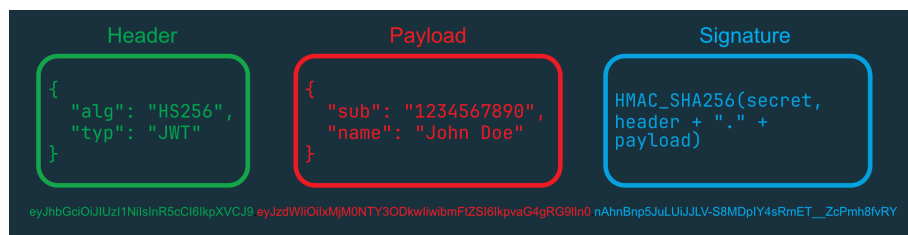


Figure 4.4: Sections of a JSON Web Token

In subsequent requests to restricted endpoints, clients attach their JWT

in the Authorization header of the HTTP request. The relevant backend, which handles requests to that particular endpoint, can then verify the claims in the JWT. Based on the subject claim of the JWT, the backend can decide if the client making the request is authorised to do so for the particular action they are performing. For example, a user can delete a post they have created but cannot delete posts from other users.

4.4.3 Middleware

Middleware is software that sits between the client request and the final logic that handles that request. It can achieve various effects, from modifying the request to rejecting it altogether (due to a lack of authentication, for example).

Middleware is crucial in modern web services, even more so in a microservices architecture. Omni utilises middleware for safety, stability, and functionality.

The most crucial and ubiquitous of Omni's middleware is the logging middleware. This middleware records each incoming request as a log, and after the request is processed, it logs the amount of time taken to serve that request. These logs follow a structured format, allowing external monitoring tools to use them to build a better understanding of how long requests take to process on average and which types of requests take the longest. This allows bottlenecks to be identified. Appendix A shows the implementation of this simple yet powerful middleware.

Another important middleware that Omni takes advantage of is MaxBytes-

Reader. This middleware sets the maximum number of bytes that can be read from the body of an HTTP request to be 1 MiB. The middleware prevents DDOS attacks using vast HTTP request bodies, where the application may run out of memory trying to decode all the information in the body. For all the Omni endpoints, the expected amount of data should never exceed 1 MiB, so any request with a body larger than that should be rejected with an error.

4.4.4 OmniAuth

The simplest of the backend services is OmniAuth, which authenticates an existing user to access restricted endpoints. OmniAuth serves just one endpoint: `POST /api/login`. The handler expects the request to have a JSON body with the fields `username` and `password`. The username is used to retrieve the user from the database. When the user does not exist, the endpoint returns a 404 Not Found HTTP error. The returned data from the database includes the Bcrypt hash of the user's password.

As mentioned above in Section 4.4.2, the `crypto/bcrypt` package compares the password sent in the request to the hashed password stored in the database. If the passwords match, the authentication request is valid. If they do not match, the request returns a 401 Unauthorised HTTP error.

Given that the passwords match, OmniAuth will create a JSON Web Token (JWT) (code shown in Listing 4.4) that can be used to authenticate the user for subsequent requests to restricted endpoints.

```
1 claims := &jwt.RegisteredClaims{  
2   ExpiresAt: jwt.NewNumericDate(time.Now().Add(time.Hour *  
   24)),
```

```

3   Subject:    fmt.Sprintf("%d", id.Id().ToInt()),
4 }
5 token := jwt.NewWithClaims(jwt.SigningMethodHS256, claims)
6 tokenString, err := token.SignedString(a.secretKey)

```

Listing 4.4: Example of Creating a JWT

4.4.5 OmniRead

OmniRead, as described in Section 3.3, is responsible for handling any HTTP Get requests. This allows us to scale read requests separately from the scaling of backend services that handle write requests. In the initial version of Omni, the data that users need to be able to read is:

- Posts
- Users
- Comments

However, we have more than three endpoints, as users may want to access different data sections differently. For example, a user may want to retrieve all the posts a user has created and the most recent posts by any user.

All the API endpoints served by OmniRead are unauthorised, meaning that anybody can access them without a JWT token. This simplifies the service regarding the middleware required for each endpoint and its runtime configuration in the Kubernetes environment.

Paging

For some endpoints that could return infinite amounts of data, such as retrieving comments on a post or posts by a particular user, paging is needed. This ensures that the database and the backend service are not overwhelmed by a denial-of-service attack, where a malicious request can cause the entire service to hang or run out of memory while processing it. Paging ensures that the data returned has a maximum size of ten items. Users who wish to see more items can request the next page, which will return the following ten items.

Achieving this paging in the application layer is trivial, but it still leaves the attack vector open. In this scenario, the application layer would still require all the data from the database, even if it only returned a subset to the user. Luckily, popular SQL databases already have this paging feature built-in through the `LIMIT` and `OFFSET` keywords. `LIMIT`, as the name suggests, limits the number of rows of data returned, and `OFFSET` skips the number of rows specified. For example, with a `LIMIT` of 10 and `OFFSET` of 0, the first 10 rows will be returned. With an `OFFSET` of 10, rows 11-20 are returned.

```
1 -- name: GetPostsPaged :many
2 SELECT
3     users.username ,
4     sqlc.embed(posts) ,
5     CEIL(COUNT(*) OVER() / 10.0) AS total_pages
6 FROM posts
7 JOIN users ON posts.user_id = users.id
8 ORDER BY posts.created_at DESC
```

```
9 LIMIT 10 OFFSET ?;
```

Listing 4.5: Example of SQLc Query with LIMIT and OFFSET

Other paging strategies also exist. For example, in the context of comments, a user may prefer to page by time, finding all the comments before or after a timestamp. This paging application is more useful for other applications that use the API, perhaps for research purposes. In contrast, users interacting with the Omni platform via the website will likely want to read the most recent comments on a post or the highest-rated comments if a liking system is introduced. The LIMIT and OFFSET approach is more efficient for these cases when compared to the client specifying a timestamp or other parameter to find comments before or after, with different sorts applied to the query.

Response Format

OmniRead returns data in the response body in a JSON format. JSON is the standard format for transmitting data in APIs on the web. Whilst other more efficient formats exist, such as [ProtoBuf](#), JSON is ubiquitous and well-supported by most languages' standard libraries. GoLang has powerful, built-in tooling to encode and decode the JSON format into standard GoLang structs. As part of a set of helper functions for all the backend services, Omni has a helper function that takes an object and an HTTP Response Writer object and writes the JSON encoding of the object to the response along with a 200 Success HTTP code. This helper function is used across all the backend services to transmit data to the request sender.

```

1 func MarshallToResponse(
2     ctx context.Context, logger *slog.Logger,
3     w http.ResponseWriter, v interface{})
4 ){
5     b, err := json.Marshal(v)
6     if err != nil {
7         w.WriteHeader(http.StatusInternalServerError)
8         return
9     }
10
11     w.Write(b)
12 }

```

Listing 4.6: Example of Writing JSON to the Response

Conforming to the HTTP Specification

Throughout the OmniRead service (and all the backend services), Omni attempts to conform as much as possible to the uniform HTTP interface defined by Fielding et al.. In practice, this means reflecting as much information as possible through HTTP Status Codes and adopting the correct HTTP verbs. Some examples include 200 Success and 201 No Content when requests are successful, with the former indicating there is some returned content in the body of the response, whilst the latter means nothing was returned. When a request is malformed or otherwise incorrect, status codes in the range 4XX are returned depending on the type of error. Finally, the service returns 500 Internal Server Error and 503 Service Unavailable errors when the backend encounters errors it cannot recover from, such as the database being down.

Consumers of the API should be able to use HTTP Status Codes as the first port of call to immediately know if a request was successful, rather than the way that some more modern JavaScript frameworks hide errors inside of 200 Success messages. The practice of hiding errors inside responses that return with a 200 code can lead to poor error handling and unexpected fatal crashes.

As discussed by Richardson & Ruby, “when the method information isn’t found in the HTTP method, the interface stops being uniform.” It is important to conform as much as possible to the specifications that underpin the modern web; otherwise, the tooling and developers working on the web will have to work harder to achieve the same baseline of safety.

4.4.6 OmniWrite

OmniWrite handles requests that could modify the database, such as creating a post or adding a new user. For each class of resource, user, post, and comment, OmniWrite handles three endpoints:

- POST - Creates a new object
- PUT - Updates an existing object by its ID
- DELETE - Deletes an existing object by its ID

The implementation for each class is mostly the same, with the only difference being the data associated with each resource in the class. For example, the implementation of creating a new comment or post is almost the same, except for the data expected in the request body and the database calls made.

The general skeleton for the implementation of each handler for this service follows the following blueprint:

1. For PUT and DELETE requests, parse the ID parameter from the request's path and check if the resource exists in the database.
2. For POST and PUT requests, decode the request's body to find the new parameters.
3. Call the relevant function in the database layer.
4. Check for errors and return the response to the client.

Before modifying the database, the handler must also verify that the caller provided a valid JWT for the request. The only exception is when creating a new user (as the user will not yet have created their password or possess a JWT).

A JWT is valid for a PUT or DELETE request if the resource owner matches the user ID in the subject field and the token has not expired. The only other thing that complicates the request handlers in OmniWrite is the amount of places where errors can arise. The error handling logic is responsible for over half of the code in each handler, ensuring that each response receives the correct HTTP status code, depending on the type of error.

4.4.7 OmniView

OmniView is the application responsible for serving HTML to browsers when a user navigates to the Omni website. Whereas the other three services all serve JSON content in their responses, OmniView responds with HTML,

CSS, and JS, which the browser can use to render content on screen for a user. There are many different methods, tools, and frameworks for building a website, such as ReactJS, NextJS, Java Spring Boot, and plain HTML (Stack Overflow 2024)

Writing static HTML pages which are served to browsers is not very common in the industry now, with contemporary solutions (even those with static sites and no dynamic content) use frameworks to generate the HTML from an easier language to work with.

Given that the web pages OmniView will be serving have dynamic designs but limited complex user interaction, HTMX and TailwindCSS will be used to render the HTML content that will be sent to browsers. HTMX is a lightweight JavaScript library that enables dynamic web interactions through HTML attributes. It allows parts of a page to be updated dynamically in response to events without writing any custom JavaScript. It keeps the rendering of HTML on the server side while maintaining the state through the URL of a webpage.

Some modern JavaScript frameworks prefer to use a single-page application, where the URL does not change when navigating to entirely new pages, instead powering all interaction through client-side rendering. However, this can lead to much more complex JavaScript running on the client than is necessary, increasing the amount of data that needs to be sent when the page is loaded. By keeping this processing on the server, OmniView only needs to send each client the rendered page for them to view, lowering the network cost of each request.

TailwindCSS on the other hand, is a CSS framework that provides low-level

utility classes to build custom, responsive designs quickly. Rather than writing custom classes for each component, Tailwind allows for the composition of utilities directly on HTML elements, increasing the locality of code and enabling rapid development and consistent styling. “The primary feature for easy maintenance is locality: Locality is that characteristic of source code that enables a programmer to understand that source by looking at only a small portion of it” (Gabriel 1996).

```
1 <div role="alert">
2   <div class="bg-red-500 text-white font-bold rounded-t px
3     -4 py-2">
4     Error
5   </div>
6   <div class="border border-t-0 border-red-400 rounded-b bg
7     -red-100 px-4 py-3 text-red-700">
8     <p>Some error message here.</p>
9   </div>
10 </div>
```

Listing 4.7: Example of TailwindCSS Classes

The combination of GoLang, HTMX, and TailwindCSS will enable Omni to serve fast, beautiful, and responsive web pages even with limited bandwidth.

The first step in creating OmniView is to set up the web server and ensure that it is serving static content. The CSS file each page will reference is the static content to be served in the case of OmniView. The Tailwind command line tool generates this content by scanning all the project’s HTML files, extracting the Tailwind classes used, and compiling the styling for each one into a minified CSS file. Generating the CSS file this way ensures that only

the Tailwind styles the website uses are sent to the client, keeping response sizes low.

The second step is to produce the website's HTML. The HTML is produced using GoLangs built-in templating language, enabling the reuse of standard sections like the navigation bar or footer and dynamic insertion of variables from the application, such as post titles. The templates also include HTMX in the elements to enable dynamic content updates, for example, when a new comment is added. Rather than reloading the whole page when a user adds a comment, we can dynamically insert the new comment at the top of the list so that the user can see the result of their interaction straight away, with a minimal impact on the network.

While the frontend design is not the primary focus of this project, efforts were made to create a responsive, accessible design which is easy for users to navigate. Some screenshots can be found in Appendix B.

4.4.8 Serving Content

With these basic components in place, the next stage of development is to start creating the handlers for each application endpoint. Most pages require a database call to retrieve the content that will be displayed. This is handled by making a request to the relevant backend service so as not to duplicate work already done.

In cases where multiple pieces of data are needed, such as viewing a user's page (which requires a call to load the information about the user and a separate call to load all the posts by that user), OmniView leverages

GoLangs' concurrency features. These features enable both requests to be made concurrently with full cancellation support. Appendix C contains a shortened example of this code.

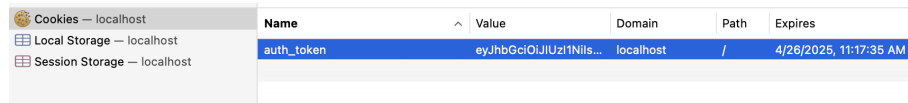
Once all the required requests have been completed, the code stops waiting and the response data object is formed. The template renderer receives this data object as input so that it can replace any fields in the template with the relevant data, before sending the rendered HTML in the response of the HTTP request.

4.4.9 Authentication in OmniView

Authentication needs to be handled slightly differently in OmniView compared to OmniWrite. This need is because the browser does not have a way to automatically set the Authorisation header when it makes requests to the web server. Instead, authentication data is transmitted and stored in a cookie. The browser knows to send cookies related to a website with every request it makes.

When a user signs into Omni via the website, the same JWT is produced by the backend. However, before the response is sent to the user via OmniView, the JWT is set as the value of a cookie, which is also sent back to the browser. When the browser receives this response, it saves the cookie to its local storage and transmits it along with every subsequent request it makes before the cookie's expiry timestamp.

When OmniView receives a request, middleware checks if the cookie is present and that the JWT inside the cookie is valid for the request. If both



| Name | Value | Domain | Path | Expires |
|------------|-------------------------|-----------|------|------------------------|
| auth_token | eyJhbGciOiJIUzI1NiIs... | localhost | / | 4/26/2025, 11:17:35 AM |

Figure 4.5: Authentication Cookie Set by OmniView

of these checks are true, the request is processed as it would be normally, and the response is sent. If the cookie is not present or is not valid, OmniView sends a redirection status code and redirects the browser to the login page, where the user can enter their credentials to receive a new cookie.

4.4.10 Parsing Markdown from External Sources

As each post’s core content is an external markdown file, it must be processed into HTML, which can be embedded on each post page.

When a post is processed, Omni downloads the data at the URL submitted as the post body. It attempts to convert the markdown it receives into HTML elements. However, embedding this raw HTML into a template and sending it back to the user is potentially dangerous (Singh et al. 2020). Before it is embedded into a template, the HTML is passed through a sanitiser, which removes any potentially dangerous HTML elements and attributes. Omni uses the bluemonday sanitiser to scrub any cross-site scripting data from the HTML.

The sanitised HTML is then inserted into the post page template and returned to the user, free of any potential ill-intended code.

4.5 Load Balancer

Many backend services are required to handle the load for a platform to scale efficiently. Requests should be distributed evenly across each service for a platform to work optimally. A load balancer is required to achieve optimal performance. Omni has a custom, configurable load balancer that serves different paths to different backends.

4.5.1 Note on Load Balancing in the Final Version of Omni

The original plan was to use a custom load balancer for the Omni platform to prevent vendor lock-in to a particular cloud service's load balancer. However, after carefully reviewing the Kubernetes documentation, particularly the relatively new Gateway API, the decision was made not to deploy the custom load balancer but rather to use the Gateway API to provision a load balancer from the cluster provider. This decision allows Omni to remain cloud-portable, allowing the Gateway API to automatically provision a cloud provider's load balancer.

Some work was needed to enable a load balancer in a custom-built, bare-metal Kubernetes cluster such as the one Omni was tested on (2x Raspberry Pis); however, [MetalLB](#) and [NGINX Gateway Fabric](#) were successfully implemented and used for testing.

4.5.2 Configuration

The Omni load balancer begins with the configuration. The configuration defines which load balancing algorithm to use (for example, the round-robin algorithm) and which paths the load balancer should expose.

The load balancer ingests this configuration file (written in YAML), on start-up and creates internal maps for each path. It also exposes the standard liveness endpoints `/livez` and `readyz`. `readyz` responds with a healthy status code when a backend exists and is ready to serve responses for each path defined in the configuration.

4.5.3 The Load-Balancing Pool

Two other endpoints are also exposed: `addz` and `removez`. The backends use these endpoints to register and unregister themselves from the load-balancing pool. When a backend adds itself to the load-balancing pool, a reverse proxy is created for the backend's IP address and added to the pool. When a client sends a request via the load balancer, the new backend will be available for the selected algorithm to choose from.

Once the chosen algorithm has picked a backend to serve the user's request, the load balancer forwards the request to the backend using its direct IP address. The request is also modified to include the `X-Real-IP` and `X-Proxy` headers to indicate to the backend nodes that the load balancer has forwarded this request and from whom the request originated.

The load balancer is also responsible for regularly checking that the registered backends are still alive and healthy. When a backend does not

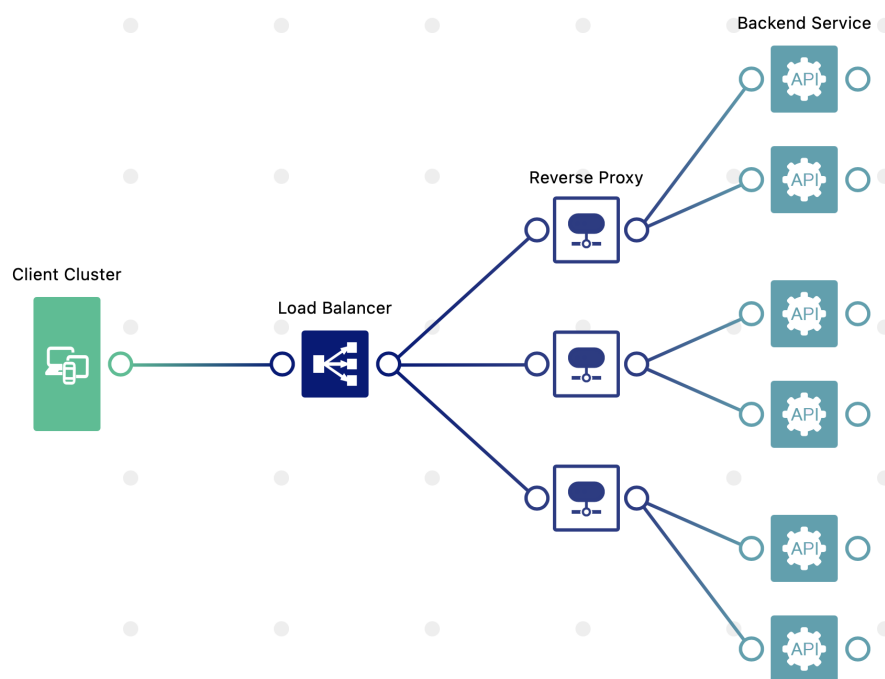


Figure 4.6: Load Balancer Design Overview

respond before the timeout, it is removed from the healthy pool of nodes until it responds again or is removed from the load-balancing pool altogether.

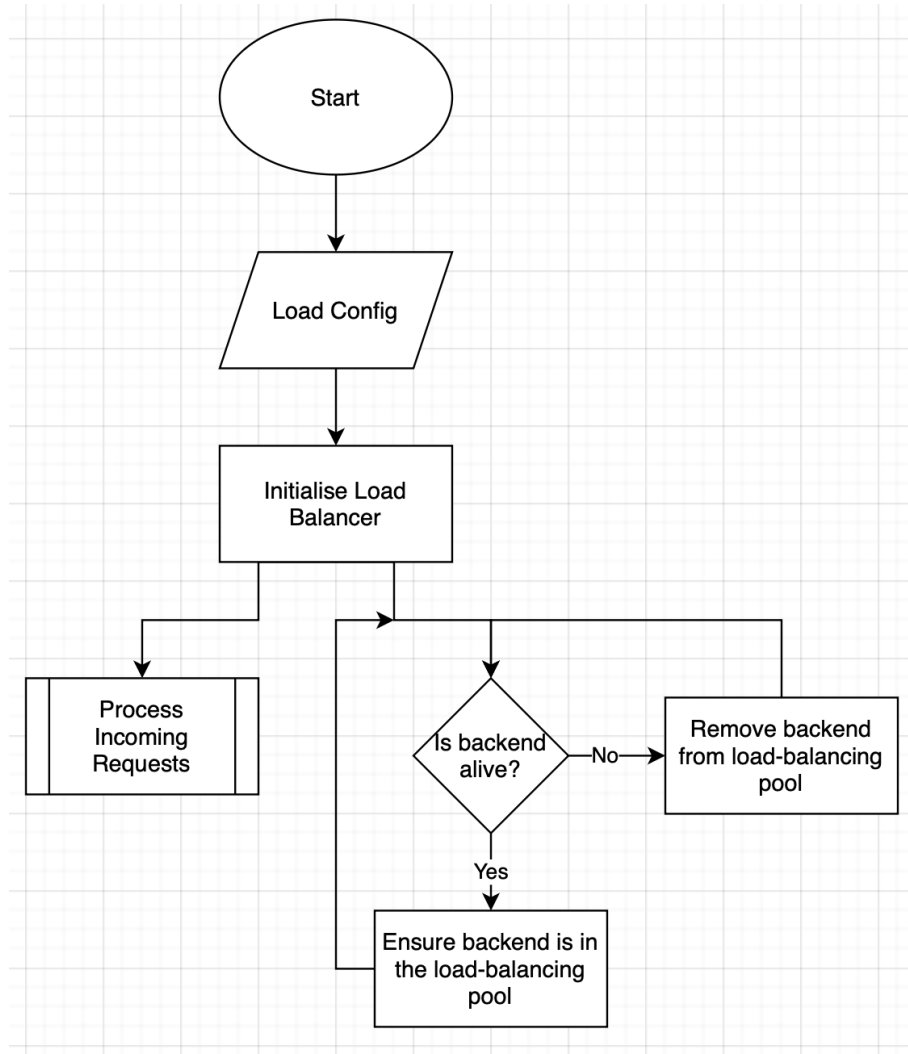


Figure 4.7: Load Balancer Flow

4.5.4 Load-Balancing Algorithms

Many different load-balancing algorithms exist, and this report does not discuss the benefits and drawbacks of each. For the first implementation of

the load balancer, a simple round-robin algorithm was implemented; however, much more complex and efficient approaches are available, such as the least connections and least response time algorithms. The study by Sharma et al. into the performance of different load-balancing algorithms is particularly informative.

4.6 Kubernetes and Deployment

Now that each platform component is built, it needs to be deployed to work in unison. As mentioned in Section 3.1.1, the microservices will be deployed into a Kubernetes cluster to enable easy inter-pod communication, autoscaling, deployment rollouts with zero downtime, and more. The database will not be deployed into Kubernetes as this does not follow the industry standard practices surrounding data storage.

Kubernetes pods are ephemeral, meaning they should be stateless and able to be killed and restarted without interrupting the application they serve. This design contradicts the stateful design of databases (otherwise, they would not be helpful) that should be resilient to failure.

4.6.1 Kubernetes Manifests

Whilst Kubernetes clusters can be configured and interacted with via a command-line tool, the industry leans towards using Infrastructure-as-Code (IAC for short), which allows infrastructure to be version-controlled using Git like the applications it hosts. IAC brings a whole host of benefits other than version control, such as the ability to tear down and rebuild environments

quickly and easily through virtualisation (Hüttermann 2012).

Two main parts are needed to deploy the services to Kubernetes: a deployment and a service. The [Kubernetes Official Documentation](#) describes each best:

- “A Deployment manages a set of Pods to run an application workload, usually one that doesn’t maintain state.”
- A service allows one to “expose an application running in your cluster behind a single outward-facing endpoint, even when the workload is split across multiple backends.”

In layman’s terms, a deployment manages a set of pods, ensuring that if one dies, another takes its place, whilst a service allows the outside (or inside) world to communicate with said pods through a single interface. Services are the key to communication between different backends inside of a cluster. Rather than a backend needing to find the IP of a specific pod to serve its request, it can send the request to the service, which, in turn, will forward it to the pods it manages.

A deployment and service manifest has been created to manage the underlying pods for each Omni service: OmniRead, OmniWrite, OmniView, and OmniAuth. The deployment manifest also includes the environment variables that power each service’s configuration, including the database connection URL and the port via which to connect.

A Word on Helm

Helm is an open-source package manager which simplifies the management of Kubernetes deployments. It allows for the installation of predefined standalone units into a cluster. The configuration of Omni’s deployment into Kubernetes has been written as a Helm chart, allowing for easy deployment and upgrade during its development lifecycle. Charts are written using the GoLang templating language, allowing the same chart to be reused across multiple environments (say, a test cluster versus a production cluster). Variables defined in the chart are replaced with different values, suited to each service.

Cluster Ingress

By default, services use the ClusterIP type, which exposes the service internally to other members of the cluster. While this may be perfect for some applications, Omni needs some sort of connection to the outside world to be functional. Traditionally, a Kubernetes Ingress would be used; however, the new Gateway API allows for a more portable definition.

Alongside the Deployment and Service for each backend application, Omni’s Chart includes Gateway and HTTPRoute manifests. The documentation defines the Gateway as “an instance of traffic handling infrastructure, such as cloud load balancer.” In the case of the bare-metal cluster Omni has been tested on, under the hood, this will link through the NGINX Gateway Fabric to the MetalLB load balancer, providing an external IP address to the Gateway. The second part of the puzzle is the HTTPRoute. Again, the

documentation defines this as “HTTP-specific rules for mapping traffic from a Gateway listener to a representation of backend network endpoints. These endpoints are often represented as a Service.” The HTTPRoutes specify the destination for an incoming request. For instance, GET requests to a path beginning `/api/` should be sent to the OmniRead service.

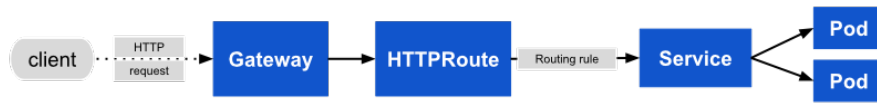


Figure 4.8: Flow of a Request through the Gateway

Combining the HTTPRoute and Gateway allows Omni to communicate via a single external IP while sharing requests across many backend applications to balance the load and service the requests. Figure 4.8 ² shows the flow of a request through the Gateway and HTTPRoutes.

Automatic Horizontal Scaling

The final piece of the Kubernetes puzzle is configuring the deployments to automatically scale horizontally (create new pods) as load increases. The key to this is using a HorizontalPodAutoScaler manifest, which defines the rules for how deployments should scale their pods. In the case of Omni, using CPU utilisation is the simplest solution. However, more complicated metrics, such as requests per second, could be used. The auto-scaler targets a CPU utilisation of 50% for each pod. The deployment specifies the minimum amount of CPU and memory that a pod requires to run and the maximum

²Kubernetes Gateway Flow’ by The Kubernetes Authors, from <https://kubernetes.io/docs/concepts/services-networking/gateway/>, licensed under CC BY 4.0.

a pod can use. The utilisation of each pod is calculated based on the limits specified. As utilisation increases over 50%, the auto-scaler triggers the creation of more pods. Once the period of high load ends, the auto-scaler waits for a specified period before scaling the pods down to their nominal amount again.

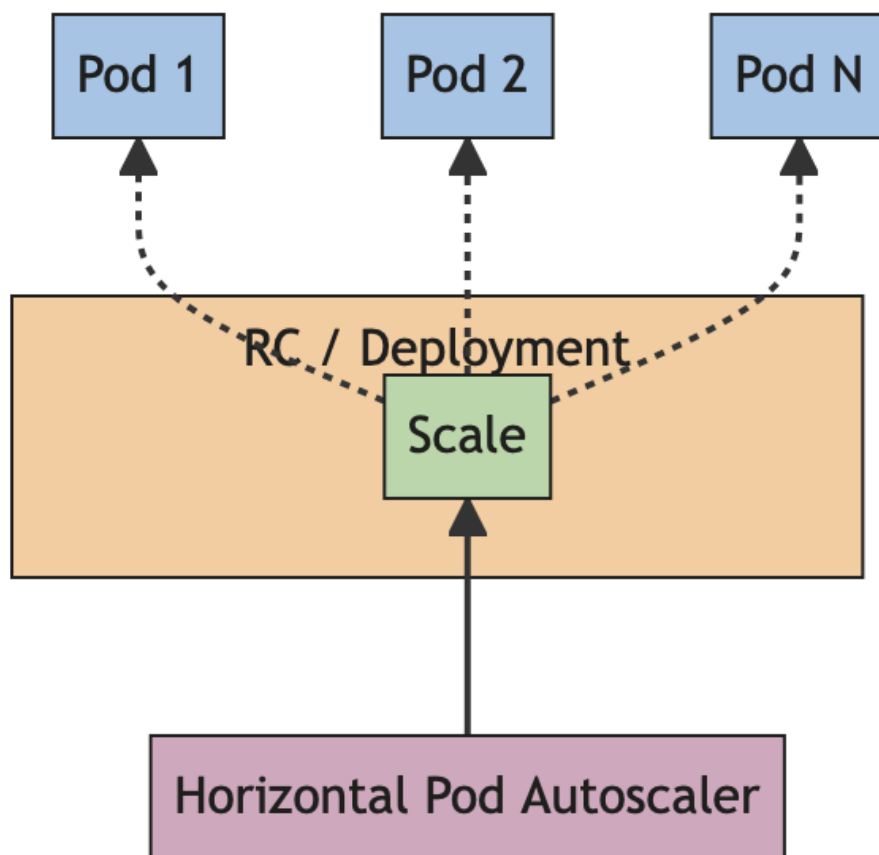


Figure 4.9: HorizontalPodAutoscaler controls the scale of a Deployment and its ReplicaSet

Figure 4.9 ³ demonstrates how the HorizontalPodAutoscaler works with

³HorizontalPodAutoscaler' by The Kubernetes Authors, from <https://kubernetes.io/docs/tasks/run-application/horizontal-pod-autoscale/>, licensed under CC BY 4.0.

the Deployment and ReplicaSet to scale the number of pods up and down as required.

Chapter 5

Testing and User Feedback

Testing is an important facet of any programming. It ensures that the code is functional and free from logical errors. Test-driven development (TDD) is the practice of writing unit tests before implementing a feature or bug fix, allowing developers to define exactly how a specific function is expected to work given a set of inputs before focusing on how the function achieves the correct outputs. Defect rates have been shown to decrease by around 50% when following TDD, compared to a traditional style of testing, where tests are written after the fact (Maximilien & Williams 2003).

5.1 Unit Testing

Unit tests are a fundamental form of testing for all applications. They are small, focused tests that verify the correctness of individual components of a system. Each test checks whether a specific function produces the expected outputs, given a set of inputs. Unit tests are reusable by design, building into

a suite of tests that are quick to run over time and ensure regressions do not occur. Regression tests are particularly valuable as they increase confidence that new changes do not break existing features unexpectedly. The field of regression testing and minimisation of regression tests is vast. However, much work has been done to automate the selection of regression tests to keep overall costs (time and energy) down whilst still providing a comprehensive suite of tests which aim to cover as much of the application as possible (Wong et al. 1997).

Omni utilises unit tests to cover most of the codebase, aiming for code coverage of over 70% but achieving close to 100% across the key, testable areas of the codebase (shown in Figure 5.1).

```

ok      github.com/harrydayexe/Omni/internal/auth      0.404s coverage: 56.0% of statements
?      github.com/harrydayexe/Omni/internal/config      [no test files]
ok      github.com/harrydayexe/Omni/internal/loadbalancer 3.367s coverage: 26.2% of statements
ok      github.com/harrydayexe/Omni/internal/loadbalancer/balancer 0.303s coverage: 96.4% of statements
ok      github.com/harrydayexe/Omni/internal/omniauth/api 0.432s coverage: 80.0% of statements
ok      github.com/harrydayexe/Omni/internal/omniread/api 14.694s coverage: 96.0% of statements
ok      github.com/harrydayexe/Omni/internal/omniwrite/api 0.625s coverage: 0.5% of statements
ok      github.com/harrydayexe/Omni/internal/omniwrite/api 0.783s coverage: 97.0% of statements
ok      github.com/harrydayexe/Omni/internal/snowflake 2.912s coverage: 81.0% of statements
ok      github.com/harrydayexe/Omni/internal/utilities 1.074s coverage: 7.9% of statements

```

Figure 5.1: Omni Test Coverage Report

Demanding code coverage requirements (such as enforcing all code to be at least 70% covered) is less effective and even detrimental to the actual defect rates of codebases. Instead, it is more effective to encourage practitioners to focus on more in-depth code coverage metrics such as Modified Condition-Decision (MC/DC) coverage, which is much more effective at highlighting faults before they become user-facing errors (Hemmati 2015).

5.2 Integration Testing

The second important aspect of testing is the use of integration tests. Unit tests, whilst powerful and robust, are inherently limited in scope. To keep them self-contained and fast to execute, they should not interact with external services such as databases or APIs. This limitation is where integration tests shine.

As the name implies, the design of an integration test allows them to test how different sections (or units) of the system integrate. Integration can include how an application interacts with a real database or external API. Integration tests do not have the same expectations about runtime and, in some cases, can take minutes or even hours to execute more complex scenarios. However, they should still enforce the same requirements around repeatability and reusability, again to build up a suite of test cases for a product to pass before an update ships to market.

Whereas unit tests should be run consistently by the engineer throughout the development lifecycle, integration tests are usually only run after an engineer is confident in their work, often by a CI/CD tool.

5.2.1 Testcontainers

Engineers often face the challenge of ensuring that the integration tests they write are repeatable. For example, a database needs to be reset to a common starting point before each run of the tests to ensure consistency across iterations.

In 2015, an open-source project called Testcontainers was released to the

public, intending to solve just that issue. Taking the example of an integration test that interacts with a database, instead of running the tests against a permanent database, which would need to be reset and modified after each run, the Testcontainers framework allows the creation of a database inside a container. Each integration test can be run in parallel, connecting to different containers, ensuring that side effects from one test do not affect another.

Because each test can define its dependencies in a container(s), the setup for each dependency is explicitly set in code and portable for any developer to run. This allows integration tests to be run locally on an engineer's computer or in a larger CI/CD pipeline.

Adopting Testcontainers for integration tests requires just a few lines of code to configure the container in each test case. It brings all the benefits that ensure tests are repeatable, consistent and not flaky.

OmniRead utilises Testcontainers for integration testing between the request handlers and the underlying database logic, verifying that the queries written are accurate and valid. A unit test cannot check the SQL queries themselves as the database layer is mocked to ensure speed when running the test suite. Figure 5.2¹ shows the containers created as part of the integration test suite, demonstrating the parallelisation possible due to each test running on a fundamentally different database.

¹The ryuk container runs for the duration of the test suite and is responsible for killing any containers that are not terminated by the test suite itself (for example if one of the tests fails early)

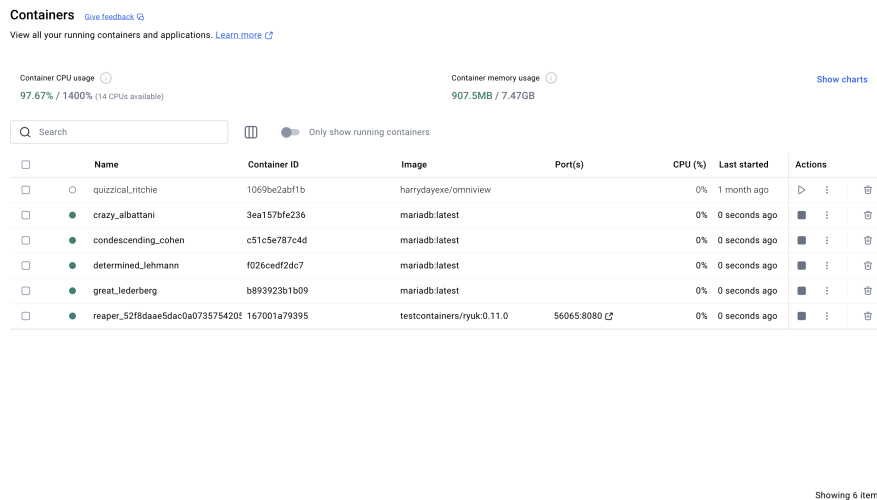


Figure 5.2: Testcontainers Running during the Integration Tests

5.2.2 Testing of the Load Balancer

Integration tests were needed to test the load balancers' ability to add and remove backends based on their health checks. However Testcontainers also uses these health checks to ensure a container is ready before allowing a test to run. In order to combat this, a custom health check container was built which exposes its actual health check on the non-standard endpoint `testcontainersz`. Using the non-standard endpoint allows the standard endpoints `healthz`, `livez`, and `readyz` to be configured for testing purposes, precisely what is needed for the load balancer integration tests.

The code for the health check tester application can be found at [GitHub](#) and the image is available on [DockerHub](#) for anyone to use.

5.3 User Survey

In order to understand how users find the application to navigate and use, a feedback survey of junior software engineers and students was conducted to collect their opinions. This survey included the following questions about the functionality and usability of the website:

- How easy or difficult did you find the site to navigate? For example, when creating an account, viewing posts or writing a comment?
- Would the platform be helpful to you as a junior software engineer?
- Do you see yourself primarily producing or consuming content on Omni?

These questions were designed to identify the opinions of potential site users, particularly regarding the frontend design. The full responses are in Appendix D.

5.3.1 Analysis of User Feedback

Overall, the feedback from the survey participants was positive. The participants enjoyed the website’s design and UI and found it easy to navigate, sign up, and create and view posts.

Most participants also mentioned they would primarily consume content, lining up with the expectation that the OmniRead service would receive much more traffic than OmniWrite. However, the participants did mention that they thought the idea of having a single place to share and discuss their projects would be beneficial for their careers and personal growth.

One gripe was the difficulty of linking to a README on GitHub, which required the user to manually copy the link for the raw content of the markdown file rather than just linking to the homepage of their product. Because most users will be linking to either GitHub or GitLab, future versions of Omni could automatically parse this correct URL rather than forcing users to find it themselves.

5.4 Scalability and Load Testing

A load test was conducted to prove the platform's scalability. A simple program that continuously sends many requests to the Omni API was written and run until the load was saturated and throughput plateaued.

5.4.1 Test Platform

The platform used for load testing was a dual-node Kubernetes cluster running Talos Linux. Each node was a Raspberry Pi 4 Model B with 4GB of memory. The MariaDB database was hosted by a Raspberry Pi 3 Model B+ running Raspberry Pi OS.

5.4.2 Test Results

Figure 5.3 shows the results of the load test. Initially, the throughput of requests was very low (around 160 requests per second) as the baseline number of pods for OmniRead (the service under test) is 2.

As the load increased, Kubernetes scaled the number of pods to meet demand. Once these pods came online, the load plateaued again at the new

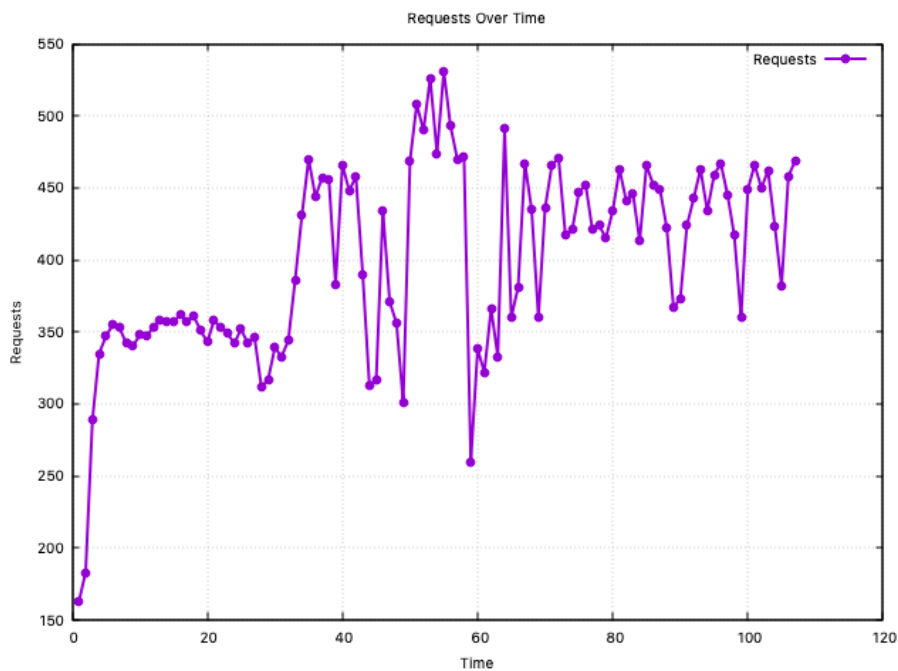


Figure 5.3: Load Test Results

ceiling before more pods were scaled up. At this point, the cluster's hardware limits any more pods from being created (as not enough memory or CPU is available to be allocated to new pods), where the throughput once again plateaus in the range of 450-500 requests per second.

```

Context: admin@homelab-talos-cluster
Cluster: homelab-talos-cluster
User: admin@homelab-talos-cluster
K9s Rev: v0.40.8 #v0.59.4
K8s Rev: v1.32.0
CPU: 54%
MEM: 52%

```

| NAME | READY | STATUS | RESTARTS | CPU | MEM | KCPUs | KCPUs/L | MEM/GB | MEM/L | IP | NODE | AGE |
|--|-------|-------------------|----------|-----|-----|-------|---------|--------|-------|--------------|----------|-----|
| omni-readapi-deployment-57f08d44c7-4kzqk | 1/1 | Running | 0 | 269 | 7 | 107 | 53 | 3 | 8 | 10.244.3.236 | homelab2 | 46s |
| omni-readapi-deployment-57f08d44c7-51z62 | 1/1 | Running | 0 | 270 | 7 | 108 | 54 | 2 | 8 | 10.244.3.237 | homelab2 | 46s |
| omni-readapi-deployment-57f08d44c7-7k2p8 | 0/1 | ContainerCreating | 0 | 0 | 0 | 0 | 0 | 0 | 0 | n/a | homelab1 | 1s |
| omni-readapi-deployment-57f08d44c7-cakta | 1/1 | Running | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.244.2.232 | homelab1 | 31s |
| omni-readapi-deployment-57f08d44c7-frmrn | 0/1 | ContainerCreating | 0 | 0 | 0 | 0 | 0 | 0 | 0 | n/a | homelab2 | 1s |
| omni-readapi-deployment-57f08d44c7-hsdgp | 1/1 | Running | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.244.3.239 | homelab2 | 31s |
| omni-readapi-deployment-57f08d44c7-n275q | 1/1 | Running | 0 | 261 | 7 | 104 | 52 | 2 | 8 | 10.244.3.238 | homelab2 | 46s |
| omni-readapi-deployment-57f08d44c7-n5c4t | 1/1 | Running | 0 | 383 | 7 | 153 | 76 | 3 | 8 | 10.244.2.222 | homelab1 | 76s |
| omni-readapi-deployment-57f08d44c7-q7k4t | 0/1 | ContainerCreating | 0 | 0 | 0 | 0 | 0 | 0 | 0 | n/a | homelab2 | 1s |
| omni-readapi-deployment-57f08d44c7-tp688 | 1/1 | Running | 0 | 234 | 7 | 93 | 46 | 2 | 8 | 10.244.2.231 | homelab1 | 46s |
| omni-readapi-deployment-57f08d44c7-w56qt | 1/1 | Running | 0 | 488 | 8 | 195 | 97 | 3 | 8 | 10.244.2.217 | homelab1 | 86s |

Figure 5.4: Pods being created while the load test progressed

Overall, the load test proved that the platform is able to scale each aspect of the backend independently. During the load test, which was performed specifically on reading data from the API, OmniRead was scaled up to meet

demand, whilst OmniAuth and OmniWrite maintained their baseline number of pods, which were more than capable of handling the demand on these aspects of the API.

Even on low-end hardware, the API efficiently handled 450+ requests per second. If Omni were deployed into a cloud environment with much smaller hardware limitations, it would be able to continue scaling to meet thousands or millions of requests per second.

Chapter 6

Reflection and Evaluation

6.1 Evaluation of Initial Aims

Reflecting on the initial objectives in Section 1.2, the user feedback and load testing indicate that these have been met. Objective 1 aimed to create a highly rated platform that allows users to view posts made by others and share their own projects. The user feedback received indicates that the participants all enjoyed the site’s design and were able to successfully create an account and post a project they had been working on.

Objectives 2 and 3 related to the scalability of the platform and its APIs. The load testing performed in Section 5.4 proved that the platform could scale up in response to ‘viral moments’ where the load massively increased.

Objective 4 discusses sharding and horizontal scaling of the database. Whilst multiple databases were not created due to hardware constraints, the schema and snowflake IDs were created to easily enable this once loads demanded a need for this feature. Forward planning in the design of the

database schema and its IDs allows for future expansion when the user base grows while still allowing a simple one-node solution to keep costs low during the platform's initial launch phase.

The final objective related to the coding style and practices used. Wherever possible, Omni utilised standard industry practices, whether that be with security (sanitisation of cross-site scripting from external markdown) or HTTP responses from the API.

Omni meets or exceeds expectations across every domain based on these initial objectives.

6.2 Future Work

Omni is by no means a finished product. It represents an initial offering that could be launched into production tomorrow, with the expectation that development will continue.

Based on user feedback, the first issue to fix is to make linking to READMEs in standard locations (such as GitHub or GitLab) easier by automatically parsing the correct URL to a README from any link to a project. This pain point represents the importance of user testing.

Currently, Omni requests the markdown data every time a post is loaded. A better solution might be to cache this data in a database or other cache so that it does not need to be requested every time the post is loaded. Some design choices around this decision are needed: For example, should a post be updated if the underlying markdown file is updated?

Other improvements include a custom recommendation algorithm, possibly

based on tags on each post. This would power a more intelligent list of posts on the homepage for logged-in users, surfacing popular content around the topics they are interested in. For example, an engineer interested in low-level systems programming may not be interested in seeing posts about web projects.

Following on from above, a Kafka queue could provide a real-time stream of updates, such as new comments on a post or new posts onto the main feed. When OmniWrite receives a request to add a new comment or post, it publishes this into the Kafka stream and writes it to the database. The consumers of the Kafka stream (the user's browser) would then stream in new content and dynamically insert them into the current page.

Finally, a cache should be added between the backends and the database to decrease the access time for the most popular posts. Again, this introduces complexity surrounding which items should be cached and how the cache should be invalidated; however, given a significant user base, the data to be able to make these technical decisions should exist.

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Appendix A

Middleware Implementations

```
1 package middleware
2
3 import (
4     "log/slog"
5     "net/http"
6     "time"
7 )
8
9 // middleware is a function that wraps http.Handlers
10 // providing functionality before and after execution
11 // of the h handler.
12 type Middleware func(h http.Handler) http.Handler
13
14 type WrappedWriter struct {
15     http.ResponseWriter
16     statusCode int
17 }
18
```

```

19 func (w *WrappedWriter) WriteHeader(statusCode int) {
20     w.ResponseWriter.WriteHeader(statusCode)
21     w.statusCode = statusCode
22 }
23
24 // NewLoggingMiddleware returns middleware which logs
    incoming requests
25 func NewLoggingMiddleware(logger *slog.Logger) Middleware {
26     return func(next http.Handler) http.Handler {
27         return http.HandlerFunc(
28             func(w http.ResponseWriter, r *http.Request) {
29                 start := time.Now()
30
31                 wrapped := &WrappedWriter{
32                     ResponseWriter: w,
33                     statusCode:     http.StatusOK,
34                 }
35
36                 logger.InfoContext(r.Context(),
37                     "handling incoming request",
38                     slog.String("method", r.Method),
39                     slog.String("path", r.URL.Path),
40                 )
41
42                 next.ServeHTTP(wrapped, r)
43
44                 logger.InfoContext(r.Context(),
45                     "finished handling request",
46                     slog.String("method", r.Method),
47                     slog.String("path", r.URL.Path),

```

```

48         slog.Int("status_code", wrapped.statusCode),
49         slog.Duration("duration", time.Since(start)),
50     )
51 })
52 }
53 }

```

Listing A.1: Logging Middleware Implementation

```

1 package middleware
2
3 import "net/http"
4
5 func NewMaxBytesReader() Middleware {
6     return func(next http.Handler) http.Handler {
7         return http.HandlerFunc(func(w http.ResponseWriter, r *
8             http.Request) {
9             http.MaxBytesReader(w, r.Body, 1048576)
10             next.ServeHTTP(w, r)
11         })
12     }
13 }

```

Listing A.2: Max Bytes Middleware Implementation

Appendix B

Screenshots of Frontend Design

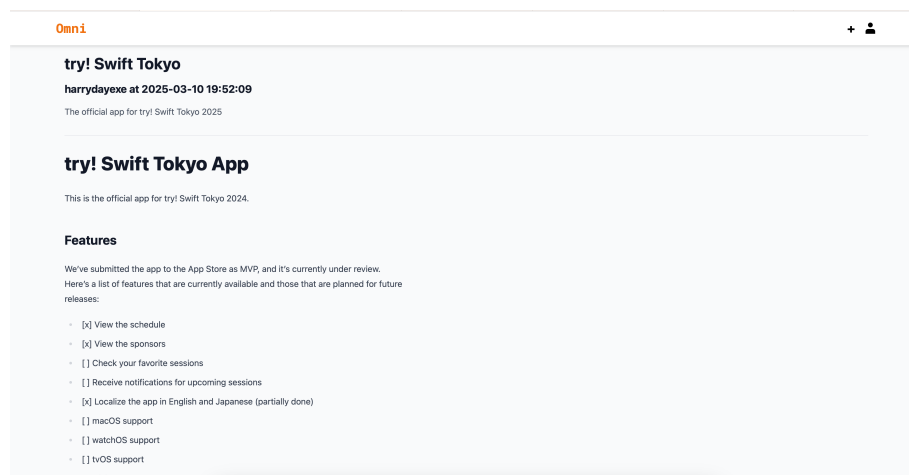


Figure B.1: Omni Post Page (Light Mode)

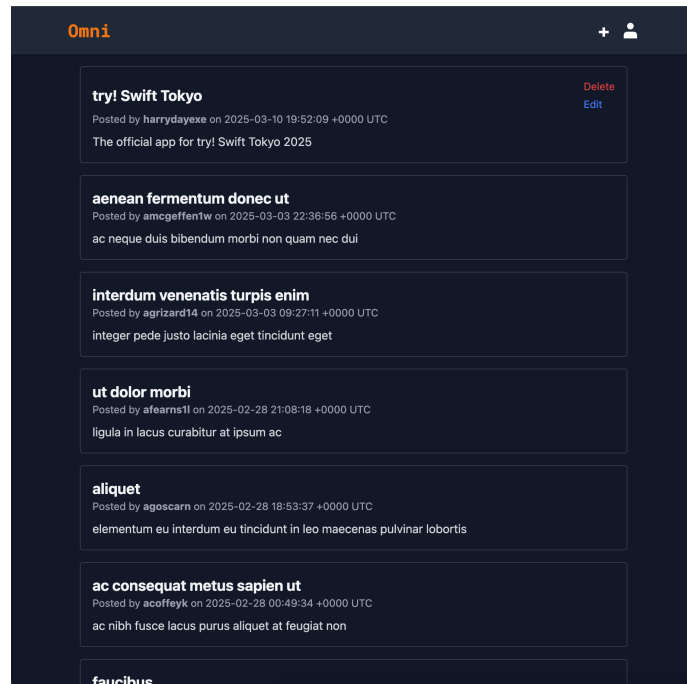


Figure B.2: Omni Home Page (Dark Mode)

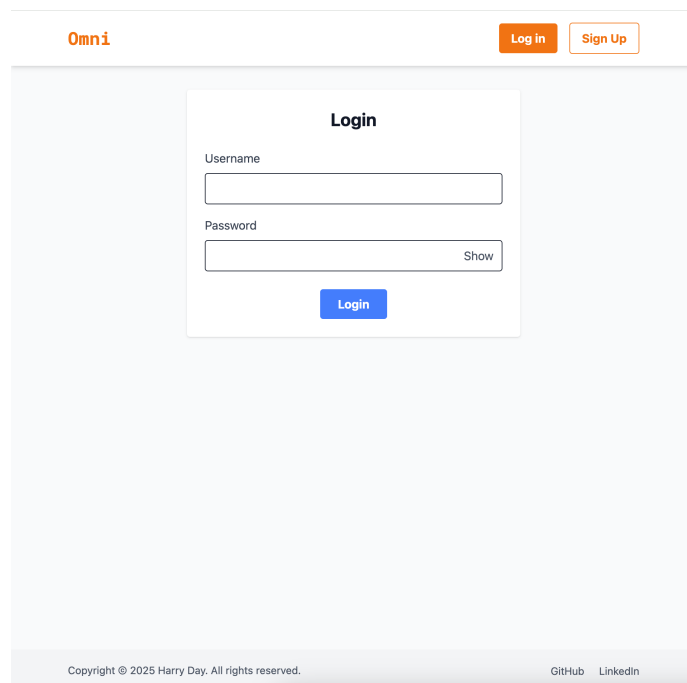


Figure B.3: Omni Login Page (Light Mode)

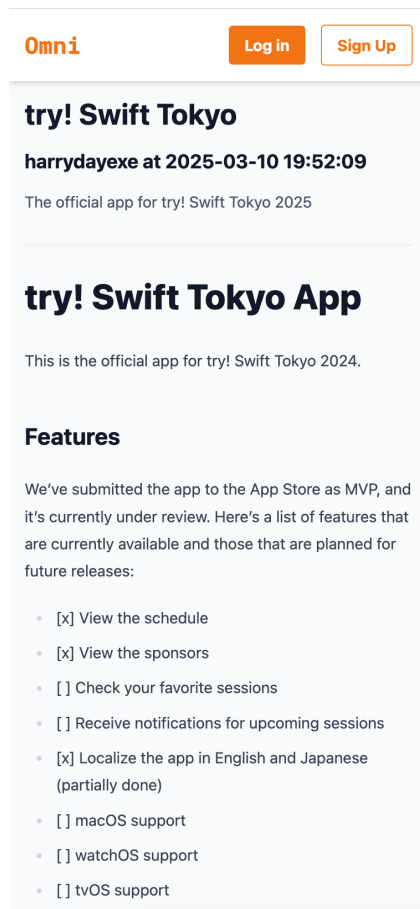


Figure B.4: Omni Post Page (Mobile)

Appendix C

Concurrency in OmniView

```
1 // Create error channel
2 errChan := make(chan error, 2)
3 // Create sub-context
4 subctx, cancel := context.WithCancel(r.Context())
5
6 // Get user
7 go func() {
8     // Make a request to backend - could take a long time
9     user, err := dataConnector.GetUser(subctx, id)
10    if err != nil {
11        // Cancel other routines
12        cancel()
13        errChan <- err
14        return
15    }
16    // Handle success here
17    errChan <- nil
18 }()
```



```

19
20 // Get user posts
21 go func() {
22     // Make a request to backend - could take a long time
23     posts, err := dataConnector.GetUserPosts(subctx, id)
24     if err != nil {
25         // Cancel other routines
26         cancel()
27         errChan <- err
28         return
29     }
30     // Handle success here
31     errChan <- nil
32 }()
33
34 // Wait for goroutines to finish
35 for i := 0; i < 2; i++ {
36     // If the error channel has an error
37     if err := <-errChan; err != nil {
38         // Handle errors here
39     }
40 }

```

Listing C.1: Concurrency in OmniView

Appendix D

User Survey Responses

D.1 Questions

- How easy or difficult did you find the site to navigate? For example, when creating an account, viewing posts or writing a comment?
- Would the platform be helpful to you as a junior software engineer?
- Do you see yourself primarily producing or consuming content on Omni?

D.2 Responses

D.2.1 Participant 1

Question 1

Using Omni was a breeze! Everything went really well, from registering to responding to posts. I appreciated how easy the site was to navigate; I never got lost.

Question 2

Of course. It seems like a great place to learn and maintain ties with the tech community. It would be really beneficial for my development to have access to project ideas, industry discussions, and advice in one location.

Question 3

I would primarily be consuming content and learning at the moment. However, I'd love to eventually start sharing my own projects and advice as well.

D.2.2 Participant 2

Question 1

I found Omni to be very user-friendly. Whether I was reading posts or leaving comments, it was easy to find what I needed thanks to the simple design.

Question 2

Yes, absolutely! It appears to be a fantastic resource for both more complex subjects and advice aimed at beginners. I could see it greatly advancing my skill set.

Question 3

I'll primarily consume content to learn at first, but eventually I'd like to share interesting things I find or create tutorials.

D.2.3 Participant 3

Question 1

I had no trouble navigating Omni. The layout made it very easy to begin interacting, and creating an account was quick. It felt very natural to write comments and posts; the platform seems to be designed to make producing posts as simple as possible.

Question 2

Of course. Omni seems like the perfect platform for me to post tutorials, share my learning experiences, and even initiate conversations with other community members. Having a platform that makes contributing so easy and friendly is encouraging.

Question 3

Without a doubt, my primary goal is to produce content. I can't wait to share resources, write posts, and perhaps even document some of my ongoing projects. It seems like a wonderful place to learn and give back.

D.2.4 Participant 4

Question 1

The site follows the classic design conventions that social networks use, which assisted in finding the correct buttons and ui elements for creating an account and posting.

Question 2

Yes, using the READMEs that I have already written for my projects is an innovative idea that reduces the barrier to producing content. However needing to find the link on GitHub to get the raw file was a little inconvenient. Maybe a future version could do this automatically. It makes it very easy to share my projects quickly.

Question 3

I would primarily be producing content to help my CV, but I would also be consuming content to get ideas from others. I think it is a great idea to have a platform that allows you to do both.