Malware Detection within Object Storage

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Abstract

Lorem Ipsum

Contents

1. Introduction

Overview

The exponential growth of data generation has made data storage an increasingly important aspect for both individuals and organizations alike. Object storage has emerged as a promising solution due to its ability to store vast amounts of unstructured data in a cost-effective and scalable manner. Unlike traditional storage techniques, object storage stores data as objects with related metadata and unique identifiers, allowing for efficient and cheap storage within buckets.

One of the most widely used object storage platforms is Amazon S3, which provides a highly scalable and reliable solution for storing data. However, an open-source alternative called MinIO has emerged as a promising contender, providing similar features to Amazon S3 while giving customers greater control over their data. MinIO is written in Go and is available for free under the Apache License 3.0 or, for commercial and enterprise purposes, at a reduced cost compared to Amazon S3. (**?**). MinIO offers a wide range of features, including high performance, data replication, encryption and erasure coding (MinIO, 2023). Most importantly, MinIO is designed to scale out horizontally to ensure that it can handle the demands of large-scale applications.

Scalability is made simple by allowing multiple types of hardware platforms to work together in separate nodes each with their own compute and storage. This is extremely attractive for customers who want to utilises their existing hardware without being tied down to a specific provider. This also applies for customers looking to migrate their data from Amazon S3 to cheaper solution without compromising on the high performance, reliability and scalability of the S3 platform.

While MinIO is a great alternative to Amazon S3, it does not offer any form of malware detection integration. This could put customers off from choosing MinIO as a viable platform to migrate to from Amazon S3 or leave existing users data vulnerable to malware attacks. This project aims to address this issue by integrating a malware detection system into MinIO. An important goal for the is to negatively impact the scalability or performance as little as possible so that MinIO is still an effective alternative to Amazon S3.

Motivation

Due to the high amount of unstructured data expected to be both written and read to the object store, there are increased risk of encountering malicious files. Therefore malware detection within object storage is crucial in modern cloud storage scenarios. Most popular off-the-shelf object storage platforms, such as AWS, already have integrated third-party antivirus software, such as ClamAV and Sophos (Srinivasan *et al.*, 2022), to mitigate security risks. MinIO on the other hand is vulnerable to malware attacks as it currently does not have any native antivirus integration. This forces customers who require complete virus protection to either not use MinIO or to use potentially costly third-party software. As antivirus scanning is inherently resource intensive, if the software is integrated incorrectly, it could reduce the ability for the storage solution to scale horizontally which negates one of the major benefits of object storage. The purpose of this project is to implement malware detection within MinIO while being mindful to not impact the scalability or performance of the platform.

Project Aims

From a personal perspective, by completing this project

2. Background

Amazon S3 Malware Detection

As MinIO's largest competitor, this project draws a lot of inspiration from Amazon S3s integrated malware detection blog page (Srinivasan *et al.*, 2022). The blog explains Amazons current approach for managing malware detection within their service. Amazon S3 uses a combination of ClamAV and Sophos as their third-party scanning engines due to their out-of-the-box nature. Amazon then gives you the option to use either of these engines or both. The blog goes on to describe the three main interaction mechanisms that Amazon S3 uses to flag files for scanning. Firstly, an API endpoint would be provided to handle all uploads. This forms a queue of uploads which are then scanned before entering the bucket. Next, event-driven scanning is used keep track of all regular file uploads. The antivirus will then scan each file after they have been written to the bucket. Finally, retro-driven scanning is used to scan all existing files within the bucket. The user then has the flexibility to define what types of files should be scanned including defining time windows. This blog has given some useful methodologies of how to keeping track of both incoming and previously scanned files. Creating a system that can match these methods is important for offering a matching level of scalability and security within MinIO.

3. Specification

The specification for this project is to help guide the project to fulfill the aims set out in the previous section. The specification is broken down into three main sections; functional requirements, non-functional requirements and constraints.

Functional Requirements

Functional requirements are used to define how the solution must work for the project to be considered a success. This project aims to supply an end-to-end solution for detecting malware within the MinIO object storage platform. This goal can be separated into a list of functional requirements:

- Provide a way of detecting the latest uploads to the object store.
- Record the results of the malware detection within the object store.
- Provision for future expansion and ongoing maintenance.
- Have a high level of customisability to allow for different use cases.
- Allow for efficient and transparent debugging in the event of failure.
- Provide the ability to measure various metrics.
- Scale alongside MinIO to ensure that it does not bottleneck the object store at high loads.

Non-Functional Requirements

Non-functional requirements are used to define the quality of the solution that is required. This project aims to be production ready and therefore the solution must be held to a high standard. These high standards come in the form of ambitious targets in which the solution will have to satisfy in order to be considered production-ready. The non-functional requirements are split into five categories with metrics to measure their success.

- Speed - The solution must be able to keep up with the rate of uploads made to MinIO. This can be measured by comparing the time difference between uploading a object to MinIO and the object being scanned and tagged.
- Availability - Over a long period of time the solution must be able to handle all requests. This can be measured by comparing the number of requests made to the number of requests completed over a large time frame.
- Capacity - The solution must be able to handle the maximum number of simultaneous requests that MinIO can handle. This can be measured by monitoring the amount of cache used by the solution under load.
- Reliability - 100% of the files uploaded to MinIO must go through the scanning process. The recorded metrics can be used to compare MinIO uploads with the number of objects scanned. It is worth noting that checking the clean and infected results add to the total sum of scanned objects
- Usability - Future additions, maintenance and debugging must be as simple as possible. This requirement is more subjective and therefore explanation of how I have achieved this will be discussed in the implementation section.

Constraints

The constraints are the limitations that the solution must adhere to. The main constraint of the project is the strict time limit given to the project. There are a total of 12 weeks to achieve a production ready product which will greatly limit the scope of the project. This means accurately prioritising the features that are most important to the project while also balancing the time spent to implement them. The second constraint is the limited resources available to the project.

Another constraint of the project is that all the external software used must be open source / available for commercial use under license or fee. This is to ensure that the project is legally viable if the solution was to be used commercially.

The final constraint is that my own knowledge and experience will increase the average time taken to implement milestones. This is due to the fact that I will need to both include time to learn each new technology and also allot excess time if I incorrectly size a task.

4. Architecture

Choosing the correct architecture for the project is critical for ensuring that the solution is scalable, performant and maintainable. Given the specification above, various potential architectures can be created and evaluated based my own thoughts and from reading the background material. An optimal design will then be chosen based on which design satisfies the most requirement with as little compromises as possible. Thought will also be given to which architecture fits within the constraints of the project.

Design 1 - Post-Write

The first design makes use of the performance benefits of MinIO by allowing puts to be initially written to the bucket without being scanned. The design then uses a event queue compatible with MinIO to keep track of all the files that have been uploaded. The queue is then used to trigger a scan of the file once an antivirus is available. The design is shown in figure 1.

This design has many benefits over other potential implementations. Firstly, it uses the storage provided by MinIO to store all incoming files without having to manage a separate storage solution. This removes a lot of complexity from the solution by not having to account for a number of failure conditions that could occur with a high availability, production ready storage solution. For example, the solution would not be responsible for handling partial writes, loss of data, or data corruption. Removing this responsibility allows the solution to focus on the core functionality of the project, the scanning of files, which is essential for keeping the project within the time constraints.

Secondly, the design also makes use of the integrated event queue provided by MinIO. This

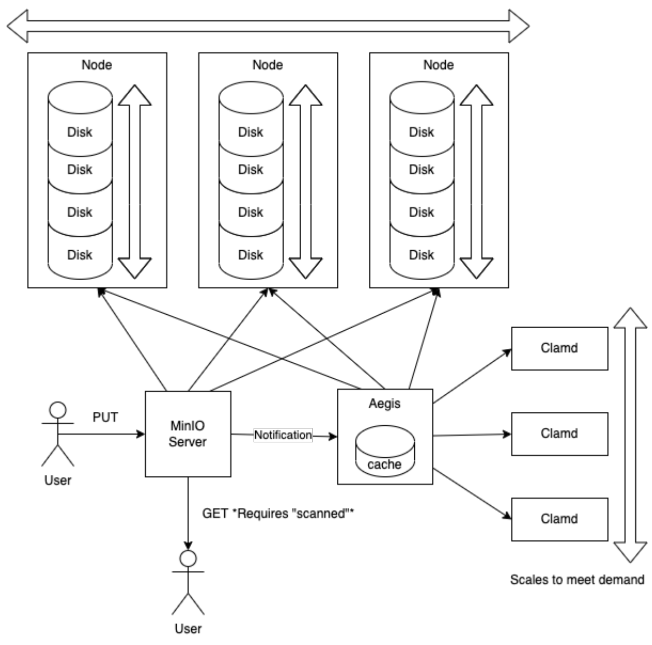


Figure 1. Post-Write Architecture

again removes responsibility from the solution by differing the scalability and reliability requirements of an event queue to MinIO.

Lastly, having Aegis dispatch the files to a scalable number of antivirus scanners allows the solution to scale to meet the demands of the system. This meets a key requirement as the solution is expected to have the capacity for a large number of operations. This method does require the use of a load balancer to effectively distribute the load across the available antivirus scanners.

The design also has a number of drawbacks. Firstly, the design still requires a small about of cache to temporarily store the object when it is being dispatched to the antivirus. Provisioning of this cache has to be large enough to handle the largest file possible to be uploaded to the object store. In reality, this cache would be provisioned even larger to allow for the temporary storage of multiple objects while multiple scans are being performed asynchronously. In addition, the cache needs to be large enough to ensure that the system does not become overwhelmed by the number of objects being scanned as the system scales. This is a minor issue as store capacity is cheap and the provisioning of the cache easy to scale up. Additionally, a higher priority can be given to scaling up and out antivirus scanners to ensure that the smallest number of files are being cached, while bring scanned, at any point.

The second drawback is that, for each event, Aegis makes a get request for the object to be scanned. This effectively doubles the number of requests made to the object store. This also means that Aegis must have the ability to get any file expected to be scanned and therefore must have access to the whole storage network. The impact of this drawback is mitigated as the solution is expected to be deployed on the same network as the object store which should reduce the latency of each request made by Aegis. However, this still leaves MinIO to handle twice as many requests with the performance loss being noticed mainly on more distributed storage topologies.

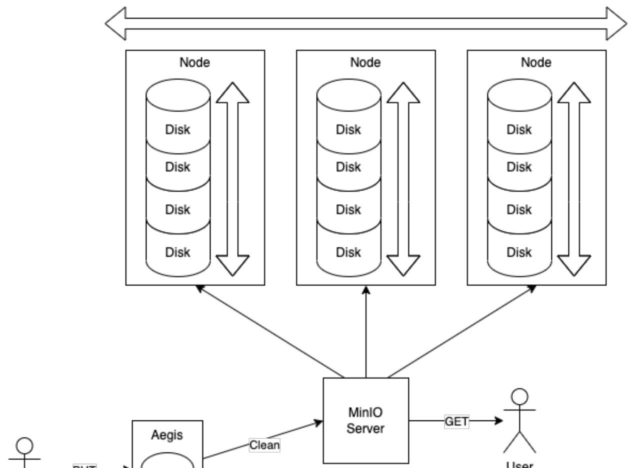
Thirdly, the design only allows for a single Aegis instance to dispatch all incoming objects to available scanners. This is a potential bottleneck for the system as this instance could become overwhelmed by the number of requests it is receiving. This is a minor issue as the dispatching of objects to scanners is not as performance intensive as other areas of the solution, such as the actual scanning, and therefore it is not expected to be a major bottleneck.

Lastly, any object uploaded to the store will have a certain period of time where it remains unchecked. In this time, the user could potentially download an unscanned object or the object could cause harm to the store before it is detected. Although the handling of infected objects is out of scope, in an actual implementation of the solution, the user could be made unable to download unscanned objects until they have been scanned.

Design 2 - Upload Queue

This design created a wrapper around MinIO that the user interacts with instead of MinIO. This means that all puts go through Aegis before being uploaded to the object store. The design is shown in figure 2.

The main benefit of this design is that the user interacts only with Aegis when uploading files. This means that all incoming files can be stored within a temporary storage before



ever entering the object store. This offers the best protection against malicious files as the user cannot ever download an unscanned or infected file as it is never uploaded to the object store. Infected files can then either be deleted or moved to a separate quarantine store for analysis.

This designs main advantage also comes with a major drawback. This design requires Aegis to handle the full throughput of all the puts to the system. Aegis then has the full responsibility of being available to all puts and, in a failure scenario, to handle the recovery of the system. Additionally, the cache provisioned must be large enough to handle the largest files at maximum throughput with extra room for unexpected delays. This negatively affects the scope of the project by requiring the solution to prioritise features that are already covered by MinIO.

Because MinIO is dependent on Aegis to handle the puts, MinIO must wait to be passed incoming objects sequentially after Aegis has finished processing the previous object. This removes the potential for aggregate performance where

Design 3 - Write Interception

Design three is very similar to the second design, however, instead of wrapping outside the MinIO service, it intercepts the writes from the client before objects are written to the object store. With this interception, Aegis can scan the object and decide whether to allow the object to be written to the store or to quarantine the object. The design is shown in figure 6.

This design has similar benefits as the second design. It offers the most protection against malicious files by never allowing either unscanned or infected objects to be stored in the object store. However, it also has similar drawbacks. This is because Aegis is still in sequence with MinIO meaning that for optimal throughput, Aegis would need to match the performance of MinIO.

Similar to the upload queue design, this design also requires Aegis to have a large cache to handle the largest files at maximum throughput. This cache must also be large enough to handle the number of objects being put by MinIO into the store. This issue cannot be mitigated without the risk of compromising performance at increased loads.

However, this design does have an advantage over the second design as there is less responsibility

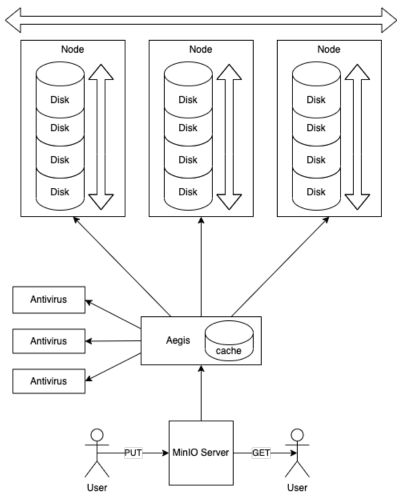


Figure 3. Write Interception Architecture

placed on Aegis to be as failure tolerant. MinIO is
still directly responsible for accepting objects into the store and therefore is still responsible for the recovery of the system in a failure scenario. This allows the scope to focus on more related features to malware scanning.

Design 4 - Per Node

The final design distributes Aegis onto each node in the object store. This means that each node has a local instance of Aegis that is responsible for scanning objects before they are written to the store. The design is shown in figure 4.

This design makes use of the distributed nature of MinIO to match the demand when scaling out the system. As more nodes are added, more Aegis instances are added to handle the increased scanning demand. This removes the need for having a cache repository as Aegis already has access to the files that need scanning. By removing this single point of failure, in theory, the system only relies on the antivirus pod to be able to scale out on its own.

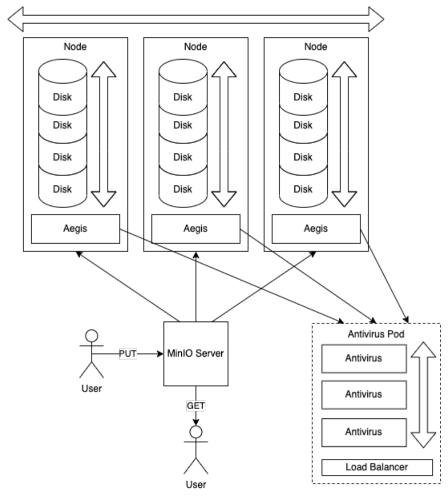


Figure 4. Antivirus per Node Architecture

Independent scaling of the antivirus pod allow for efficient usage of available hardware. A simple load based auto-scaler can be used to scale the number of pods based on the current load. This allows for the system to flexible scale with the demand of the system and to reduce usage of valuable resources, such as power. There is also the opportunity to use intelligent scaling techniques to predict the load on the system and prematurely scale the system to meet the demand. For example, to scale the number of pods depending on the time of day or the day of the week.

The major drawback of this design is that it replies on the ability to scan whole files by only using data on a single node. In actual implementations, MinIO makes use of erasure coding to add increased redundancy to the store (MinIO Erasure Coding, 2023). Erasure coding splits objects into multiple parts known as blocks, and then calculates corresponding parity blocks. These data and parity blocks are then distributed among all nodes in the system allowing for on-the-fly data recovery even with the loss of multiple drives or nodes . This means that the Aegis instance on each node only has access to the part available on their node and therefore will not be able to reconstruct the whole file for scanning. This makes this design unsuitable for MinIO as it erasure coding is one of its key features.

Optimal Design

Given the above evaluations of each design, design one best meets the requirements and constraints of the project. It makes the most use of the existing features that MinIO provides in order to handle failure scenarios and to scale out. This also means that this design has less critical responsibility and will better fit the scope constraints allowing for more time to be spent on supplementary features, such as testing, logging, and metric collection. Because of this, the produced solution will be closer to production-ready than the other designs.

This design keeps the user in control by giving them the ability to store unscanned files / known malware without wasting resources on a scan. Protection can be added per bucket therefore a user could have a known malware bucket and a clean bucket within the same object store. This allows for the system to be more flexible and to be able to handle more use cases. Designs two and three would not be as able to handle this use case as they both scan all objects before they are written to the store.

The size of the cache required is smaller than all other designs as it only needs to store the objects actively being scanned. This is in opposition to upload queue and write interception designs as they have to be prepared to handle the full demand placed on the store. This makes design one the most lightweight of all the designs which should lead to a smaller resource footprint.

Overall, implementing design one is the best option to create a lightweight yet secure and scalable solution.

5. Implementation

Initial Service Creation and Configuration

Before I started to code the solution, I needed to research, create, configure and most importantly understand each external service that I would be using. Up to this point I know what types of services I would need to create, but I did not know what specific services I would be using. This section will go through the process of how I chose each service and then initially configured them to form a bare-bones proof of concept.

Object Store - MinIO

The object store is the only service that I did not need to research or compare as it is already the subject of this project. However; I did need to create and configure a local instance of MinIO for development. MinIO itself is available from many sources, including Docker, Homebrew, and the MinIO website. I chose to use Homebrew, a MacOS package manager, as it is the easiest to install and update. I then used the MinIO documentation to create a local instance of MinIO where I can access the web client on http://localhost:9000. From this I could create buckets, upload objects to the store and get more familiar with MinIO's features.

MinIO has integrated the ability to send notifications to event queues depending on what operation is performed on the store. This makes it quick and easy to set up a locally running instance of an event queue to read messages sent by MinIO. MinIO offers wide support for many different event queues, such as Kafka, Webhook, Redis, PostgreSQL, and many more.

Event Queue

Kafka is a popular and well-supported event queue that is used in many different industries. It offers many features that make it a good choice for this project, such as high-throughput, low latency and open-source. Kafka is also available from both Docker and Homebrew make it easy to install and run locally. Most modern event queues offer similar high throughput and low latency, but Kafka is lighter in resource usage than other queues, such as RabbitMQ (Levy, 2022). This is beneficial as it will be easier to implement and not over use resources when it has a simple use case.

Kafka has a dependency on Zookeeper, which is a distributed coordination service. Zookeeper must be installed as a separate service but is available from the same sources as Kafka. Kafka can be run in Kafka Raft mode (KRaft) which will eventually replace Zookeeper, but as of writing KRaft has not been fully adopted yet (M, 2022).

With Kafka and Zookeeper setup, I use Kafka's command line interface (CLI) to start the service and create a topic. I then use the MinIO documentation to configure MinIO to send all put notifications to the Kafka topic. I can then use the Kafka CLI to read messages from the topic and see the messages sent by MinIO. This proves that the event queue is working and that MinIO is sending messages to it whenever I perform a put operation. An example Kafka message is available in the appendix in listing 1.

Antivirus

The antivirus we choose has to meet a list of requirements for it to be suitable for use in this project. Firstly, it must be able to be scaled with the solution in order to keep up with the demand placed on the system. Secondly, it must have a CLI that our program can interact with in order to scan files. Finally, it must be free or as cheap as possible to make it viable for commercial use. This narrows down the available options to a few contenders.

Sophos is a popular antivirus that is used by many businesses and is available for free for personal use, however; is it paid

ClamAV however is completely free and open-source. It comes with a scalable and multi-threaded daemon which can be accessed via CLI for high-performance and on-demand file scanning. (ClamAV, 2023). It is capable of scanning many different file types, including archives and mail files. Build-in is freshclam, a tool for automatically updating the virus database definitions. The virus database itself is also open-source and is updated regularly by the open source community. ClamAV has a docker image and is available from Homebrew.

I have chosen to use ClamAV as it is totally free for commercial use, open-source and has a CLI that can be used to scan files. It is also very well documented and has a large community of users. Sophos

ClamAV comes with a daemon, clamd, that can be run in the background and can be accessed via a CLI using clamdscan, the clamd client. A configuration file is needed to point clamdscan to the IP address that the daemon is running. In this case it is running locally on port 3310. Performing the clamdscan command and providing a file will scan the file and return the result. An example of this is available in the appendix in listing 2.

Metric Collection

As the project is expected to be as production-ready as possible, a system for collecting metrics is needed. This will allow the system to monitor its activity for easier maintenance and debugging. A few different options are available for metric collection, such as Prometheus, InfluxDB, and Graphite. Each of these

From this comparison, I chose to use Prometheus as it is open-source, uses a pull model with the option for a push gateway and it does not require a distributed system to run, unlike InfluxDB. Prometheus is available from both Docker and Homebrew.

Prometheus is currently unusable as I am not sending it any metrics to collect. I can still launch the Prometheus server and access the web interface on port 9090. In the meantime I can use the Prometheus documentation to create a configuration file defining the port and endpoint I expect to be exposing metrics to, in this case port 2112 and /metrics.

Audit Log Store

Production-ready software should have a way to store logs for auditing and analysis purposes. This is a relatively simple requirement as a central database can be used due to the expected low amount of data needing to be written. The purpose of the audit log is to store information about the scans performed by the system with information such as, time and result of the scan as well as the antivirus used. This gives the system a way to look back at previous scans which could help with debugging and maintenance.

There are many different options for a database to store the audit logs, such as PostgreSQL, MySQL, MongoDB, and many more. PostgreSQL remains the most versatile out of these options as it is a relational database and can be used for many different purposes. As the use case is simple, keeping to a single database service is the best option for maintainability and usability. PostgreSQL is also available from both Docker and Homebrew.

Like Prometheus, PostgreSQL is currently unusable as I am not sending it any data to store. However, I can still launch the PostgreSQL server and access the database via PostgreSQL shell prompt (psql). I can create a database and a user for the database to use. This database can then be exposed to port 5432 on the localhost ready for Aegis to use.

Data Visualisation

Graphana

Aegis

Now all of the dependencies have been downloaded, initialised and configured, Aegis can now be coded to interact with them.

The most common language to use for micro-service based projects is GoLang. Go is a compiled language that is statically typed and high concurrency support. This makes it a perfect fit for this project to ensure that the system is as performant as possible. MinIO is also written in Go should allow for easier integration. Go has certain standards and guidelines for clean architecture that should be followed to ensure high usability and efficiency.

In Go you should the separate the code into different packages, where each package represents a distinct function of the system. This allows for easier maintenance and debugging in the future. These packages are then grouped into different directories depending on their intended scope. There are three main directories that are used in GoLang projects, cmd, pkg and internal. The cmd directory is used to store the main.go file which manages the workflow and is the entry point of the program. The pkg directory is used to store all of the packages that are intended to be used by external applications, in this case our other services. The internal directory is used to store all of the packages that are intended to be used by the application itself. This is where the packages in the pkg directory will be consumed to perform the Aegis' core actions as follows:

- Listen for PUT events on the event queue
- Read the message from the event queue and extract the bucket and object path
- GET the object from the object store and store in cache

- Initiate a scan on the object using the antivirus software
- Collect the result of the scan and add tags to the object
- Collect metrics throughout the process
- Store the result of the scan in the audit log
- Expose metrics to Prometheus

From these requirements, the internal design of Aegis can be planned. We can visualise this plan using a class diagram. It is worth noting that Go itself does not have classed but instead uses structs which can be used to achieve the same effect. This plan is shown in figure **??**.

This is shown in figure **??**.

Implementation Milestones There are many key milestones that can be used to measure the progress of the project through the duration of its implementation. It is worth noting that these milestones were created before the implementation of the solution and therefore are subject to change.

diagrams/aegis-plan.png

Figure 5. Plan of Aegis' Internal Packages

- Setup local antivirus instance
- Setup local MinIO instance
- Setup local event queue instance
- Detect PUT message on Kafka
- Read JSON of message to find bucket and object path
- Create AV manager service in GoLang
- Request GET on Object using message data
- Scan Object using Clamd
- Act on result of scan - Add tags, result, time and AV used
- Configuration file using viper
- Add metric collection with Prometheus
- Add structured logging with zap
- Create Database of Audit Logs with postgresql
- Termination of connections to services
- Create tests for each package using mockery
- Prepare for Kubernetes deployment with k3d
- Containerise Aegis with Docker
- Automatically configure and start MinIO, Kafka, Clamd, Postgresql, Prometheus and Aegis with Helm
- Port forward MinIO out of the cluster
- Load balancing / performance analysis for Clamd
- Expose Postgresql and Prometheus for analytics
- Prepare configurations for demo, release etc
- Clean-up version control and write readme.me

These milestones can be broken down even further into smaller tasks. These are best represented in Gantt / burndown charts which can be found in the appendix.

5.0.1. Code

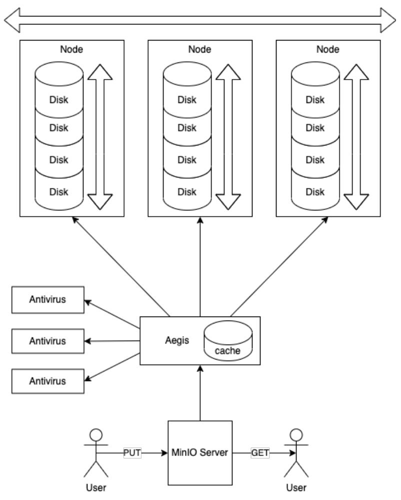


Figure 6. Write Interception Archi

Kubernetes Deployment

6. Results and Evaluation

7. Product Issues / Future work

8. Conclusions

9. Reflection on Learning

10. Appendix

Listing 1. Example Kafka Notification

```
{
  "EventName": "s3:ObjectCreated:Put",
  "Key": "test-bucket/gantt.png",
  "Records": [
    {
      "eventVersion": "2.0",
      "eventSource": "minio:s3",
      "awsRegion": "",
      "eventTime": "2023-03-24T12:23:27.844Z",
      "eventName": "s3:ObjectCreated:Put",
      "userIdentity": {
        "principalId": "minioadmin"
      },
      "requestParameters": {
        "principalId": "minioadmin",
        "region": "",
        "sourceIPAddress": "127.0.0.1"
      },
      "responseElements": {
        "content-length": "0",
        "x-amz-id-2": "e3b0c44298fc1c149afbf4c8996fb92427ae41e4649b934ca495
        "x-amz-request-id": "174F5A6C715ECB50",
        "x-minio-deployment-id": "439d9d33-3cca-42ae-b778-d703cbf9bbf7",
        "x-minio-origin-endpoint": "http://192.168.1.138:9000"
      },
      "s3": {
        "s3SchemaVersion": "1.0",
        "configurationId": "Config",
        "bucket": {
          "name": "test-bucket",
          "ownerIdentity": {
            "principalId": "minioadmin"
          },
          "arn": "arn:aws:s3:::test-bucket"
        },
        "object": {
          "key": "gantt.png",
          "size": 92704,
          "eTag": "22c4ae87e652bce0865536964cb8bb8d",
          "contentType": "image/png",
          "userMetadata": {
            "content-type": "image/png"
          },
          "sequencer": "174F5A6C71C977E8"
        }
      },
      "source": {
        "host": "127.0.0.1",
        "port": "",
        "userAgent": "MinIO (darwin; arm64) minio-go/v7.0.49 MinIO Console
      }
    }
  ]
}
```

Listing 2. Example Kafka Notification

```
/Users/username/test.jpg: OK

----------- SCAN SUMMARY -----------
Infected files: 0
Time: 0.332 sec (0 m 0 s)
Start Date: 2023:03:27 11:53:15
End Date:   2023:03:27 11:53:16
```

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