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BACHELOR OF SCIENCE (HONS) APPLIED COMPUTING

Heimdall - A Kubernetes Extension

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1   Plagiarism Declaration

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2 Acknowledgements

I would like to express my deepest appreciation to my Mentors Ciaran Roche and Laura Fitzgerald who provided invaluable experience and contributions to this project. I would also like to extend my deepest gratitude to my Project Supervisor Lucy white for guiding and encouraging me throughout the process.

3 Introduction

This project, Heimdall, is an open-source Kubernetes Extension built for multi-operator Kubernetes environments. Implementing Heimdall will allow developers to configure it to watch resources of their choosing in a Kubernetes cluster. Heimdall will prevent any unwanted Operators from changing that resource, while simultaneously sending an interactive notification to the developer via a pre-configured Slack Channel regarding the issue.

3.1 Background

In 2022 I completed an 8-month internship at Red Hat for my 3rd-year work placement. I worked on the Red Hat OpenShift API Management (RHOAM) team. RHOAM utilises multiple OpenShift Operators, which are automatically managed and configured applications, to provide a comprehensive API solution to its customers. The API management features provided by RHOAM include [Red Hat Developer, 2020]

- Limiting the number of API requests based on the customer's purchased quota
- Creating security policies to manage API access
- Monitoring API health
- An API portal for sign-up and documentation

While working on this team, I had the opportunity to contribute to applications which utilize various technologies like Kubernetes, OpenShift, and Go Operators.

3.2 Motivation

Throughout my internship, I ran into a number of technical issues including one with RHOAM's rate-limiting service which has become the motivation for my project, Heimdall. A rate limit is the maximum number of API calls allowed during a specified period of time [IBM API-Connect, 2022]. RHOAM uses the Marin3r Operator to provide rate-limiting for RHOAM customers. It works by injecting a rate-limiting container into a Pod. The container then acts as a middleman for API requests by only redirecting requests to the destination container if the API request limit has not been reached. Pods, containers, and other terms mentioned here are discussed further in Section 5.

I discovered a bug with the port that API requests were sent to for rate-limiting. The port was being overwritten by a conflicting Operator who had a different desired state for that Pod. This meant that customers who had RHOAM installed were not being consistently rate-limited.

It took multiple days of debugging to figure out what was going wrong and another week passed before my code changes were merged. This meant that this problem had been occurring on customer clusters for an unknown amount of time before the fix reached them. After speaking to developers on various Red Hat teams, it became apparent that this problem was not unique to our team and is an issue that all Kubernetes and OpenShift product teams face. Fixing this will not only benefit Red Hat teams but any team working on a Kubernetes-based application that utilizes Operators.

3.3 Problem Statement

In Kubernetes (K8s), custom resources (or objects) have a state in which they should remain which are stored in YAML files called custom resource definitions. When an Operator is watching a resource's state, it continuously compares the state defined in that resource's YAML definition with its actual state. If these don't match, it is the Operator's job to make the necessary changes in order for the desired state and actual state to match [Operator Pattern, 2022].
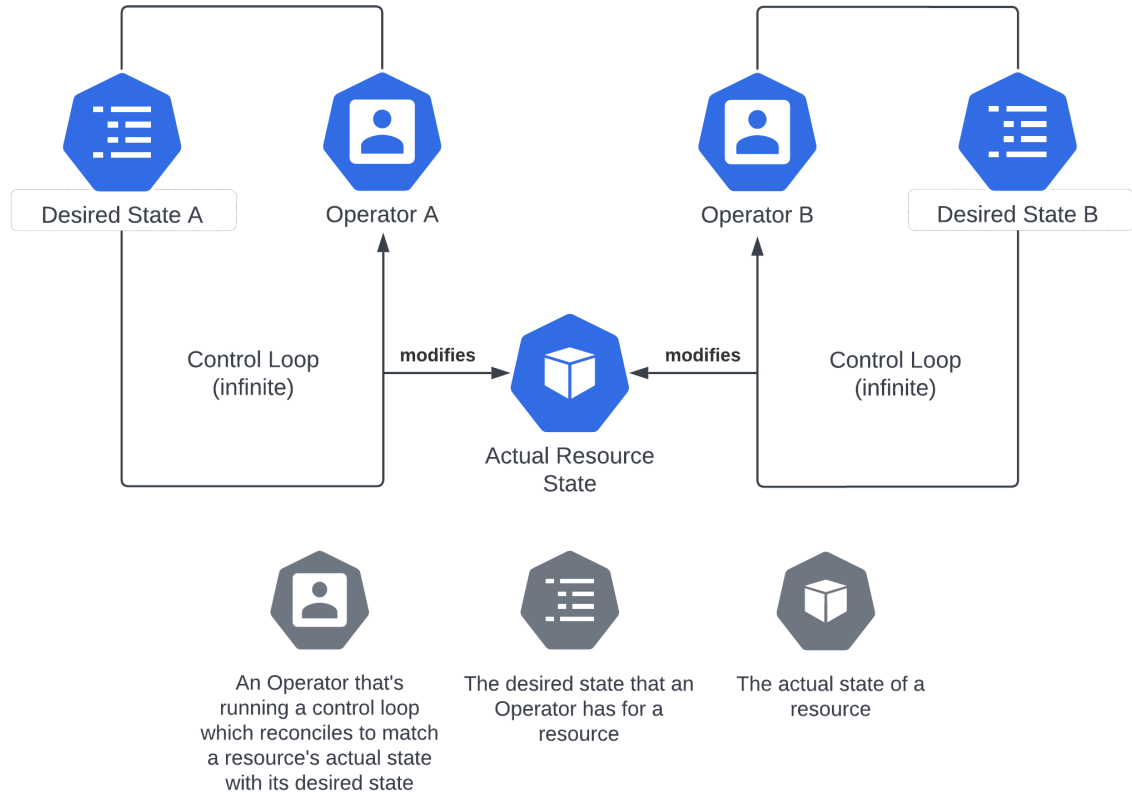
Figure 1: Model of The Problem - Two Operators Fighting Over a Resource's State

This pattern works well until two Operators with conflicting YAML definitions are both set to watch a resource. This will cause the resource's state to continuously change as both Operators attempt to synchronise its actual state with their unique desired state. The model shown in Figure 1 shows this problem in action. Each Operator watches their Custom Resource desired state and instructs their controller to make the necessary changes to ensure the actual resource state matches.

3.4 Industry Example

As an example, the open-source e-learning platform Moodle will be used. In an education environment, one might have a Moodle Operator and a MySQL Operator as that is the back-end database used by the platform. The MySQL Operator manages the storing, of course, student, and module information. This application may then install a Tutors Operator, which is another e-learning platform which houses course notes and lab work. Since there is already a MySQL database via the MySQL Operator, Tutors can use the same database to store course notes and lab work.
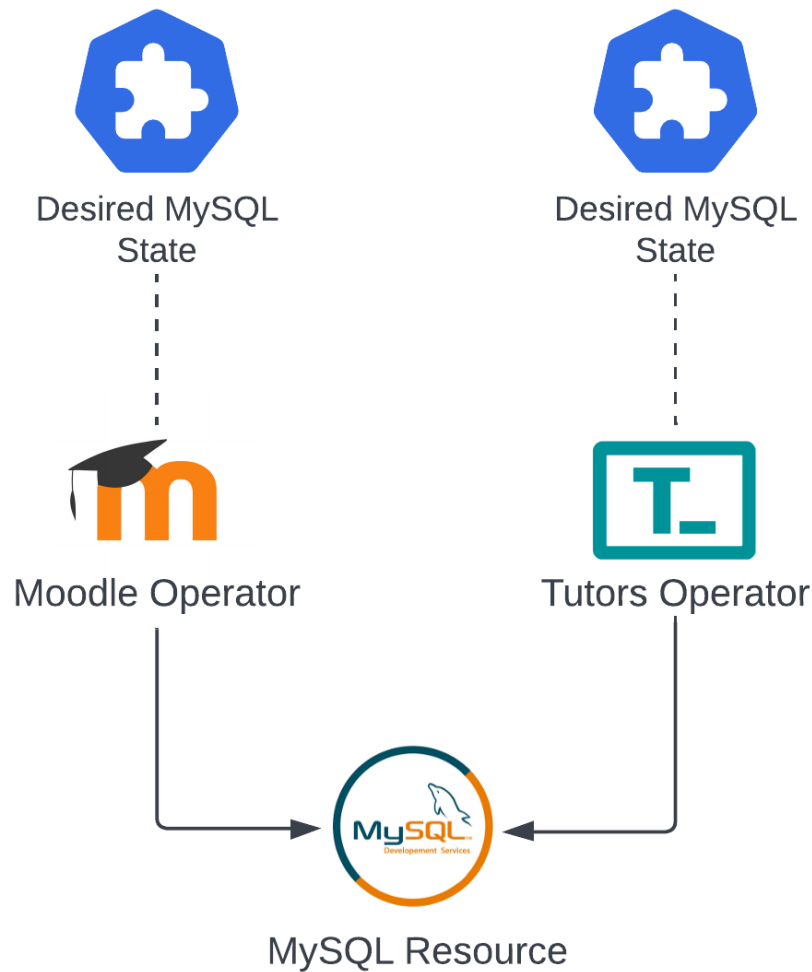
Figure 2: Model of Moodle, Tutors, and MySQL Industry Example

In this example, it would be very easy to misconfigure one of the Operators to have a diverging desired state for the MySQL resource. This would cause both Operators to constantly change that resource. Imagine Moodle wanted the port in which database access occurred to be port 8000 and Tutors wanted the database access to occur through port 8001. This would cause the MySQL resource's access port to be changed back and forth. If a lecturer or student was attempting to access information through Moodle, but at that point in time the MySQL resource's port was configured by the Tutors Operator, the user would not be able to retrieve the data.

3.5 Aims and Objectives

The solution is to create a custom Kubernetes controller which will monitor resource states. A Kubernetes Operator can create a resource, become its owner, and will set the controller to watch that resource for changes. If another operator changes the resource the controller will fire an alert, notify the developer via a slack integration and allow the developer to fix the problem without the need for time-consuming debugging.
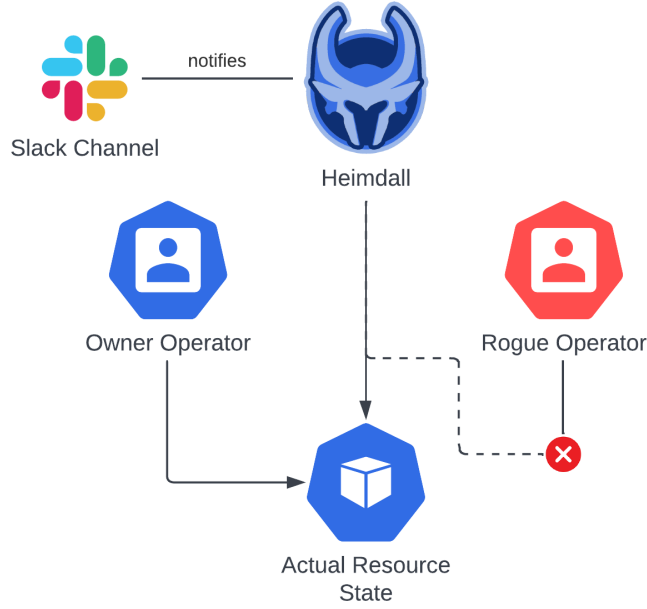
Figure 3: Model of the solution: Heimdall

Figure 3 models the proposed solution where the Owner Operator and Rogue Operator are attempting to change a resource's actual state. Once the Owner Operator is installed, it creates the resource with the addition of a label that Heimdall is looking for. Heimdall sees a new resource has been created with this label and begins monitoring its state. The Rogue Operator is installed and begins changing the resource.

The minimum viable product for Heimdall involves the controller watching for non-owners changing the state of a resource. It will then generate an interactive notification for slack with details on the issue to allow the developers to find and fix the problem with relative ease. The stretch goals for Heimdall will involve allowing for an atomic owner of a resource to be set and blocking of changes from non-owners. This will not only allow the developer to fix the problem with ease but also stop the issue from occurring and prevent any downtime for the end user.

3.6 Risks

TODO(): this is a risky project as it has never been done before

3.7 Contributions

3.8 Outline

4 Methodology

The chosen methodology for software development teams is paramount for the successful planning and development of a product. Historically, the Waterfall Methodology was commonplace - but now Agile is the gold standard. Waterfall involved a distinct sequence of actions for engineers to follow. In short, it involved extensive design and planning before ever writing a line of code. Long documents detailing product design and strategy were written to fit the stakeholder's requirements. This proved to be ineffective as in most cases, holes in the design are discovered after beginning the implementation. In recent years, Agile has begun replacing this framework as it has proven much more efficient for software development teams [M. McCormick, 2012].

4.1 Agile

"Agile is an iterative approach to project management and software development that helps teams deliver value to their customers faster and with fewer headaches" [What is Agile?, 2022]. TODO() DISCUSS AGILE + SCRUM

4.2 Scrum Roles

Scrum has three main roles: Scrum Master, the Product Owner, and the Development Team. These are used to help describe the responsibilities of each stakeholder for a product.

4.3 Scrum Artifacts

Teams who practice Agile and Scrum methodologies often collect Scrum Artifacts. These are pieces of information that a product's stakeholders and the team developing it use to describe its development. The main Scrum Artifacts used for this project include Product Backlog Refinement, Sprint Planning, and Sprint Reviews. There are also various Extended Artifacts that are not included in the official Scrum Artifacts definition. These include reporting mechanisms like Burn down Charts.

4.4 Version Control

What is VCS, Git, GitHub,

4.5 Continuous Integration

Version control lies at the heart of Continuous Integration. CI is an Agile practice of integrating code changes to a product automatically from various contributors (product teams and open-source community contributions). It is a method used to consistently merge code changes into one central repository which runs automated tests and builds to ensure code functionality and integrity.

4.6 Continuous Delivery

Continuous Delivery is an approach

4.7 Testing Approach

4.8 Open Source

5 Technologies

5.1 Kubernetes

6 Tools

Minikube, Kubebuilder, Docker, Podman, Git, GitHub, Jira

7 Design

7.1 System Architecture Overview

7.2 Requirements

7.3 Functional Requirements

7.4 Non Functional Requirements

7.5 Core Requirements and Stretch Goals

7.6 User Stories

As a Developer, I want to be aware of changes to resources that I own. In order to be aware of changes to resources that I own, as a k8s developer, I want to be notified by some channel, such that I don't have to manually watch resources in a cluster. As a Developer, I want to control the cadence of alerts so that I can control noise created from alerts. As a Developer, I want to claim ownership of the resources that I control As a Developer, I want to control the changes to resources that I own.

7.7 Personal Stories

As a student, I want to have achieved First Class Honors, so that I can reach my academic goals As an aspiring Software Engineer, I want to have contributed a solution to a common problem faced by Software Engineers working with Kubernetes, so that I can make a valuable contribution..?? - something like that

7.8 User Definitions

7.9 Models

8 Prototypes

8.1 Proof of Concept

9 Reflection

10 Summary

10.1 Review

10.2 Semester 2 Outline

11 Appendices

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