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# Basilisk – Continuous Benchmarking for Triplestores

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# Erklärung

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Ort, Datum

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Unterschrift



**Abstract.** The process of benchmarking triplestores can be very time-consuming. When a new version of a triplestore is released, it has to be installed and setup in order to perform a benchmark on it.

The idea of the Basilisk platform is, that the process of benchmarking new triplestore releases gets fully automated. To accomplish this, the platform can observe Docker Hub and GitHub repositories. When a new release is detected, a benchmark job is created. The platform automatically downloads the new release, sets up a Docker container and configures the IGUANA framework before starting the benchmark. After the benchmark, the results measured by IGUANA are stored in the result triplestore.

During this thesis, we analyzed and reviewed the existing implementations of the Basilisk platform. We then implemented the entire benchmark process for repositories on Docker Hub and prepared the benchmark process for GitHub repositories. Finally we evaluated the automated benchmark process and compared it to a manual setup using the IGUANA framework.



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# Introduction

In the field of Semantic Web, knowledge graphs are the central structure to represent data and its relationships. To easily store and query the data in knowledge graphs, some specialized knowledge graph databases are required. The special kind of database developed to store knowledge graphs are called triplestores.

Since knowledge graphs can contain huge amounts of data of various structure which can also be subject to many changes, triplestores need to be able to handle many different workloads. Some scenarios need to handle huge amounts of data being added, while others need to handle a lot of changes on the current data.

more example for things that can be different, e.g. simple ontologies vs complex

To better test and compare triplestores in these diverse scenarios, benchmarks are performed to allow an appropriate comparison between different triplestores [20].

In general, benchmarks are used to measure and compare the performance of computer programs and systems with a defined set of operations. Often they are designed to mimic and reproduce a particular type of workload to the system [19, 16]. In the context of triplestores, a benchmark consists of creating a given knowledge graph on which multiple queries and operations are performed [8].

Usually triplestores are developed in long iterations and are benchmarked only in a late stage of such a development iteration. Benchmarks and the evaluation of their results are often done manually and bind time of developers. Thus, performance regressions are found very late or never.

Several benchmarks for triplestores have been proposed [20]. Most benchmarks are executed in their own execution environment. To better compare different benchmarks, benchmark-independent frameworks have been developed. IGUANA is such a benchmark-independent execution framework [8], that can be used to measure the performance of triplestores under several parallel query request. Currently the benchmark execution framework needs to be configured and started manually for every new benchmark configuration.

Basilisk<sup>1</sup> is a continuous benchmarking service for triplestores which internally uses IGUANA to perform the benchmarks. The idea is that the Basilisk service will check automatically (continuously) for new versions of a given triplestores and starts benchmarks with the IGUANA framework. Further, it should be possible to start custom benchmarks on demand. If a new

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<sup>1</sup><https://github.com/dice-group/Basilisk>

version is found in a provided GitHub or Docker Hub repository, Basilisk should automatically setup a benchmark environment and start a benchmarking suite.

continue paragraph

This means that developers do not have to worry about performing benchmarks at different stages of development.

it not clear yet that basilisk was there before. also it would be better to move the notion of the previous code basis above the Basilisk is a cont... paragraph (or at its start).

In this thesis, we continue the development of the Basilisk platform and deploy an instance to a publicly available virtual machine.

The thesis is structured as follows: In Chapter 2, we take a look at the state of the art of triplestore benchmarking. Chapter 3 introduces the fundamental concepts and topics necessary for understanding this thesis. This consists of topics from the field of Semantic Web as well as topics from the field of software development. In chapter 4, we describe and review the architecture used in the Basilisk platform. Chapter 5 presents the development and implementations that are performed to finalize the platform. Finally, in chapter 6 we evaluate the platform and its provided benefits to the triplestore benchmark process.

## Related Work

This chapter reviews the state of the art of triplestore benchmarking.

Several benchmarks have been proposed and developed to test triplestores [7, 12, 16, 19, 21]. Many of these existing benchmarks focus on different goals and scenarios. Section 2.1 and 2.2 explain the different benchmark types used to benchmark triplestores. Section 2.3 gives a short introduction to benchmark execution frameworks. An introduction to benchmarking in general is given in section 3.2.1.

### 2.1 Synthetic Benchmarks

Synthetic benchmarks are benchmarks where the data is artificially generated. Often the generation is influenced by real world scenarios to generate data comparable to real world datasets [12]. These synthetic benchmarks have the advantage, that they can be generated to arbitrary sizes. The main point of criticism for synthetic benchmarks is that the generated data can easily become skewed and repetitive. Often the generated scenarios are criticized for not being representative enough of a real world scenario [19]. In the following paragraphs we introduce three benchmarks that are often mentioned when considering synthetic triplestore benchmarks.

The Lehigh University Benchmark (LUBM) Benchmark [12] is a synthetic benchmark which focuses on the reasoning and inferencing capabilities of the triplestores under test. The test data is located in the university domain and can be generated to arbitrary size. Fourteen extensional queries are provided that represent and test a variety of properties.

Another synthetic benchmark is SPARQL Performance Benchmark (SP<sup>2</sup>Bench) [21]. The data generated stems from the DBLP scenario. During the generation process, the generated key characteristics and word distributions are chosen to match the distributions of the original DBLP dataset. The provided queries are mostly complex and the mean size of the result sets is above one million [19]. They also test for SPARQL features like union and optional graph patterns.

The Waterloo SPARQL Diversity Test Suite (WatDiv) generates a synthetic benchmarks and consists of multiple tools [7]. First tool is the data generator which generates scalable and customizable datasets based on the WatDiv data model schema. The query template generator generates diverse query templates which will then be used to generate actual queries. The queries get generated with the query generator which instantiates the templates with actual Resource

Description Framework (RDF) terms from the generated dataset. For each template multiple queries can be generated. The benchmark only focuses on SELECT queries that do not make use of the union and optional pattern features of SPARQL.

## 2.2 Real-World Benchmarks

Real-world benchmarks use real datasets that were used in productive settings or are still being used. The real queries are often taken from query logs of triplestores and the datasets are based on real datasets [16, 19].

FEASIBLE is a benchmark generation framework which generates queries from provided query logs [19]. This has the advantage that the data used for the benchmark could stem from queries about a specialized real world topic rather than an abstract synthetic model. FEASIBLE can also generate queries for the other SPARQL query types beside SELECT.

## 2.3 Benchmark Execution Frameworks

Benchmark execution frameworks, as the name suggests, help in the execution of database benchmarks. Their tasks are to load the data, execute the test queries and measure the defined metrics to evaluate the system under test.

Many benchmarks provide their own execution environments, which makes the comparison between benchmarks difficult. Often those environments are specialized for the given benchmark and are not easily interchangeable [8].

The next sections focus on benchmark-independent execution frameworks.

### 2.3.1 IGUANA

IGUANA is a SPARQL, benchmark-independent execution framework [8]. The framework gets a dataset and a set of queries and operations as input and then uses the SPARQL endpoint of the triplestore to load and update the data, as well as to perform the benchmark queries. It allows the measurement of the performance during loading and updating of data as well as parallel requests to the triplestore. IGUANA is independent of any benchmarks which allows it to run in different configurations and with various existing benchmarks and datasets. This includes synthetic benchmarks (2.1) and benchmarks based on real data (2.2). The benchmark process is highly configurable by passing a configuration file to the IGUANA framework.

### 2.3.2 HOBBIT Framework

The HOBBIT framework is a distributed benchmarking platform designed to be able to scale up benchmarking for big linked-data applications [17]. It is a big framework which needs to be deployed on a local cluster or online computing services like Azure<sup>1</sup> or AWS<sup>2</sup>. The deployment of the platform and deploying new benchmarks to the platform can be challenging for new users of the system [17]. The data for benchmarks has to be stored in docker containers or it needs to be generated or downloaded before a benchmark, which increases the complexity of the system. The data is then sent over message queues to the benchmarked system.

With the Basilisk platform we developed a specialized solution for continuous benchmarking of triplestores which does not need the technical complexity present in the HOBBIT framework.

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<sup>1</sup><https://azure.microsoft.com/>

<sup>2</sup><https://aws.amazon.com/>

## CHAPTER 2. RELATED WORK

Implementing this functionality into the HOBbit framework would introduce another level of complexity to the system. Basilisk focuses on a smaller use-case of benchmarking SPARQL endpoints continuously with as little overhead as possible.



This chapter introduces the fundamental topics and background information that we use throughout this thesis. The Basilisk platform, that is developed in this thesis, focuses on benchmarking triplestores. Triplestores are used in the research field of Semantic Web, therefore we give a short introduction to the most important topics from that research field. Since the platform is actively developed during this thesis, software development is the second big topic we introduce in this chapter.

In section 3.1, building blocks of the Semantic Web are introduced. In section 3.2, required topics from the field of software development are covered.

## 3.1 Semantic Web

The following topics stem from the research area of Semantic Web. Semantic Web is the research field that tries to represent information on the internet in a way that makes it processable by computers [14].

Since this thesis focuses mostly on the implementation and deployment of the Basilisk platform, these topics are mainly introduced to give a basic understanding to the context in which the Basilisk platform will be used.

### 3.1.1 Knowledge Graphs

Knowledge Graphs are graphs intended to represent knowledge of the real world or small scenarios. The knowledge stored in Knowledge Graphs is modeled in a graph-based structure. Nodes represent entities which are connected by various types of relations, represented by labeled edges in the graph. This has the benefit of being able to represent complex relations between different nodes and edges [15].

The simplest Knowledge Graph consists of three elements. The subject entity, the object entity and the labeled edge between them describing their relation. This atomic data entity is called *triple*. In figure 3.1, a simple example of a Knowledge Graph is shown.

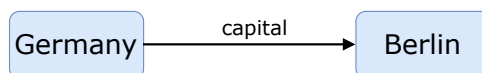


Figure 3.1: Simple Knowledge Graph

This Knowledge Graph could be extended in all directions. For example, the "Berlin" entity could get an edge labeled "population" which would be pointing to the population size of Berlin.

Since a graph structure is hard to store in a classic relational database a different type of storage is needed. The special kind of database developed to store knowledge graphs are called triplestores. Triplestores will be explained in section 3.1.3.

### 3.1.2 RDF

The Resource Description Framework (RDF) is a framework for describing data and knowledge in a standardized way [5]. It is part of the W3C standard. The information is written down as subject-predicate-object triples, representing the basic structure that is also present in Knowledge Graphs (3.1.1). The elements of those triples can be Internationalized Resource Identifiers (IRIs), blank nodes or datatyped literals.

RDF graphs can be encoded with different syntax styles. A popular syntax is TURTLE [6] which is a compact way of writing down a RDF graph structure. Using the example of section 3.1.1, the knowledge graph would be represented with the TURTLE syntax as seen in listing 3.1. The first two lines of the TURTLE document define abbreviations for the used IRIs so that the triple in line three is more readable.

Listing 3.1: RDF example in TURTLE syntax

```
1 @prefix dbr: <http://dbpedia.org/resource/> .
2 @prefix dbo: <http://dbpedia.org/ontology/> .
3 dbr:Germany dbo:capital dbr:Berlin .
```

### 3.1.3 Triplestore

Triplestores are a special kind of database developed to easily store and access knowledge graphs through queries [18]. They differ to relational databases, by being purposefully build to only store and access data in set of triples. Data is accessed through the query language SPARQL, which gets introduced in section 3.1.4. Often bigger datasets can be imported or exported using RDF or other syntax.

Example of triplestores are TENTRIS<sup>1</sup>, GraphDB<sup>2</sup>, Virtuoso<sup>3</sup>, or Jena TDB<sup>4</sup>. Since TENTRIS is actively developed, by our research group, we wil focus our tests and evaluations of the platform on this triplestore.

This thesis focuses on triplestores that have a SPAQRL endpoint and accept SPARQL queries, since the used benchmark framework IGUANA is using the SPARQL endpoint to perform benchmarks (see section 2.3.1).

### 3.1.4 SPARQL

SPARQL (SPARQL Protocol and RDF Query Language) [13] is a query language for manipulating and retrieving RDF data stored in triplestores. Just like RDF, SPARQL is part of the W3C recommendations for technologies in the semantic web.

The syntax for SPARQL queries looks similar to the SQL syntax, since its main parts are also a **SELECT** clause, stating which variables to query for, followed by a **WHERE** clause giving restrictions and conditions.

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<sup>1</sup><https://tentris.dice-research.org/>

<sup>2</sup><https://graphdb.ontotext.com/>

<sup>3</sup><https://virtuoso.openlinksw.com/>

<sup>4</sup><https://jena.apache.org/documentation/tdb/>



Queries can contain optional graph patterns, conjunctions, disjunctions, as well as aggregation functions. These extensions can help formulate more complex queries.

There are two example SPARQL queries in listings 3.2 and 3.3. Executed against the DB-Pedia SPARQL endpoint<sup>5</sup>, the following results can be found: The first example query (3.2) requests the variable which matches the **WHERE** clause searching for the capital of Germany, which is **dbr:Berlin**. The second query (3.3) requests all relationships that can be found between Germany and Berlin, which will return **dbo:capital**, which we expected, but also **dbo:wikiPageLink**, which means that there is a link from the Wikipage of Germany to the Wikipage of Berlin.

Listing 3.2: SPARQL query searching the capital of Germany

```

1 PREFIX dbr: <http://dbpedia.org/resource/>
2 PREFIX dbo: <http://dbpedia.org/ontology/>
3
4 SELECT ?capital
5 WHERE {
6     dbr:Germany dbo:capital ?capital .
7 }
```

Listing 3.3: SPARQL query searching all relations between Germany and Berlin

```

1 SELECT ?relation
2 WHERE {
3     dbr:Germany ?relation dbr:Berlin .
4 }
```

## 3.2 Software Development

The following topics can be grouped under the field of software development. For the topic of benchmarks (section 3.2.1) we focus on database benchmarks and especially triplestore benchmarks, since this is the main task of the Basilisk platform. The sections Microservice (3.2.2) and Microservice Architecture (3.2.3) explain the basic idea and concept of the microservice architecture. In the sections RabbitMQ and Spring (3.2.5, 3.2.4) we give a short introduction and description of the main technologies that are used for the development of the Basilisk platform.

### 3.2.1 Benchmark

Benchmarks for databases consist of a dataset and a set of operations or queries which will be performed on the dataset. These operations are designed to simulate a particular type of workload to the system. The goal of a benchmark is to measure different metrics for a better comparison between various systems. Metrics used for databases and triplestores are e. g., number of executed queries (NoQ) and queries per second (QPS) [3].

A distinction is made between micro and macro benchmarks [11]. Micro benchmarks focus on testing the performance of single components of a system. Macro benchmarks test the performance of a system as a whole. The benchmarks performed by the Basilisk platform will only cover macro benchmarks.

### 3.2.2 Microservice

A microservice is an independently deployable piece of software that only implements functionalities that are closely related to the main task of the service [9]. All Microservices can be individually deployed and managed. They interact via messages through a defined protocol with

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<sup>5</sup><https://dbpedia.org/sparql>

other services. The idea is that individual microservices can be combined like modules to create any desired complex software.

A common example is online shop system that is divided into microservices. One service of this system could be a service managing the customer data, like contact details and shipping addresses. If another service needs this information, it can send a request to this service over defined protocols.

### 3.2.3 Microservice Architecture

A microservice architecture is a way of designing a software application as a set of microservices which interact with each other to provide the designed functionality [9, 4]. The functionality of the application gets split up into microservices which interact only through a defined message protocol. This allows for a distributed system, in which the individual services could be implemented in different programming languages and also could be located on different servers.

Extending the example from section 3.2.2 we have a microservice architecture with three services. One service manages the customer data, a second service manages the incoming orders, and the last service manages the shipping process. When an order arrives in the order service, it will send a message to the shipping service, with the order items. The shipping service will then request the customers shipping address from the customer-data service.

### 3.2.4 Spring and Spring Boot

Spring<sup>6</sup> is a widespread open-source Java framework which facilitates the development process for various kinds of java applications and systems.

Spring Boot<sup>7</sup> is an extension to the Spring framework that follows the convention-over-configuration design paradigm. This means that the implementation of applications has to follow common design conventions that replace a need for configuration files for many standard scenarios. Spring Boot also comes with preconfigured standard libraries for the Spring platform to ease the development for many standard applications like web-apps or microservices.

Spring and Spring Boot uses different annotations to decorate classes and methods. These annotations configure the classes automatically and tell the Spring framework how to handle and interact with their objects.

The Spring framework and Spring Boot use different software design conventions to structure the code and classes.

### 3.2.5 RabbitMQ

RabbitMQ<sup>8</sup> is an open-source message broker that supports different messaging protocols like MQTT, STOMP and AMQP. The system supports a variety of asynchronous messaging techniques e.g., delivery acknowledgment, and flexible routing.

Since RabbitMQ is a widely used message broker, the Spring framework (3.2.4) already comes with the needed libraries to work with the RabbitMQ system.

describe what guarantees the message types we use provide

In the context of the Basilisk platform we only need the most basic functionalities of message queues with a single producer and a single consumer.

---

<sup>6</sup><https://spring.io/>

<sup>7</sup><https://spring.io/projects/spring-boot>

<sup>8</sup><https://www.rabbitmq.com/>

### 3.2.6 Docker

Docker is a platform for containerizing applications for development and deployment [1]. Following the idea of a shipping container used on freight, a Docker container can be installed on any system that supports the Docker technology. That means that there are no other software requirements than the Docker engine to run a container. Inside the container, all requirements and libraries are installed that are needed by the application that is run in the container.

The application can only reach the outside of the container and, vice-versa, can be reached from the outside, if the required ports are published. This encapsulates the application from unwanted accesses, as well as protects the host system from malicious software that could be run inside a container.

A Docker container is always build from a Docker image. A Docker image is a read-only template to create a Docker container with the running application inside.

There are two main ways to create a Docker image. First, it could simply be downloaded from Docker Hub. The second option is to build the Docker image from a Dockerfile. A Dockerfile<sup>9</sup> contains the instructions for building a Docker image. The Dockerfile first references the base image which is used to build the image. This could be, for example, a standard Ubuntu distribution. After the base image, the Dockerfile defines which commands are run or which files should be copied from the host system into the image.

After the image is build or downloaded from Docker Hub, the container can be further configured before it gets started. For example, ports can be published to make the service running inside the container available to the outside.

Often multiple containers are needed to deploy a complete service platform. For example, the Basilisk platform consists of three containerized services, a RabbitMQ container and a container running Fuseki. For these situations, Docker offers Docker Compose<sup>10</sup> files, which help to orchestrate multiple containers in a Docker network.

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<sup>9</sup><https://docs.docker.com/engine/reference/builder/>

<sup>10</sup><https://docs.docker.com/compose/>



## Approach

In this chapter we give an overview to the design of the Basilisk platform. We will explain the different processes used in the platform in section 4.2. In section 4.4 we will analyze and review the current software architecture and implementation status of the Basilisk platform.

mehr roter Faden, Verbindung zw den genannten Punkten

The purpose of the Basilisk platform is to provide an easy way to continuously perform benchmarks on triplestores. Triplestores are often developed in teams who collaborate in Git repositories. Releases of those triplestores are then published on GitHub or as a Docker image on Docker Hub. The idea is that the Basilisk platform will automatically check for a new release of a registered triplestore repository and will then perform benchmarks on this release.

Benchmarks are also relevant during the development process. A benchmark performed automatically, for example, when a new pull request is added, is a good way to estimate if a newly developed feature will impact the performance of the triplestore before the changes are merged.

On the Basilisk platform, a user can register a triplestore for a continuous benchmark by setting up a hook to the repository on GitHub or Docker Hub. The repository will then be observed by the Basilisk platform. If there is a new release of the triplestore, Basilisk will generate a new benchmark job. This benchmark job will then be executed by fetching and building a new Docker container, containing the newest release of the triplestore. On this container the benchmark will be performed. The measured results of the benchmark will be stored in a triplestore and are then available through the web frontend for review.

The basic architecture pattern of the Basilisk platform is the microservice architecture (see chapter 3.2.3 for a short description). This means that the platform is divided into multiple services on which the workload and the different tasks are divided. The services can be run on different hardware systems and they interact with each other via the RabbitMQ (3.2.5) message queue system.

### 4.1 Programming Language and Frameworks

All services of the Basilisk platform are implemented with Java and are using the Spring Boot framework. The services use Java version 17 and Spring Boot version 2.6.6.

The package structure used for the implementation of the services is similar in all three services. It is strongly influenced by the structure recommended for the Spring Boot framework.

## 4.2 Main Services

The next sections explain the idea of the three main services of the Basilisk platform, namely Hooks Checking Service (HCS) (section 4.2.1), Jobs Managing Service (JMS) (section 4.2.2), and Triplestore Benchmarking Service (TBS) (section 4.2.3).

This explanation follows the flow of actions that happen while a user is configuring a continuous benchmark and the process that happens when a benchmark is initiated. This is based on code review and analysis, and information and diagrams provided by former developers of the project.

Figure 4.1 gives an overview of the three microservices of the Basilisk platform. It shows the most important messages sent between the services and the interactions with GitHub and Docker Hub. The services and the messages send between them will be explained in the following sections.

es sollte noch klar abgegrenzt werden, dass 1. user per rest-API bzw. endpoint, in jedem fall aber stateless per http mit dem server comunizieren 2. intern per rabbitMQ kommuniziert wird 3. Anfragen von Komponenten an registries per API/download, also auch wieder per http durchgeführt werden

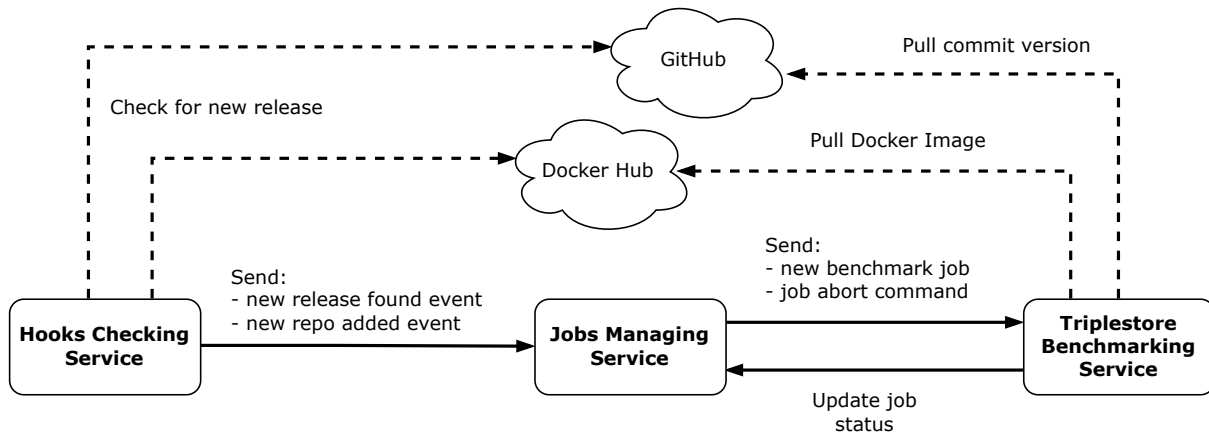


Figure 4.1: Overview of the three microservices

### 4.2.1 Hooks Checking Service

The main task of the HCS is to observe GitHub and Docker Hub repositories of triplestores for new releases or changes.

When a user wants to set up a new continuous benchmark, a triplestore is registered at the HCS by defining the repository (GitHub or Docker Hub) that has to be observed for changes. This happens through REST API calls to the HCS providing the repository's name and owner. The HCS will then create a hook for the repository to get noticed about changes. A hook is in general a piece of code or software that attaches itself to a software component to intercept messages and react to those messages, e. g., with function calls. In the case of the HCS the hooks can be seen as bookmarks for the repositories. Each hook stores the latest known version of

a repository. The service will query the saved repositories regularly and compare their current version to the version stored in the hook.

hooks mit polling umgesetzt

When the HCS notices a new release for a repository, it updates the corresponding hook to the newest version. Then it sends a message about the new version to the Job Request Queues from which the Jobs Managing Service retrieves the message.

## API and Messaging

The HCS is controlled by the user over a REST API.

The continuous checking of the repositories can be started and stopped over a REST endpoint. The other endpoints are for adding and deleting GitHub and Docker Hub repositories. Figure 4.2 shows these endpoints.

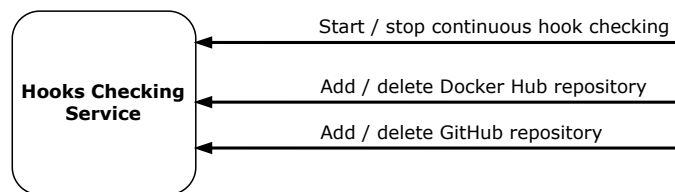


Figure 4.2: REST API of the Hooks Checking Service

The communication between the HCS and the Jobs Managing Service is done with RabbitMQ (3.2.5) messages, by using the Job Request Queues. The messages contain different events that can occur in the HCS. For example, an event is sent when adding or deleting a repository, or a new release is detected.

### 4.2.2 Jobs Managing Service

The Jobs Managing Service (JMS) has two core functions: first, it manages configurations of triplestores. These are used for its second function, the creation and management of benchmark jobs. Lastly, the JMS manages the status for running and pending jobs sent to the TBS.

There are three configuration types needed for a benchmark job. First, the platform needs the configuration for the triplestore. This configuration includes, for example, the SPARQL endpoint as well as the user and password for the connection to the endpoint. The IGUANA framework needs these arguments to properly connect to the triplestore under test [2].

Secondly, the platform needs configurations for datasets and query files. The dataset configuration simply consists of the dataset name and the URL for the location of the dataset on the server. The query configuration consists similarly of a name for the queries and the URL for the location of the query file.

All of the named configurations are managed over the REST API of the JMS.

When the JMS receives an event from the HCS regarding a new release of a repository, the JMS will create benchmark jobs for the new release. A benchmark job consists of the current version of the repository, a query configuration and a dataset. For each event multiple benchmark jobs are created. Each benchmark job has a query file and a dataset that is used for the benchmark.

These benchmark jobs will then be sent to the TBS over the Benchmark Job Queue.

The management of the running and pending benchmark jobs is done by the REST API of the JMS. When an endpoint is triggered, e. g., to abort a pending job, the JMS sends an event to the TBS.

### API and Messaging

The JMS communicates with the HCS and the TBS over RabbitMQ message queues. Repository events are received from the HCS and benchmark job events are send to the TBS over the Benchmark Job Queue (BJQ).

Interaction with the user is handled over the REST API. The API offers endpoints for adding and deleting the different configurations of triplestores, datasets and queries. A second set of endpoints are for querying the job status of running and pending jobs, and for stopping individual jobs. Figure 4.3 shows these endpoints.

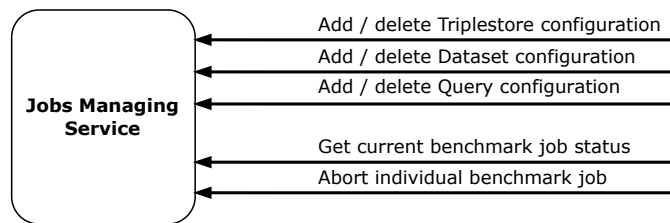


Figure 4.3: REST API of the Jobs Managing Service

### 4.2.3 Triplestore Benchmarking Service

The Triplestore Benchmarking Service (TBS) executes the benchmark jobs it receives from the JMS and saves the benchmarking results to the Job Storage Triplestore.

To execute a benchmark the service needs a running instance of the triplestore with the loaded dataset on which the benchmark will be executed. This instance is build from the information and configurations provided in the benchmark job. The TBS will query the provided repository (GitHub or Docker Hub) for the version specified in the job.

If the repository is from GitHub, the TBS downloads the source code for the provided commit and searches for a Dockerfile. The service then builds and runs a Docker container from that Dockerfile.

If the repository is from Docker Hub, the TBS pulls the image with the provided tag. The service then runs the image as a Docker Container.

#### loading of data

After starting the Docker Container, the TBS create a configuration file for the IGUANA framework. IGUANA will then perform the benchmark with the provided configurations.

When the benchmark is finished, the results are written to the Job Storage Triplestore.

### API and Messaging

The TBS has no REST API. The service is controlled through the JMS by events send over RabbitMQ.

The events received from the JMS are new benchmark jobs and pause or abort commands for running benchmark jobs. The TBS sends short events containing the status of benchmark



jobs, e. g., a job has started, or it has finished and the results are uploaded to the Job Storage Triplestore.

### 4.3 Basilisk Frontend

The Basilisk platform can be extended with a web frontend. The frontend is implemented using JavaScript and the JavaScript Framework Vue.js.

The idea is that the frontend functions as a graphical interface for the REST APIs of the three services explained in section 4.2. The user can setup new repositories, triplestores and datasets. Further, the user can request information about current benchmark jobs, abort jobs or remove pending jobs. Lastly, the frontend can request and visualize the benchmarking results stored in the Job Storage Triplestore.

### 4.4 Architecture Review

#### Vergangenheit!

In this section, we review the architecture of the three services of the Basilisk platform. We point out possible problems with the previous implementations and list missing implementations that need to be added.

#### 4.4.1 Code Refactoring

During the code analysis some inconsistencies in the code style and duplicate code snippets have been found. In other parts the code structure differs from the design patterns recommended for the Spring and Spring Boot framework.

In general, an in-depth code refactoring is recommended to increase readability and maintainability of the source code.

#### 4.4.2 Management of Repositories and Configurations

Currently, the observed repositories are managed and stored in the HCS while the configurations for the triplestores are managed and stored in the JMS. This makes it difficult to internally link a repository to a triplestore configuration, since they are stored in different services.

The current implementations tries to solve this problem, by sending events about repository creations from the HCS to the JMS. This results in the duplication of the repository storage in both services. This contradicts the idea of microservice, which should be separated as much as possible from each other.

Therefore we recommend restructuring the management of repositories.

#### 4.4.3 Creation and Management of Benchmark Jobs

When a new release is found by the HCS, the Jobs Managing Service will create and manage benchmark jobs which will be executed by the TBS. Currently, the JMS will create multiple jobs. For each query file a job will be created for each dataset. This means that each dataset is mixed with each query file, which could lead to queries executed on the wrong datasets.

A benchmark should only use a defined pair of a matching query file and dataset. Therefore, the logic for creating the benchmark jobs needs to be changed, as well as the data model for storing the benchmark jobs.

#### 4.4.4 Data Model Restructure

The JMS manages and stores the different configuration types needed for a benchmark job.

The configurations are stored in an internal database. Figure 4.4 shows the current database schema.

The schema has logical errors and is in parts incomplete. Following we list some inconsistencies and possible problems that could arise:

- The only way to identify a repository as GitHub or Docker Hub repository is to check in the triplestore configuration. If a repository is assigned to the false type, the resulting benchmark job would not be executable, because GitHub and Docker Hub need to be handled differently during a benchmark as explained in section 4.2.3.
- Each triplestore configuration can have exactly one GitHub or Docker Hub repository. This means that for every repository a new triplestore configuration needs to be added. There would be less duplicate configurations if multiple repositories could point to the same configuration. For example, a hook could be set up to observe a GitHub repository for new releases and another hook could be set up to observe the same GitHub repo for pull requests. In this case both hooks should use the same triplestore configuration, since it is the same triplestore which gets benchmarked.
- As explained in section 4.4.3, the creation and storage of benchmark jobs needs to be changed. Currently, the data model structure for benchmark jobs, datasets and query files is too complicated. Since the creation process of the jobs needs to be changed, the data model will also need changes and a cleanup of the model relationships.

Therefore, the data model for the JMS needs a restructure to better cover real world requirements.

#### 4.4.5 Missing Implementations

The Basilisk platform is not yet fully implemented. After reviewing the source code, the following overview was created:

##### Hooks Checking Service

The implementation of the Hooks Checking Service is well developed. Small additions have to be implemented.

- The REST endpoints for deleting GitHub and Docker Hub repositories needs to be added.
- Currently Pull Requests for GitHub repositories can not be observed.

##### Jobs Managing Service

The implementation of the Jobs Managing Service is mainly missing the REST API and some internal logic. The following REST endpoints have to be added:

- Adding / removing triplestore configurations
- Adding / removing benchmark configurations
  - Adding / removing dataset configurations
  - Adding / removing query configurations

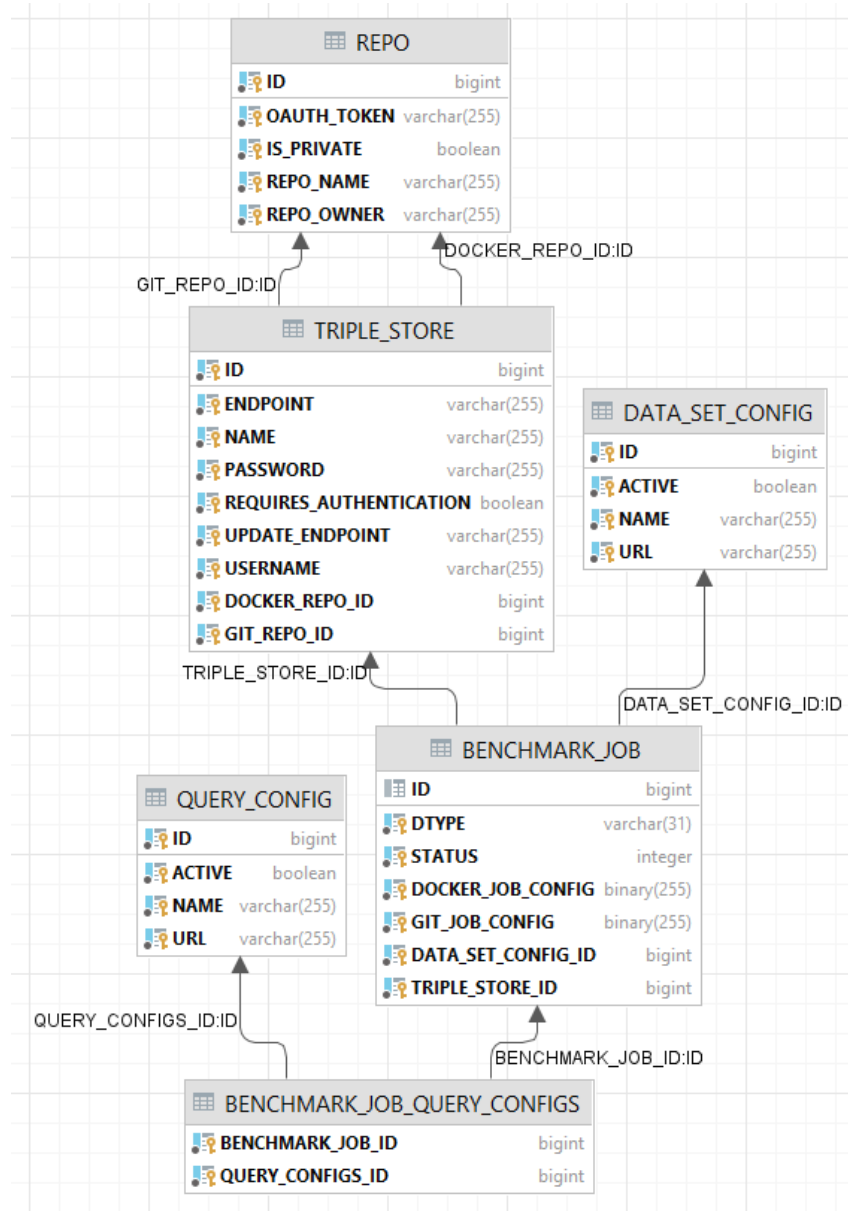


Figure 4.4: Diagram of the current database schema used in the JMS

Since the JMS also manages the running and pending benchmark jobs, the REST API and internal logic for managing these jobs need to be implemented too.

- List running / pending jobs and their status
- Aborting a benchmark job

### **Triplestore Benchmarking Service**

The implementation of the Triplestore Benchmarking Service currently contains only a few classes for the data models, and simple structures of service classes. Big parts of the logic still needs to be implemented.

Existing classes are mainly for storing and manipulating data models, configurations and basic message queue interactions. These classes do not carry much functionality.

The main functionality of the TBS needs to be implemented. This consists of setting up the Docker containers which contain the triplestores for benchmarking:

- Pulling Code from GitHub
- Pulling images form Docker Hub
- Building Docker containers from Dockerfiles / images
- Connecting to the Docker containers

Then the usage of the IGUANA framework needs to be implemented. The framework needs to be setup to write the benchmark results to the Job Storage Triplestore.

To have a better control of the running jobs and the benchmarking service in general, we recommend to add a small REST API. This API could be similar to the one of the HCS, that starts and stops the continuous checking. The API for the TBS can function like a switch, which indicates if a new benchmarking job will be started or not. If it is set to off, the current benchmarking job will be finished, but no new job will be started.

Lastly, after performing of a benchmark, the cleanup of the Docker containers needs to be implemented.

#### **4.4.6 User Management and Security**

The Basilisk platform has no user management or any kind of access control implemented. Currently, the REST APIs of the services allow interactions with any user. If the platform is needed to run publicly, some user management and further security measures are needed. That includes registering new users and user groups with different user rights. Some users should only be able to read benchmark results, while other users should be able to create repositories and abort jobs.

Secondly, confidential information need to be kept secret. This is for example the OAuth-Key needed for accessing private GitHub repositories.

#### **4.4.7 Frontend**

The frontend introduces new programming languages and frameworks. A short review of the current source code resulted in the following findings:

- Currently only a small web view is implemented

## CHAPTER 4. APPROACH

- Functionality to communicate with the REST APIs is missing

As explained in section 5.1, the priority for the frontend has been lowered. The priority of the thesis lies in finishing the main services and their functionality.



# Implementation

This chapter describes the implementation of the concepts explained in chapter 4. Parts of the system were already implemented by other developers before this thesis.

As stated in section 4.4 parts of the functionality are still missing and need to be implemented. This chapter documents the design and implementation of the explained shortcomings.

The following sections of the thesis differ slightly from the proposed time schedule and task list, which was originally planned in the thesis proposal. In Section 5.1 we explain why we had to alter the original thesis schedule based on the findings of the architecture review in section 4.4.

In section 5.2 we describe how the missing parts of the platform are designed and implemented. Possible problems or new insights found during this process are explained and dealt with. Lastly we explain how the platform is deployed in section 5.3.

## 5.1 Thesis Time Schedule

The time schedule of the thesis had to be altered to allow for more time designing and implementing the Basilisk platform.

Before starting this thesis it was hard to quantify how much implementation work was still needed. After the in-depth architecture review (4.4) it became clear that the implementation workload was greater than anticipated in the thesis proposal.

Therefore an alteration of the time schedule and work plan for the thesis was needed.

Further, we discuss task priorities. First priority had the development of the core functionality for the platform. We wanted to be able to perform the full process for at least one repository type. This means that the main services are required to successfully check for new versions of observed repositories, create benchmark jobs for theses releases. Then the platform has to perform these jobs on the triplestores and save the measured result metrics to a triplestore.

Functionalities like user management (4.4.6) were marked with a lower priority and were unfortunately not developed in this thesis. The least priority had the Basilisk frontend (4.3), since it is not necessarily needed to run the platform. Secondly, it introduces more programming languages and frameworks to the project. The time schedule for the thesis can not provide enough time to fully acquire the understanding for this technology stack. Therefore the frontend will not be further implemented and deployed in the context of this thesis.

In the end one more functionality had to be left unimplemented. This is the performing of benchmark jobs on GitHub repositories. Although the platform is able to observe various configurations of GitHub repositories and can create benchmark jobs for such, the benchmark process for these repositories introduced a lot more complexity that we were not able to implement during this thesis.

As stated above the first priority was to implement the full Basilisk process for Docker Hub repositories, which we were able to do.

## 5.2 Revised Solution Design

The Basilisk platform is missing some key functionality to successfully run benchmark jobs. In this section we describe the designed solutions for the shortcomings listed in section 4.4.

### 5.2.1 Code Refactoring

As stated in section 4.4.1, an in-depth code refactoring was recommended. Before starting to design and implement new functionality, we performed an in-depth refactoring and restructuring of the code base. This created a clean code base on which all future implementations can be built on.

Code refactoring is the process of restructuring the source code of an application without changing its functionality [10].

### 5.2.2 Management of Repositories and Configurations

In section 4.4.2 we explained the problem of storing and managing repositories, the corresponding hooks and the triplestore-configurations between the Hooks Checking Service (HCS) and the Jobs Managing Service (JMS).

Different solutions were considered for merging the functionality of the two services.

In the designed solution, the management and storing of the repositories is moved into the JMS. This includes the corresponding REST endpoints and internal logic of the HCS that are needed for the management. The different repositories (GitHub and Docker Hub) are added over the REST API of the JMS.

In section 4.4.5 (Hooks Checking Service) it is listed, that the HCS is missing the REST endpoints for deleting repositories. Since the repository management is moved to the JMS, these endpoints are also added there.

The JMS communicates with the HCS over RabbitMQ message queues. Through these messages the HCS gets the needed information about the repositories it should observe. These include the URL and for GitHub repositories details like the observed branch and potentially an OAuth token for authenticating with the API.

The functionality used when a new release is found does not need to be changed. When a new release is found, the HCS still sends a message containing the relevant information about the release to the JMS.

Figure 5.1 shows the restructured REST APIs and the adjusted messaging between HCS and JMS.



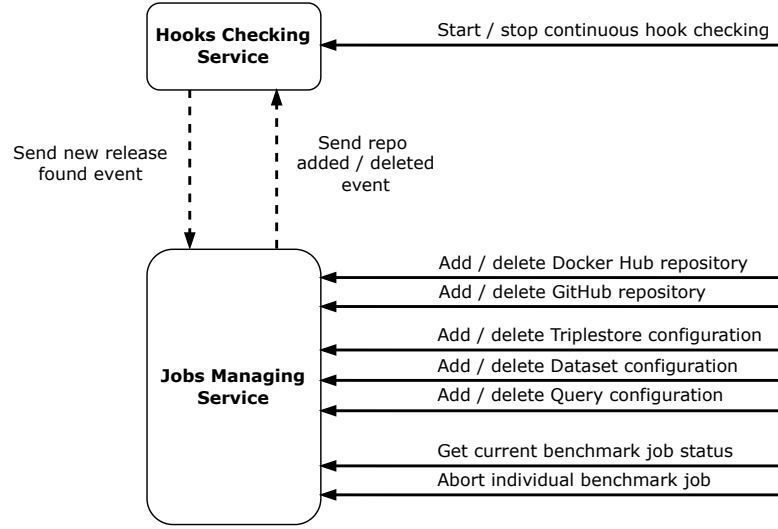


Figure 5.1: Overview of the restructured REST APIs and adjusted messaging

### 5.2.3 Restructure of Data Models in the Jobs Managing Service

In section 4.4.4 we reviewed the data model used for storing and managing the different configuration types inside the JMS. To mitigate the stated problems with the data model, we designed the database schema shown in figure 5.2.

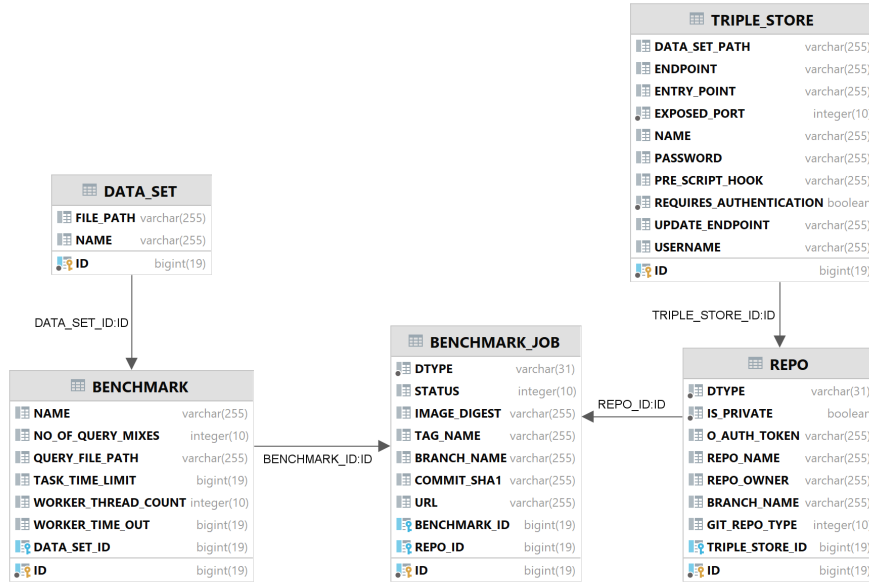


Figure 5.2: Diagram of the proposed database schema for the JMS

This design takes advantage of persistence technology that is already part of the Spring framework. The models for the GitHub and Docker Hub are inherited from an abstract repository class, since the basic information like repository name and owner are needed for both repository types. The Spring framework automatically manages the different repositories and identifies them through the stored DTYPE.

Secondly, the relationship between triplestore (TS) configurations and repositories is inverted. Now each repository points to a TS configuration. This means a TS configuration can

be used for different observed repository setups.

Lastly, the benchmark job and dataset models are cleaned up. Now each benchmark specifies a datasets and a query file as well as multiple parameters which are later used by IGUANA during the execution of an benchmark job. Each benchmark is now a single entry in the benchmark table.

The individual repositories and benchmarks are then linked inside a benchmark job.

### 5.2.4 Creation and Management of Benchmark Jobs

Section 4.4.3 described how the creation of benchmark jobs needed to be changed in the JMS. As explained in section 5.2.3, benchmarks are now stored in a database table and have a single dataset and query file.

When a new message about a new release arrives, the JMS will now create a benchmark job for each benchmark that is configured in Basilisk.

To manage the created benchmark jobs, new API-endpoints are created to get a list of all benchmark jobs and to abort jobs that have not yet been started.

### 5.2.5 Hooks for Pull Requests in GitHub Repositories

Currently the Basilisk platform can not check for new pull requests published to an observed repository. This functionality would greatly support the continuous benchmarking during the development process of triplestores.

As explained in chapter 4, triplestores are often developed by teams who collaboratively work on Git repositories. A standard way of introducing a newly developed feature to a source code repository is a pull request. Pull requests contain a description of the proposed changes, as well as the name of the development branch which should be pulled into the main branch of the repository.

Often these changes are developed in a forked repository. A forked repository is basically an independent copy of the main repository. GitHub provides functionality to merge the latest changes of the original repo into the forked repo. To send changes from the forked repo to the original repo, a pull request is needed.

In this forked repo the developer can work independently on his changes and later create the pull request to the original repository.

The difficulty for the Basilisk platform is that these pull requests can stem from these forked repositories. Since the repository containing the changes has a different URL to the original repo observed by the Basilisk platform, more information than usual are required to create and run a benchmark job for a pull request.

The solution we designed for this issue is an extended message. This message gets sent in the situation in which the pull requests originates from a different repository. The message contains the URL, repository and branch name for the GitHub repository. Therefore the message handling in the HCS and JMS needs to be adjusted to handle this new message type.

The benchmark jobs and the Triplestore Benchmarking Service did not need to be changed. It is not relevant for a benchmark if the repository, from which the Docker container is built, is different from the observed repository.

### 5.2.6 Missing Implementations of the Jobs Managing Service

In this section we describe how the missing implementations are developed that are listed in section 4.4.5.

The tasks for the HCS are already dealt with in sections 5.2.2 and 5.2.5. Also the tasks for the JMS regarding the management and aborting of benchmark jobs are dealt with in section 5.2.4.

Lastly, only the REST APIs for adding and removing the configurations of triplestores and benchmarks need to be added to the JMS. Since the basic functionality of those endpoints are similar to the endpoints for adding and removing repositories, it is straight forward to implement those endpoints. The configuration and relationships of the added data models are based on the data model designed in section 5.2.3.

### 5.2.7 Triplestore Benchmarking Service

The implementation of the Triplestore Benchmarking Service was lacking big parts of its functionality. To explain the implementation steps, we follow the benchmarking process that is used when a new benchmark job is send to the TBS.

The JMS sends the created benchmark jobs via the message queues of RabbitMQ. The TBS stores these jobs internally in a job queue. Benchmark jobs can be manually aborted by the user over the REST API of the JMS. When a benchmark job is aborted, the JMS will send a message to the TBS. If the job has not been processed yet, the TBS will skip the job when looking for the next job to run.

When a benchmark job is started, the TBS needs to create a Docker image first, that contains the triplestore that will be benchmarked. Afterwards, a container is build and configured from the image. The configuration is stored in the data model of the JMS and is provided with the benchmark job to the TBS. Then, the IGUANA configuration file is created and the framework gets started. After IGUANA performed the benchmark on the Container, IGUANA writes the results to the Job Storage Triplestore (JSTS) and the TBS stops and removes the Docker container.

The implementation of this process is explained in the following sections.

#### Creation of Docker Images

The setup and creation of the Docker images containing the triplestore for a benchmarking job can be divided into two branches. Triplestores from Docker Hub repositories are easier to setup than triplestores stored in GitHub repositories.

For a benchmark of a triplestore that is configured as a Docker Hub repository, the only task is to pull the Docker image from Docker Hub by providing the repository name and owner and the image tag that marks the new release.

The creation of a Docker image from a GitHub repository is more complicated than simply downloading an image from Docker Hub. First the source code of the repository has to be downloaded. Then the Dockerfile needs to be located and a build needs to be initiated, which often requires additional parameters and configurations. Because of this increased complexity, we focused on the benchmark process of Docker Hub repositories. As explained in the time schedule (5.1) the first priority was to implement a fully running process, which was easier to accomplish for a Docker Hub repository.

After the creation of the Docker image, the benchmark process is the same for both repository types.

### Creating and Starting a Docker Container

After the Docker image is available, a Docker container is configured and started.

The triplestore which is the target of the benchmark job will be run in the Docker container. For a successful benchmark the triplestore needs to be accessible from the TBS and also needs access to the dataset to calculate the results for the benchmark queries.

To be accessible from outside the container, the container is configured to expose and listen to specific ports on the network. Through these ports the SPARQL endpoint will be accessible, which IGUANA uses to send queries and receive the results.

To give the triplestore access to the dataset of the benchmark, the dataset can be provided in two different ways. Either it is available inside the Docker container through a published volume provided by the server. In this case the triplestore can use the file directly from the file system. The second option is to provide the dataset by uploading it through the SPARQL endpoint of the running triplestore. For this option a shell script needs to be provided by the triplestore configuration. This script is executed by the IGUANA framework before the benchmark is started.

After these configurations, the container gets started and the actual benchmark can run.

### Configuration and Start of the IGUANA Framework

The actual benchmark is performed by the IGUANA framework (2.3.1). The framework takes a YAML or JSON file containing the benchmark configuration as the start parameter. Therefore the TBS creates this configuration file from the provided information of the current benchmark job. This contains the name of the dataset, the address of the SPARQL endpoint and the configuration of the benchmark to be performed. The benchmark configuration contains the location of the query file and possible time limits or thread counts for the IGUANA-workers. Lastly the connection for the JSTS is provided. This connection is used after the benchmark to write the benchmark results to the storage. The IGUANA configuration gets encoded in JSON and is written to a temporary file on the server.

The next step is to start the benchmark by starting the IGUANA framework with the created benchmark configuration. The IGUANA framework is located on the server as an executable jar file. It gets started as an individual process on the server with the configuration file as the argument. If the dataset needs to be loaded after the triplestore is started, IGUANA executes the provided loading script first, before starting the actual benchmark.

### REST endpoint to Control Job Starting

To have a better control of the execution of the benchmark jobs, the TBS is extended with REST endpoint that can start or stop the execution service. This functionality works similarly to the HCS. When the service is started over the endpoint, the queue of benchmark jobs is read and the next job in the queue is started. When the user decides to stop the benchmark execution service, the running job will be finished, but no new job will be started from the job queue.

### Benchmark Cleanup

When the IGUANA framework has finished the benchmark some cleanup is happening to free server resources. This includes removing the IGUANA configuration file, the Docker container

and the Docker image. The Docker container gets stopped and removed by the TBS. After that the Docker image is also removed to free up disk space.

### 5.3 Deployment

After the implementation phase, the Basilisk platform is deployed on a virtual server. The virtual server used is provided by the IRB (Informatik Rechnerbetrieb) of the computer science department at Paderborn University. Figure 5.3 show the specification of the VM. The VM was configured to be powerful and to have a lot of memory and storage.

Specifications	
CPUs	16 cores
Memory	128GB
Storage	2TB
Operating System	Debian GNU/Linux 11 (64bit)

Figure 5.3: Specification of the virtual machine on which the platform is deployed.

The Basilisk platform consists of the 3 main services described in section 4.2. For the communication between these services, the platform also needs a RabbitMQ message server. Also, a triplestore is required as the Job Storage Triplestore for storing the benchmark results.

For the platform to be easily manageable we decided to deploy the whole platform in Docker containers. This has the advantage of using a single Docker Compose file for configuring the services and the network.

The individual services are compiled into jar files and the Docker build copies them into individual Docker images. The build of the containers for the HCS and JMS is simple and straight forward. The container for the TBS needs two additional configurations for the service to run. First, the IGUANA framework is installed inside the container. Afterwards, the container is configured in the Docker Compose file to has access to the Docker socket of the server. This is needed for the service to start and manage the Docker images and containers of the triplestores that are getting benchmarked.

The RabbitMQ message server is available as an official Docker container on Docker Hub. For the JSTS we decided to use the Fuseki<sup>1</sup> triplestore, which also is available as a Docker container.

In total the Docker Compose configuration consists of 5 containers that can be started and stopped with simple commands. During a benchmark a sixth container is started which is running the triplestore. An overview of the setup is shown in figure 5.4.

The three microservices of the Basilisk platform are available through the ports 8080 (HCS), 8081 (JMS), and 8082 (TBS) of the host server. RabbitMQ container is available through port 5672 and the Fuseki triplestore which is used as the Job Storage for the benchmark results is reachable at port 3030 of the host server. During a benchmark, the tested triplestore is started in its own Docker container which also has port 81 published for reaching the SPARQL endpoint.

<sup>1</sup><https://jena.apache.org/documentation/fuseki2/fuseki-main>

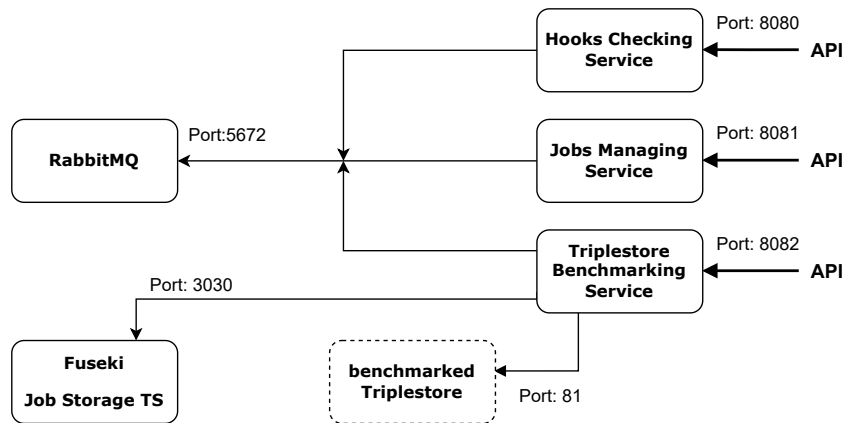


Figure 5.4: Overview of the deployed Docker containers and used Ports.

This chapter evaluates the Basilisk platform based on the developments described in chapter 5 and the ease of using the platform to setup a continuous benchmark job for an existing repository. We will compare the manual benchmarking process using IGUANA to the use of the Basilisk platform and evaluate the added value the platform creates for the benchmarking process.

The main goal of the platform is to simplify the process of benchmarking known triplestores. The platform automates the detection of a new release of a configured triplestore and automates the execution of a benchmark job for the new releases.

To evaluate the capabilities of the platform, we setup continuous benchmarks for two different triplestores. The first triplestore is TENTRIS<sup>1</sup> which is developed by the DICE-research group. The second triplestore benchmarked in this thesis is Oxigraph<sup>2</sup>.

The triplestores are chosen because they both are available as a ready-to-run docker image on Docker Hub. They also differ in the way the benchmark dataset is loaded into their internal storage. The TENTRIS triplestore accepts the dataset file as an argument at program start, while Oxigraph needs to be started before the data is uploaded through the SPARQL endpoint of the triplestore.

## 6.1 Initial Benchmark Setup

In this section we compare the steps needed for setting up an initial triplestore benchmark using the IGUANA framework. In general the execution of a benchmark has the following four requirements: A running triplestore, the IGUANA framework, a dataset file and a query file.

The next two sections describe the initial setup for a manual benchmark run and the recommended process to create a Basilisk configuration for a triplestore.

### 6.1.1 Manual Benchmark Setup

To manually run a benchmark, first the triplestore needs to be installed and started. For a manual test run this can be done either as a full installation or by using a Docker container. Often it is easier to use a ready-to-run docker container that contains all needed dependencies

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<sup>1</sup><https://tentris.dice-research.org/>

<sup>2</sup><https://github.com/oxigraph/oxigraph>

and a running installation of the triplestore. On the host system only the Docker engine is needed to run a container.

When the triplestore is running, the dataset needs to be loaded into the triplestore. This can be done either by providing the dataset during startup or by uploading the data through the SPARQL endpoint. Lastly the IGUANA framework needs to be configured by providing a configuration file containing the query file and SPARQL endpoint.

This process is similar for TETRIS and Oxigraph. The only difference is in the upload of the dataset.

### 6.1.2 Basilisk Benchmark Setup

When a triplestore is fully configured in the Basilisk platform, the platform will automatically provide all four requirements for a benchmark, when a new benchmark job is automatically created.

To create a working triplestore configuration for the platform we recommend to develop and test a local setup first. The process to create this initial test setup is similar to the setup of a manual benchmark explained in section 6.1.1. But in this case we need to use a Docker container, since Basilisk is only working with a container setup.

The local setup should consist of a triplestore running in a Docker container, which is also reachable over the SPARQL endpoint. To make sure that IGUANA is able to perform a benchmark, it is also advised to start a short benchmark with a simple IGUANA configuration.

The IGUANA configurations for the tested triplestores will slightly differ for loading the dataset into the triplestore. In case of TETRIS, the dataset is configured to be provided inside the Docker container to be loaded on startup. For Oxigraph, the dataset does not need to be provided inside the Docker container. In this situation the dataset needs to be loaded after the startup. IGUANA needs to be configured with a pre-hook-script that will be executed before the real benchmark starts. The task of the pre-hook-script is to take a dataset file as input and upload the file to the running Oxigraph instance. This script should be implemented and tested with the local test setup.

When a working setup is found, the setup can be transferred into the Basilisk platform. Again, the setup for TETRIS and Oxigraph are mostly the same. For Oxigraph, the custom load script is provided and the Basilisk configuration will point to the script when creating an IGUANA configuration.

### 6.1.3 Comparison of Initial Setups

The initial setup to perform one benchmark for one triplestore version is nearly the same for the manual process as well as for the Basilisk process. In both scenarios the triplestore and IGUANA is setup and run manually. The configuration of the Basilisk platform is more complicated for the case of loading the dataset through the SPARQL endpoint, since a custom load-script is needed. Additionally, the configuration needs to be transferred to the Basilisk platform before a benchmark can actually be started.

## 6.2 Setup of further Benchmarks

The real advantage of the Basilisk platform can be seen when further benchmarks have to be run for an already configured triplestore.

We look into two scenarios that require the run of further benchmarks on a known triplestore. Both scenarios will be looked at for the manual setup and a already configured Basilisk setup.



The first scenario is the usage of a different dataset and query file as a new benchmark that is to be run. The second scenario is the benchmark of a different version of a configured triplestore.

Both scenarios are evaluated in the following sections.

### 6.2.1 Using a different Benchmark

In the scenario of using a different benchmark, a new dataset and query file are used. For the manual setup described in section 6.1.1 multiple steps have to be done to update the dataset and query file. First, the dataset needs to be loaded into the triplestore. This can be done by using the SPARQL endpoint to upload the data or by restarting the triplestore and providing the new dataset at startup. For TETRIS it is usually easier to restart the triplestore with the new dataset as a argument on startup. Secondly the the IGUANA configuration needs to be adjusted to use the new query file.

In case of the Basilisk setup, only the new dataset and query file have to be configured in the platform. When a new benchmark job is executed, the IGUANA configuration is automatically generated using the new benchmark setup. If the load-script for Oxigraph is setup correctly the new dataset will also be automatically uploaded to the triplestore. To perform the new benchmark, a manual job can be started by sending a request to the API of the JMS.

### 6.2.2 Benchmarking a new Version

If a new version of a triplestore should be benchmarked, again multiple steps are needed for the manual benchmark process. The first step is to download the new version and started as a Docker container. Then, the dataset needs to be loaded into the triplestore and lastly the IGUANA configuration needs to be updated to the new SPARQL endpoint location.

The Basilisk configuration does not need to be changed. If a new version has to be benchmarked, either the platform has already noticed the new version on its own and created a new benchmark job automatically, or the user can create a manual benchmark job by providing the benchmark that should be used and the triplestore version to the API of the JMS. The platform will then automatically setup the container and configure IGUANA to run the benchmark job. This is the main idea why the platform was originally developed. Of course, this will only work if the other versions of the triplestore can use the same basic configuration for startup, loading the dataset and providing the SPARQL endpoint. If there are major changes to the setup and structure of a triplestore, a new configuration in Basilisk is needed.

### 6.2.3 Comparison of Benchmark Changes

As seen in the description of the above scenarios, the triplestore configuration of the Basilisk platform is not changed at all. Only the new benchmark files are registered in case a new benchmark should be performed.

In contrast to this, the manual setup requires a lot of manual changes. Each change to a running configuration basically requires the user to setup the benchmark configuration from the start. Either the triplestore is downloaded and setup again, or the IGUANA configuration needs manual changes. This results in a lot of manual work that is often similar to tasks what have been done for other setups.

### 6.3 Basilisk Evaluation

The idea of the Basilisk platform is focused on the use-case of automatically benchmarking triplestores through their SPARQL endpoints. The Basilisk platform fulfills this task of automating the benchmark process of configured triplestore repositories stored on Docker Hub.

The comparison of the Basilisk platform to the manual benchmark process shows the advantage of using Basilisk to perform multiple benchmarks on different triplestore versions.

Setting up the Basilisk platform is initially more complicated and a little more restricted than a manual setup of a triplestore. But as soon as the second benchmark is performed, the Basilisk platform has no manual setup time by the user and the whole process is already faster than a manual approach. Once the triplestore is configured, either the benchmark jobs are created automatically by the system, or the user can manually create a job. The setup and execution of the benchmark job is then done completely automatic by the platform and no further user interaction is needed.

Using the system we were able to perform 16 benchmarks on different TENTRIS versions using the SWDF dataset in just one hour. It would not been possible to benchmark all versions manually by downloading and setting up the Docker images in a similar time.

In figures 6.1 and 6.2 we visualized two measured metrics that were measured during the performed benchmarks of the TENTRIS and Oxigraph versions. Figure 6.1 shows the number of query mixes that are executed per our on the different triplestore versions. The average of the penalized queries per second are shown in figure 6.2. A query gets penalized if it failed, e. g. if the timeout is hit, or the triplestore returned a wrong return code.

All benchmark results are available through the SPARQL endpoint of the Fuseki triplestore in which the results are written after each benchmark.

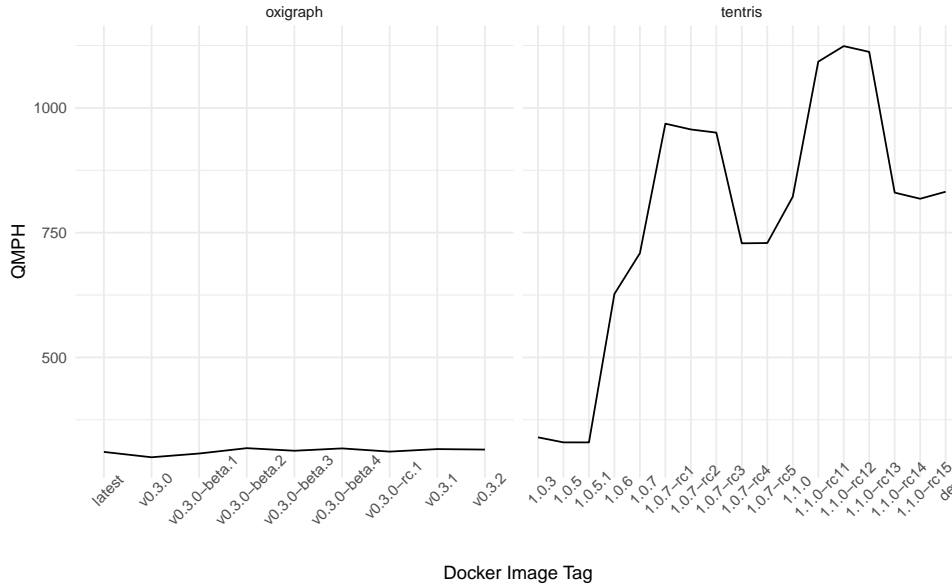


Figure 6.1: Measured QMPH of the benchmarked triplestore versions

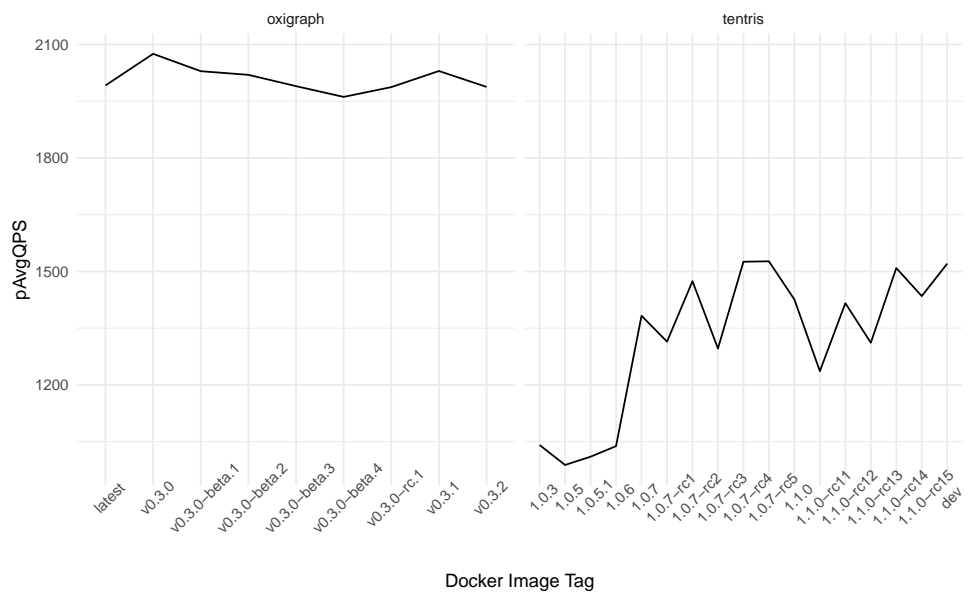


Figure 6.2: Measured pAvgQPS of the benchmarked triplestore versions



## Summary and Future Work

In this chapter we summarize our development of the Basilisk platform and highlight the key findings of the evaluation phase. Lastly we point out the future work that can be done to extend the functionality of the platform.

### 7.1 Summary

Benchmarking of triplestores is in general very time consuming and often requires a lot of configuration and setup time. Because of this, triplestores are often benchmarked late in the development process. To improve this time consuming process and to try to automate the benchmark process as much as possible, the development of the Basilisk platform was started. The main task of the platform is defined to continuously benchmark triplestores. This means that the platform is configured once and will then automatically perform benchmarks on new versions of the configured triplestores.

In this thesis we have continued the development of the Basilisk platform. The platform is designed to continuously check for new triplestore releases and to automatically perform benchmarks if a new release is found. triplestore releases could be found either in Docker Hub or GitHub repositories. The complete process of checking for new releases and benchmarking new releases is fully implemented for Docker Hub repositories.

During this thesis we have performed an in-depth architecture and code review of the platform. Based on that review we defined implementation tasks for improving and extending the existing code base.

The main improvements were the restructure of the microservices and a restructure of the used data models. These changes were implemented before starting on the missing implementations of the benchmark service.

Most of the functionality of the Triplestore Benchmarking Service was not yet implemented. The implemented functionality initializes the triplestore inside a Docker container and performs the benchmarks. During this thesis we focused on completing the benchmark process for triplestore releases in Docker Hub repositories. To provide the same functionality for GitHub repositories some further steps are needed which are explained in section 7.2.

To perform the benchmarks, the benchmark-independent IGUANA framework is used. The configuration for IGUANA is generated from the information stored in the triplestore configurations inside the Basilisk platform.

Finally the Basilisk platform was deployed on a VM hosted inside the network of the Paderborn University. On this deployment the TENTRIS and Oxigraph triplestores were configured and multiple versions of both triplestores were successfully benchmarked. The user only needs to start the system and to configure the triplestores. No further interactions are needed during the benchmark process. When the benchmarks are completed, the results are available in the Job Storage Triplestore.

## 7.2 Future Work

The development performed in this thesis has resulted in a running version of the Basilisk platform. Currently the benchmark process for Docker Hub repositories is working and benchmarks are successfully performed.

Because the thesis time schedule had to be altered during the implementation process, some functionalities could not been fully implemented. Most of these missing functionalities are not strictly relevant to successfully run the platform, but would be a nice-to-have from a user perspective.

These functionalities are for example, a user management system, extended triplestore configurations, and the Basilisk frontend. The user management system could manage different user roles and access rights for the various system functionalities. For example some users could be only allowed to view the job status or create a manual job, while admin user could change the triplestore configurations. The extended triplestore configurations could define a range or list of version for which a configuration is valid for use. If for example a newer triplestore version requires the dataset to be loaded differently, a new configuration could be setup to be used with that version. Lastly the Basilisk frontend would provide a fast and easy way to interact with the benchmark results and could also offer a user interface for setting up and managing the configured triplestore and benchmarks.

The most important functionality that is still missing in the platform is the performing of benchmark jobs on GitHub repositories. As stated in section 5.1 the functionalities for observing GitHub repositories and creating benchmark jobs are already implemented. What is still missing is the functionality for downloading the source code from GitHub and building a Docker image from the source code files. After that the process of starting the image and running the benchmark will be the same as with Docker Hub repositories.

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