UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft
Faculty for Computer Science, Electrical Engineering and Mathematics
Department of Computer Science
Research Group DICE Group

Bachelor's Thesis

Submitted to the DICE Group Research Group
in Partial Fullfilment of the Requirements for the Degree of

Bachelor of Science

Basilisk – Continuous Benchmarking for Triplestores

by
Fabian Rensing

Thesis Supervisor:
Prof. Dr. Axel-Cyrille Ngonga Ngomo

Paderborn, March 16, 2022

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Abstract. Abstract

Contents

1 Introduction

In the field of Semantic Web, knowledge graphs are an important structure to represent data and its relationships. To easily store and query the data in these knowledge graphs, some data structure or database is needed. The special kind of database developed to store knowledge graphs are called Triplestores.

Since knowledge graphs can contain huge amounts of data which can also be subject to many changes, Triplestores need to be able to handle many different workloads. Some scenarios need to handle huge amount of data being added, while others need to handle a lot of changes on the current data. To better test and compare Triplestores in these diverse scenarios, benchmarks are performed to allow an appropriate comparison between different Triplestores[17].

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. In the context of Triplestores, a benchmark usually consists of creating a given knowledge graph on which multiple queries and operations are performed.

Often Triplestores are developed in long iterations and are bench-marked only in a late stage of such an development iteration. Today benchmarks and the evaluation of their results are usually done manually and bind developers time. Thus, performance regressions are found very late or never.

Several benchmarks for Triplestores have been proposed [17]. IGUANA is a benchmark-independent execution framework [9] that can measure the performance of Triplestores under several parallel query request. Currently the benchmark execution framework needs to be installed and benchmarks need to be started manually. Basilisk 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 Triplestores and start benchmarks with the IGUANA framework. Further it should be possible to start custom benchmarks on demand. If a new version is found in a provided GitHub- or Docker Hub-repository, Basilisk will automatically setup a benchmark environment and starts a benchmarking suite.

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

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 to understand this thesis. The chapter 4 describes the architecture use in the Basilisk platform.

2 Related Work

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

Several benchmarks have been proposed and developed. Many of these existing benchmarks focus on different goals and scenarios to test the Triplestores. 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. Benchmarking in general is explained 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[11]. These synthetic benchmarks have the advantage, that they can be generated to arbitrary sizes. The main point of criticism is that the generated scenarios can easily be abstract and not representative of a real world situation [16].

The LUBM Benchmark[11] is a synthetic benchmark which focuses on the reasoning and inferencing capabilities of the Triplestores under test. The test data is about the university domain and can be generated to arbitrary size. The benchmark provides fourteen extensional queries that represent and test a variety of properties.

Another synthetic benchmark is SP²Bench[18]. The data generated stems from the DBLP scenario. The benchmark generation tries to accomplish that the key characteristics and word distributions are close to the original DBLP dataset. The provided queries are mostly complex and the mean size of the result sets is above one million[16]. They also test for SPARQL features like union and optional graph patterns.

The WatDiv suite generates a synthetic benchmarks and consists of multiple tools[7]. First 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 generate with the query generator which instantiates the templates with actual RDF terms from the generated dataset. For each template multiple queries can be generated. The benchmark only focuses on SELECT queries that does not make use of Union and Optional patterns.

2.2 Benchmarks Using Real Data

Benchmarks using real data are benchmarks for which copies of real datasets and queries are used to perform a benchmarks. The real queries are often taken from query logs of Triplestores and the datasets are based on real datasets[14, 16].

FEASIBLE is a benchmark generation framework which generates datasets and queries from provided query logs[16]. This has the advantage that the data used for the benchmark could stem from queries about a specialized real world topics 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, since those environments are specialized for the given benchmark and are not easily interchangeable[9].

The next sections focus on benchmark-independent execution frameworks.

2.3.1 IGUANA

Iguana is a SPARQL benchmark-independent execution framework[9]. 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 and 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 Iguana.

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[15]. It is a big framework which needs to be deployed on a local cluster or online computing services like Azure[1] or AWS[2]. The deployment of the platform and deploying new benchmarks to the platform can be challenging for new users of the system[15]. The data for benchmarks has to be stored in docker containers, generated or downloaded before an benchmark, which increases the complexity of the system. The data is then send over message queues to the benchmarked system.

With the Basilisk platform we try to develop a specialized solution for continuous benchmarking of Triplestores which does not need the technical complexity present in the Hobbit framework. 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.

[1] `https://azure.microsoft.com/`
[2] `https://aws.amazon.com/`

3 Background

This chapter explains the fundamental topics required to understand this thesis.

3.1 Semantic Web Topics

The following topics come from the research area of Semantic Web. Since this thesis focuses mostly on the implementation and deployment of the Basilisk platform, these topics are mostly introduced to give a basic understanding of the context in which the Basilisk platform is used.

3.1.1 Knowledge Graphs

Knowledge Graphs are graphs intended to represent knowledge of the real world or smaller 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 to represent complex relations between different nodes and edges[13].

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.

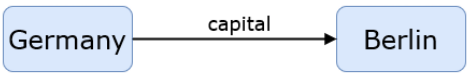

Figure 3.1: Simple Knowledge Graph

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.

3.1.2 RDF

The Resource Description Framework is a framework for describing data and knowledge in a standardized way [5] and 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 IRIs (internationalized resource identifiers), 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 seen in figure 3.2. The first two lines of the TURTLE document define abbreviations for the used IRIs so that the triple in line three is more readable.

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

Figure 3.2: Example of an RDF graph in TURTLE syntax.

3.1.3 Triplestore

Triplestores are a special kind of database developed to easily store and access knowledge graphs through queries. Example of Triplestores are Tentris[8], GraphDB[1], Virtuoso[2], or Jena TDB[3].

This thesis focuses on Triplestores that 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)[12] 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, following by an `WHERE` clause giving restrictions.

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

Following the example from section 3.1.1 and 3.1.2 there are two example SPARQL queries in figure 3.3. Executed against the DBPedia SPARQL endpoint[4] the following results can be found:

The first example query requests the variable which matches the `WHERE` clause searching for the capital of Germany, which is `dbr:Berlin`. The second query 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.

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 goal of the Basilisk platform. The sections Microservice and Microservice Architecture (3.2.2, 3.2.3) explain the basic idea and concept of the microservice

[1] `https://graphdb.ontotext.com/`
[2] `https://virtuoso.openlinksw.com/`
[3] `https://jena.apache.org/documentation/tdb/`
[4] `https://dbpedia.org/sparql`

```
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  }
8
9  ---
10
11 SELECT ?relation
12 WHERE {
13         dbr:Germany ?relation dbr:Berlin .
14 }
```

Figure 3.3: SPARQL query examples

architecture style. In the sections RabbitMQ and Spring (3.2.4, 3.2.5) 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 data set and a set of operations or queries which will be performed on the data set. 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 and queries per second[2].

A distinction is made between micro and macro benchmarks. 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, which will be set up in this thesis, will only perform 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 [10]. All Microservices can be individually deployed and managed and they interact via messages through a defined protocol with other services. The idea is that individual microservices can be combined like modules to create any desired complex software.

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 [10, 3]. 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 service could be implemented in different programming languages and also could be located on different servers.

3.2.4 RabbitMQ

RabbitMQ 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, flexible routing[4].

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. Since RabbitMQ is a widely used message broker, the Spring framework (3.2.5) already comes with the needed libraries to work with the RabbitMQ system.

3.2.5 Spring and Spring Boot

Spring[5] is a widespread open-source Java framework which facilitates the development process for various kinds of java applications and systems.

Spring Boot[6] is an extension to the Spring framework that follow 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 come with different annotations to decorate classes and methods that configure these 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. The package structure found in the source code of the Basilisk microservices is influenced by Spring Boot and tries to represent those different design conventions.

3.2.6 Software Design Patterns

Repository Pattern

fill

Domain Driven Design

fill

3.2.7 Stateful / Stateless Microservices

fill

[5] https://spring.io/
[6] https://spring.io/projects/spring-boot

4 Approach

In this chapter we give an overview of the current software architecture on which the Basilisk platform is build.

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 for the Basilisk platform is to offer the possibility to automatically perform benchmarks for a new Triplestore release.

Benchmarks are also relevant during the development process. An benchmark performed automatically for e. g. a new pull request 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 a docker image from Docker Hub containing the Triplestore, which will then be observed by Basilisk. If there is a new release of the Triplestore, Basilisk will internally 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 could be run on different hardware systems and they interact with each other via a 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 11 and Spring Boot version 2.6.3.

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. The Spring and Spring Boot framework are shortly described in chapter 3.2.5.

4.2 Main Services

The next sections explain the three main services, namely Hooks Checking Service (section 4.2.1), Jobs Managing Service (section 4.2.2), and Triplestore Benchmarking Service (section 4.2.3).

This explanation follows the flow of actions that happen while configuring a continuous benchmark and the actions that happen when a benchmark is initiated.

The explanations are based on provided diagrams, code review and analysis, and information 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 send between the services and the interactions with GitHub and Docker Hub.

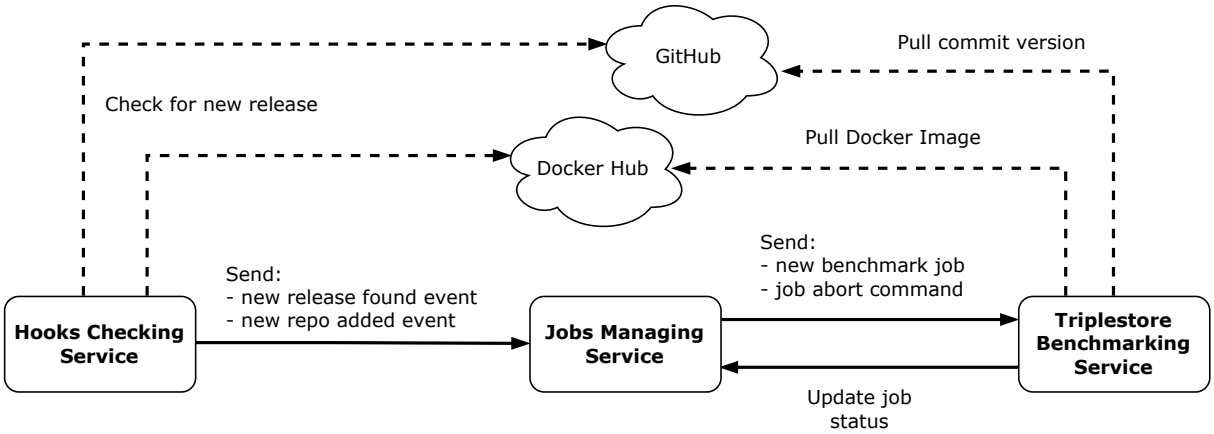

Figure 4.1: Overview of the three microservices

4.2.1 Hooks Checking Service

The main task of the Hooks Checking Service (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, the HCS needs to be informed which repository (GitHub or Docker Hub) has to be observed for changes. This happens through REST API calls to the HCS providing the repository name and owner. The HCS will then create a hook for the repository to get notice 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 an repository. The service will query the saved repositories regularly and compare their current version to the version stored in the hook.

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 most important endpoints are for adding and deleting GitHub and Docker Hub repositories. Figure 4.2 shows these endpoints.

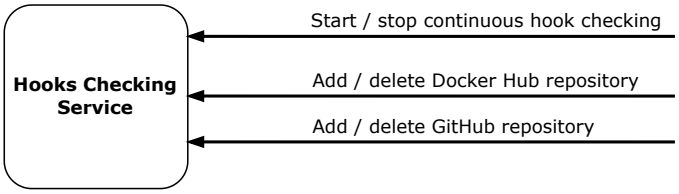

Figure 4.2: REST API of the Hooks Checking Service

The communication between the HCS and the Jobs Managing Service is done over RabbitMQ (3.2.4) messages, over the Job Request Queues. The messages contain different events that can occur in the HCS. For example an event is send when adding or deleting a repository, or a new release is detected.

4.2.2 Jobs Managing Service

The main task for the Jobs Managing Service (JMS) is to create benchmark jobs, when a new release was found by the HCS. Other important functionality of the JMS is the management of configurations needed for the benchmarks. Lastly the JMS manages the status for running and pending jobs send to the Triplestore Benchmarking Service.

There are three configuration types needed. First the platform needs the configuration for the Triplestore. This configuration include for example the SPARQL endpoint as well as the user and password for the connection to the endpoint. This is needed by the Iguana framework to properly connect to the Triplestore under test[1].

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

These configurations are added over the REST API of the JMS.

When the HCS sends an event 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 can be created. For each query configuration and dataset one benchmark job will be created.

These benchmark jobs will then be send to the Triplestore Benchmarking Service over the Benchmark Job Queue.

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

API and Messaging

The JMS communicates with the HCS and the Triplestore Benchmarking Service over RabbitMQ message queues. The service receives repository events from the HCS and sends benchmark job events to the Triplestore Benchmarking Service over the Benchmark Job Queue (BJQ).

Interaction of 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.

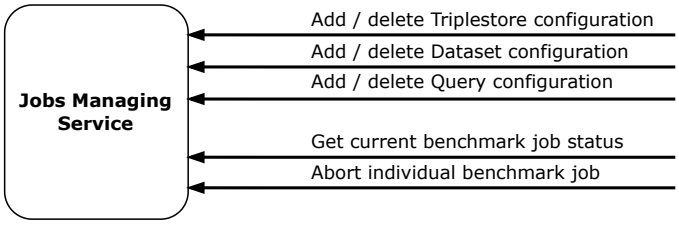

Figure 4.3: REST API of the Jobs Managing Service

4.2.3 Triplestore Benchmarking Service

The Triplestore Benchmarking Service (TBS) executes the benchmark jobs send by the JMS and saves the benchmark results to a Triplestore.

To execute a benchmark the service needs a running instance of the Triplestore under test 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 looks for a Dockerfile. It 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. It then runs the image as a Docker Container.

After starting the Docker Container the TBS starts the Iguana framework. Iguana will perform the benchmark with the provided configuration from the benchmark job.

When the benchmark is finished the results are written to a Triplestore called 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 Architecture Review

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

Not yet final.. only a first collection of thoughts and implementation todos

4.3.1 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 connect 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.

4.3.2 Code Refactoring

During the code analysis some inconsistencies in the code style and duplicate code snippets have been found. In other parts the code structured differs to 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.

4.3.3 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 quite complete. Only small additions have to be implemented.

- The REST endpoints for deleting GitHub and Docker Hub repositories needs to be added.
- Currently Pull Requests in 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 dataset configurations
- Adding / removing query configurations

The structure for the internal data models has logical errors and is in parts incomplete. The resulting database model for the internal database is contradicting itself on some points and needs a restructure.

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

- List running / pending jobs and their status
- Set the status for a job

Triplestore Benchmarking Service

The implementation of the Triplestore Benchmarking Service is currently only a bare structure of basic classes. Big parts of the logic still needs to be implemented.

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

The main functionality 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
- connection 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 the benchmark, some cleanup of the Docker containers needs to be implemented.

5 Implementation

This section describes the implementation of the concepts explained in chapter 4. Parts of the system were already implemented.

6 Evaluation

- Experiment setup, requirements - Performing of benchmarks - Result evaluation

7

Summary and Discussion

- Summary of the work - Highlighting the key findings of the evaluation stage

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