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Integration of standard datasources with interactive data visualization solutions

BACHELOR'S THESIS

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HALLGATÓI NYILATKOZAT

Alulírott *Orova Márton*, szigorló hallgató kijelentem, hogy ezt a szakdolgozatot meg nem engedett segítség nélkül, saját magam készítettem, csak a megadott forrásokat (szakirodalom, eszközök stb.) használtam fel. Minden olyan részt, melyet szó szerint, vagy azonos értelemben, de átfogalmazva más forrásból átvettem, egyértelműen, a forrás megadásával megjelöltem.

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Budapest, 2019. december 12.

Orova Márton
hallgató

Kivonat

Manapság egyre nagyobb hangsúlyt kapnak azok a technológiák, amelyek az adatok tárolásának, feldolgozásának és bemutatásának problémájával foglalkoznak. Az iparnak szembe kell néznie a sokszínű adarforrásokból származó információk integrálásának kihívásokkal teli feladatával. Ugyan léteznek már erre megoldást kínáló különféle szabványok, azonban ezek átjárhatósága limitált.

Ezen szakdolgozat keretein belül ismertetem a leginkább elterjedt adatforrások jellemzőit és felhasználási területeit. Bemutatom az egyik legelterjedtebb, nyílt forrású adatvizualizációs platformot - a Grafanát - különös figyelmet fordítva a felhasználói interaktivitást lehetővé tevő funkcióira. Ismertetem a Grafana és két adatforrás (RapidMiner Server és egy Python alapú implementáció) közti lehetséges integráció tervezési és megvalósítási szempontjait, lépéseit. A létrejött architektúra lehetővé teszi az adatforrások és a Grafana közti kétirányú kommunikációt. Kiegészítve a Grafana beépített bővítményeit további funkcionalitást vezettem be annak érdekében, hogy a felhasználók könnyebben tudjanak hatékonyan lekérdezéseket küldeni az adatforrások felé, illetve hogy egyszerűbben kaphassanak egy konzisztens képet a megjelenő adatokról. A megvalósítás részletezését követően kielemezem a RapidMiner Server és a Grafana közti átjáró komponens előnyeit és hátrányait, valamint javaslatot teszek a jövőbeni esetleges fejlesztésekre is. Végül röviden megemlítem a szakdolgozat témájához hasonló feladatokat megoldani kívánó munkákat.

Abstract

Today, the technologies aiming to solve the problem of storing, processing and visualizing data are getting more and more attention. The industry has to face the challenging task of integrating information originating from various data sources. There are already multiple standards attempting to solve this issue, however, using these together still presents many difficulties.

In this thesis project, I review the features of the main types of data sources and the use-cases, where they proved to be the most efficient. I introduce the de facto open source industry standard visualization tool - Grafana - focusing on its capabilities that enable user interactivity. I present the steps and considerations of designing and implementing the integration of Grafana and two data sources (RapidMiner Server and a Python data source). The created architecture grants the ability to make two-way connections between Grafana and its data sources. I also extended some built-in plugins in Grafana in order to allow users to send effective queries towards the data sources and to provide them with a more consistent visualization of the data. Following the details of the implementation, I analyze the gateway component that connects RapidMiner Server and Grafana, highlighting its advantages and drawbacks. I also make a few suggestions for future development possibilities. Finally, I briefly review the related works of this thesis project which try to solve the similar problem as the integration discussed here.

Chapter 1

Introduction

Nowadays, the question of storing, processing and displaying the data is becoming more and more important throughout every industry. The time, when the collected data was only useful for computers and specialists, passed. Today, the need for showing data in an easily understandable form is significant. It is no wonder, people through the whole hierarchy of a company would like to be well-informed about the results and the ongoing processes. In addition, it is getting highly valuable to be able to display vast amount of data in a way that even outsiders can comprehend.

Because of this trend, many technologies attempting to solve these problems have appeared, creating a wide variety of tools which organizations can use.

In enterprise-grade environments, the use of complex systems - so called data-pipelines - are becoming increasingly common. These tools provide an integrated solution for transforming and querying data coming from data sources built with different technologies. With the help of these data-pipelines, it is possible to collect many types of data, no matter the format or the frequency.

All these things for one reason, to prepare the data for machine or human decision-making.

1.1 Problem definition

Every organization needs to take care of the sometimes cumbersome task of managing data. It is common, that this data does not come from one place, but from multiple sources, which can present various problems, especially if at some point, merging all the available data is necessary. It can happen for example, if the organization wants to visualization of the data to be in one place.

The most fundamental challenge is maybe the issue of the data format and the way of accessing the data. There are already numerous industrial standards available, however, using these together can cause difficulties. The problem is not only the conversion between different data formats, but also handling the different frequency of incoming information from each data source.

In addition, each of these heterogeneous components need to be configured in different ways, with varying set of parameters. Keeping up with all of the technologies, which may change over time independently from each other, can produce a heavy overhead for the data-specialists.

Thus, we can establish the notion, that a universal tool for integrating different types of data sources is highly desired to allow the visualization of the recorded information in one place.

1.2 Motivation

There are numerous reasons why I choose to work on this thesis project. In this section I try to collect them together in order to better express my motivation towards this task.

It was expressed in the previous section, that it is quite valuable for an organization to be able to display its collected data in one visualization tool. Achieving this would allow an easily understandable and centralized way of presenting the data.

Throughout this project, I focus on integrating different data sources with a popular, open source visualization tool called Grafana. Working with this allows me to get familiar with the details of complex systems and their architecture. To combine the data sources with Grafana, I need to look into many different technologies, which surely widens my knowledge about various programming languages and design principles.

1.3 Goals

There are a couple objectives to achieve during this thesis project.

First of all, an investigation is needed about the mainly available data sources and their varying features. This is necessary to get into context and to establish further decisions concerning this work.

Following that, we have to conduct a research on the available interactivity capabilities of Grafana. It would be great, if throughout this project, we could utilize as many of them as possible and integrate them into our work. In addition, as Grafana is an open source project, there are probably plenty of possibilities for extending or customizing it in the context of interactivity. We should briefly look into it and make an attempt at implementing some simpler use-cases.

As it was already expressed above in section 1.1, softwares for integrating different types of data sources are indispensable. We need to design a tool that can handle this task in case of two data sources and connect them to Grafana, an industry standard for data visualization. More specifically, we need this component to be able to connect a RapidMiner data source and a Python data source to Grafana in way that allows a two-way link between them to enable further interactivity capabilities.

After the design of such tool, a sample implementation is needed to ensure the functionality of the architecture and demonstrate its effectiveness. Afterwards, we need to analyze the created gateway, discovering and presenting its advantages and disadvantages.

Chapter 2

Background

2.1 Data sources

As its name suggests, a data source is a location where the data that is being used originates from. A data source can be for example a database or a dynamic stream of data service such as constantly collecting the measured temperature in a room. In the context of this thesis project, we focus on database-like data sources, because in general, a visualization tool needs to be able to read the data to be displayed from a backend storage. [34] [35]

Concerning the types of databases, there are different categories, each with varying features and purposes. In the following sections, I briefly introduce some of the most used types of databases.

2.2 Relational database

Probably the most popular databases are the relational databases. They store data points that are related to one another. Relational databases are based on a relational model, representing the data in tables. They are widely utilized in cases, when related data points need to be stored and managed in a secure, rules-based, consistent way. [29]

2.3 Time series database

A time series database is optimized for storing time-stamped or time series data. Time series data are measurements that are tracked and aggregated over time. This

could be metrics about servers, application performance, network data, etc. A time series database possesses enhanced capabilities to handle the measurement of change over time compared to other types of databases. [11]

2.4 Key-Value database

A key-value database is type of nonrelational database that uses a simple key-value method to store data. The data is stored as a collection of key-value pairs in which the key fulfills the role of a unique identifier. Both the keys and the values can have any type, simple objects, like number or string or even complex compound objects. This means that the schema of the data is defined per item, instead of on a collection or table level, like in the case of relational databases. Key-value databases are mostly utilized for cache management or storing information in session-oriented applications. [3]

2.5 Document database

Document databases are another type of nonrelational database that are designed to store and query the recorded information as flexible, semistructured JSON-like documents. They make it easier for developers to handle data in the database by using the same document-model format they use in their application code. Document databases allow flexible indexing and powerful ad hoc queries. [2]

2.6 Grafana

Grafana is one of the most popular open source analytics and monitoring solution that can be connected to the majority of the main data sources out-of-the-box. It allows its users to query, visualize and alert on the collected metrics.

Although Grafana has got plenty of useful features, only those relevant to the scope of the thesis project will be briefly explained here.

2.6.1 Data Source

Grafana supports many different storage backends (Data Source). Each Data Source has a specific Query Editor (see later in section 2.6.3) that is customized for the

features and capabilities that the particular Data Source exposes. Of course, this leads to the fact that the query language and capacity of each Data Source are obviously very different. [16]

Grafana mainly favors time series data (e.g. from Prometheus or InfluxDB), but it can work with other types of data source (e.g. relational databases (MySQL, PostgreSQL, MSSQL), logging and document databases (Loki, Elasticsearch)).

2.6.2 Panel

The Panel is the basic visualization building block in Grafana. Each Panel provides a so called Query Editor (dependent on the Data Source selected in the panel) that allows the user to create data source specific queries (e.g. an SQL query for a MySQL data source) in order to extract the desired metrics as precisely as possible. [19]

There are multiple built-in Panel types available in Grafana, however, custom panels made by the open source community are also accessible. Probably the most widely used Panel types are the Graph, Table, Singlestat and Gauge. An example of the Graph Panel can be viewed in Figure 2.1.

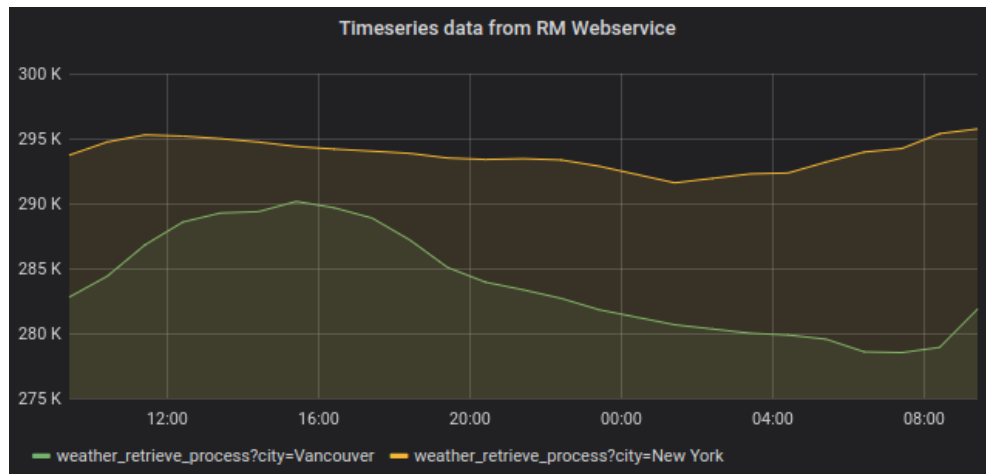


Figure 2.1: Graph Panel

2.6.3 Query Editor

The Query Editor exposes the capabilities of the Data Source and allows the user to query the metrics that it contains. The queries created in the Query Editor of a panel determine what data will be displayed on the panel. [20] An example Query Editor is shown in Figure 2.2.

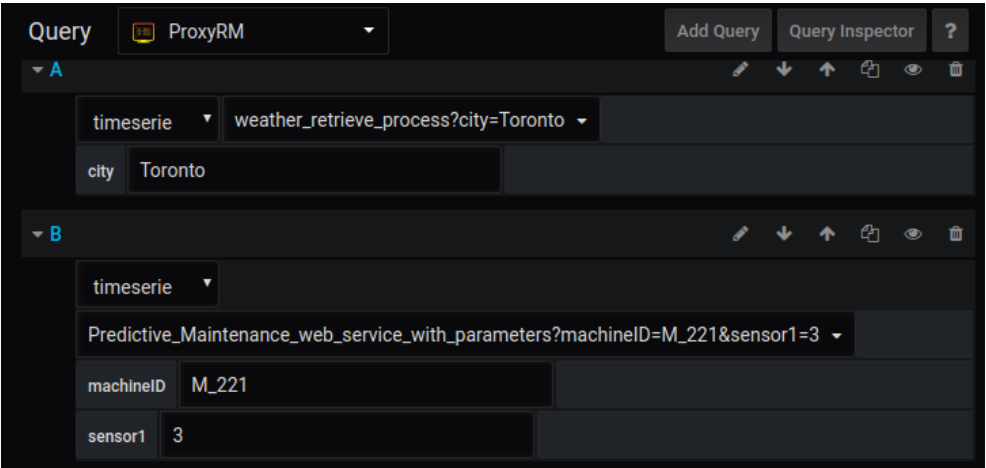


Figure 2.2: Query Editor

2.6.4 Dashboard

The Dashboard is where all the previously mentioned building blocks come together. Dashboards can be thought of as an organized set of Panels. [15]

We can use the Dashboard to visualize different metrics in one, easily manageable place. This is quite useful, when many aspects must be taken into account in order to be able to thoroughly understand our currently inspected data set. An example Dashboard about a Kubernetes cluster can be viewed in Figure 2.3.

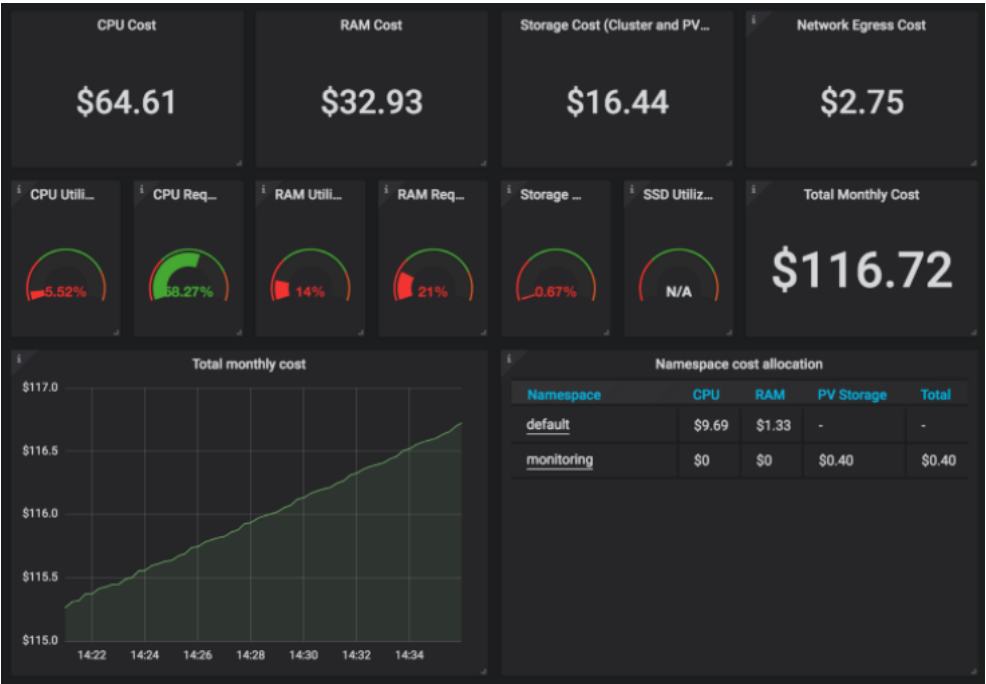


Figure 2.3: Dashboard [14]

2.6.5 Interactivity in general

When working with and visualizing massive amount of data is a major part of one's profession, it can be quite convenient if the tools can provide the ability to allow some user-interaction. Meaning that the user do not have to work with static diagrams or rewrite complex configurations so that he or she is capable of further analyzing the collected data.

Commonly available interactivity options can be the followings [13]:

- *statistic indicators* - easily accessible statistic information (e.g. average value, spread-diagram) about individual objects shown on the diagram (this is usually achieved by mouse-hovering)
- *local interactions* - changing the outlook of a diagram without affecting other displayed objects (e.g. reordering the bars on a bar-chart, rescaling the axis on a graph or other diagram-specific modifications)
- *selection and linked highlighting* - when we have multiple diagrams displaying different views of the same data set, selecting a subset of the data on one diagram (e.g. a bar on a bar-chart) highlights that particular part of the data on another diagram (e.g. a set of points on a scatter-plot)
- *linked analysis* - for example, selecting a subset of the data triggers a reactive analysis, creating a statistic model (regression, scatter-plot, spread-diagram) using that specific data set

2.6.6 Interactivity in Grafana

While it is hard to find a tool, which possesses all the before-mentioned interactivity capabilities in section 2.6.5, Grafana supports certain features to enable efficient user-interaction for the purpose of solid understanding of the data.

2.6.6.1 Time Range Controls

Grafana provides numerous ways to interactively manage the time ranges of the data being visualized. [21]

On the Dashboard-level, the 'Current time range' selector can be used to change the dashboard time. Doing this refreshes the whole dashboard with each panel on it. Those panels, which display time-dependent information, will only show data-points with timestamps that are in the newly set time range.

If there is a Graph Panel on the dashboard, there is another possibility to change the Dashboard-level time range. We can select a time range on the Graph Panel with the cursor. This method is quite effective, when we would like to swiftly zoom into the data to review more refined details. An example for that feature is displayed in Figure 2.4.

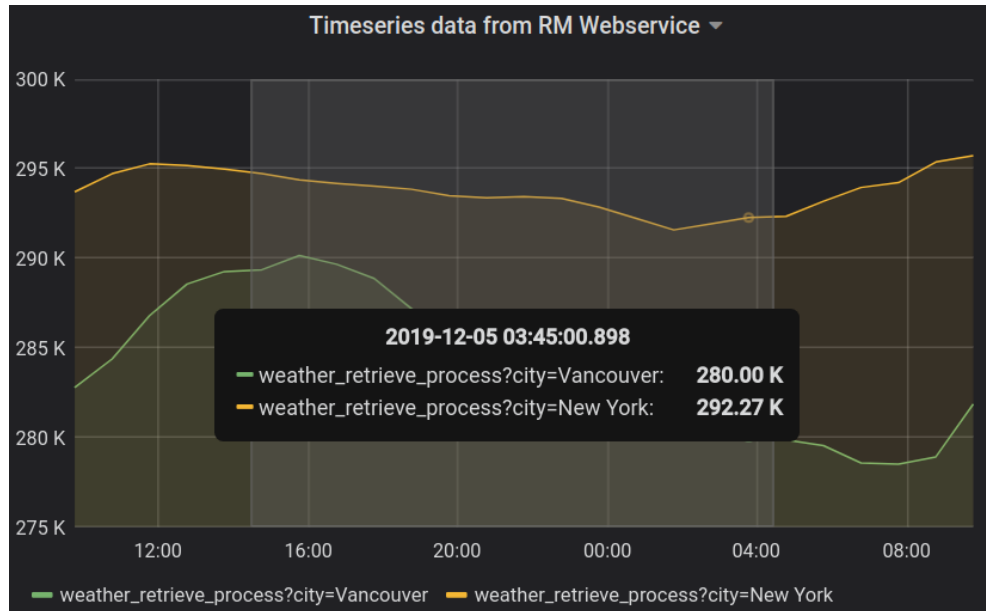


Figure 2.4: Zoom into the time range

2.6.6.2 Variables and Templating

Variables in Grafana allow for more interactive and dynamic dashboards. We can use variables in metric queries and in panel titles.

Their role is similar to that of the 'conventional' variables in programming languages. Instead of hard-coding things into the program, we can use them to create algorithms, that operate on a more abstract level, resulting in more effortlessly maintainable softwares.

In Grafana, we can use the variables to write more generalized metric queries. For example, if we have multiple servers and we collect metric data from all of them, we could store the names or addresses of the servers in a variable, rather than defining numerous queries, which only differ in the server name. Variables are shown as dropdown select boxes at the top of the dashboard. These dropdowns make it easy to change the value of each available variable, thus to adjust the data being displayed in the dashboard [22]. An example of that can be seen in Figure 2.5.

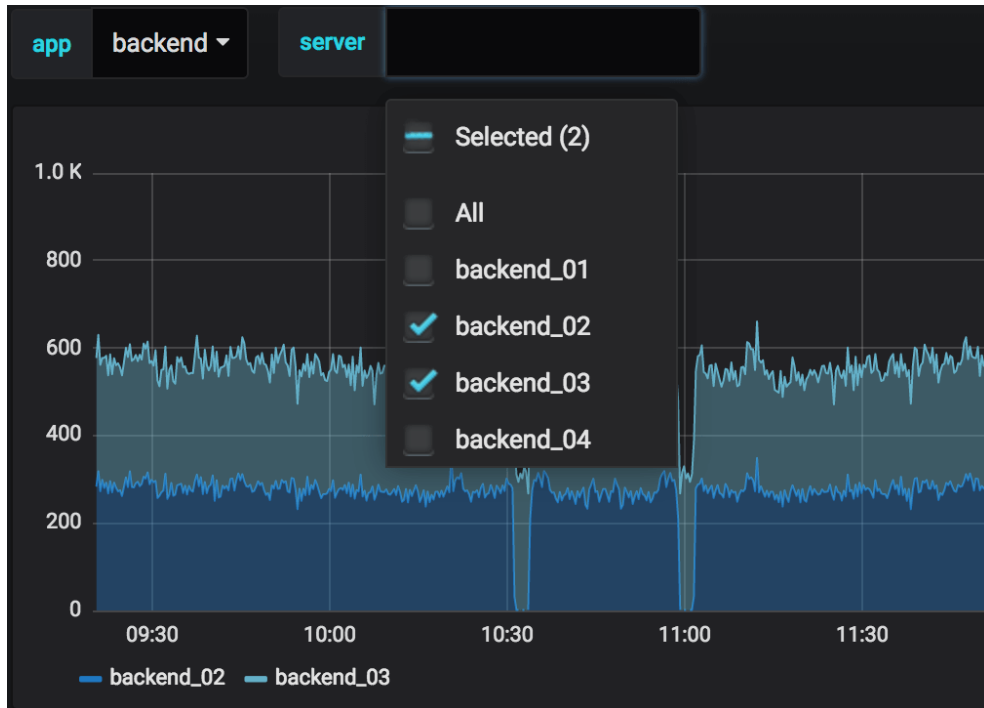


Figure 2.5: Variable dropdown [23]

There are different types of variable that can be used to make dashboards more dynamic. [24]

- *Query* - This variable type allows for writing a data source query that usually returns a list of metric names. For example, a query that returns a list of server names, sensor ids, or data centers.
- *Interval* - This variable can represent time spans. We can use them, when we need to aggregate data-points by time or date.
- *Data source* - This type makes it possible to quickly change the data source for an entire Dashboard. This feature can be quite suitable, when we have multiple instances of a data source in, for example, different environments.
- *Custom* - This variable can be used to manually define the value options for the given variable.
- *Constant* - This variable can be handy for example to easily declare metric path prefixes.
- *Text box* - This variable type displays as a free text input field with an optional default value.

- *Ad hoc filters* - It is a quite special kind of variable that only works with some data sources (e.g. InfluxDB, Elasticsearch). It allows the user to add key/value filters that will automatically be added to all metric queries the use the specified data source.

2.6.6.3 Basic statistic values in legend

Statistic indicators were already mentioned above, where we discussed interactivity in general. In Grafana, we can display some basic statistic values (minimum, maximum, average, total) in the Graph Panel. An illustration of this feature is displayed in Figure 2.6.



Figure 2.6: Basic statistic values on Graph Panel

2.6.6.4 Data links

Data links provide a way to add dynamic links to the visualization. These links can link to either other dashboards or to an external URL. When using data links, additional built-in variables become available that enable creating dynamic links. [18]

These variables are:

- `__series_name` - the name of the series or the table
- `__value_time` - the timestamp of the point that is clicked on (in millisecond epoch)
- `__url_time_range` - the current time range

- `__all_variables` - adds all current variables and their current values to the URL

2.6.6.5 Creating custom interactivity

As Grafana is a fully open source project, it is possible for the community, to develop unique objects in Grafana or to extend built-in ones. This way, it is achievable to create custom interactivity features according to the needs of the user.

2.7 RapidMiner

RapidMiner is a data science software platform that provides an integrated environment for data preparation, machine learning, deep learning, text mining and predictive analytics. [30] [36]

RapidMiner follows the principle of defining data science workflows in processes. These processes can perform various actions like retrieving or transforming data to build different kinds of models from them. As result of a process, a data set is returned, which can be further utilized according to the business use-case.

RapidMiner includes several components, however, only the ones with relevant features to this thesis project are introduced briefly in this section. [31]

2.7.1 RapidMiner Studio

The RapidMiner Studio is the desktop IDE for creating the data science processes. These workflows can be defined in a code free manner, using a graphical interface. This allows for easily comprehensible processes and eliminates the possibilities of wrong syntax.

The created processes can be deployed to the RapidMiner Server component.

2.7.2 RapidMiner Server

RapidMiner Server is the central component in the architecture. Users can interact with it via a web interface or via RapidMiner Studio.

Its main responsibilities are to store, schedule and expose data science processes that were deployed onto it, like model building, predictions, data ETL (Extract,

Transform, Load) operations, etc. Long-running jobs are executed externally via Job Agents. The RapidMiner Server stores its data in an external database.

2.7.2.1 Web services

The Server can expose certain processes that can be invoked via simple HTTP requests. These are the so called web services which can be used to run predictions or any other application of models, where the need for a real-time response is paramount. The result of the exposed processes can be used by any outsider consumer softwares.

In order to make this service more dynamic, additional parameters can be sent with the requests to get more accurate information. The user can acquire the results of these processes through the same API in JSON format.

2.7.3 Job Agent

RapidMiner Server offers a queue system for long-running jobs, which are executed externally via Job Agents. The computing power of the stack can be increased by adding more Job Agents.

2.8 JSON

In this thesis project, I use the JSON data-interchange format to send information between the various components. For this reason, a brief description of the JSON format is appropriate in this chapter.

The JSON stands for Javascript Object Notation and it is a lightweight format for storing and transporting data. We can say that JSON is easily read by both humans and machines, as a JSON object is merely an unordered set of name/value pairs. The name is a string and the values can be different types of data, for example a number, a string, an array or another object. These types are supported in all modern programming languages in one form or another, thus despite what its name suggest, the JSON format can be regarded as an universal data structure [12]. An example JSON object can be seen in the code snippet Listing 2.1.

```
1 { "name": "Test", "age": 23 }
```

Listing 2.1: Example JSON

Chapter 3

Case study

It is certainly evident by now that this thesis is rather a practical implementation and an integration problem, than a research project. As one of the main goals is to combine different kind of data sources, it seems to be convenient from several aspects to have some data to work with. It makes the development easier, because we can see immediately, if the components can handle the data or that in what way they change it. The possession of sample inputs can also help to demonstrate the results and provides the capability of some independent verification.

I used the Historical Hourly Weather data set from Kaggle that contains hourly measurement results of various weather attributes, such as temperature, humidity, air pressure, etc. The data is available from several cities from the USA, Canada and Israel from October 2012 to November 2017 [10].

datetime	Vancouver	Portland	San Francisco	Seattle
Oct 1, 2012 1:00:00 PM CEST	284.630	282.080	289.480	281.800
Oct 1, 2012 2:00:00 PM CEST	284.629	282.083	289.475	281.797
Oct 1, 2012 3:00:00 PM CEST	284.627	282.092	289.461	281.790
Oct 1, 2012 4:00:00 PM CEST	284.625	282.100	289.446	281.782
Oct 1, 2012 5:00:00 PM CEST	284.623	282.109	289.432	281.775
Oct 1, 2012 6:00:00 PM CEST	284.621	282.118	289.417	281.768
Oct 1, 2012 7:00:00 PM CEST	284.619	282.126	289.403	281.760

Figure 3.1: Extract from the temperature data set

3.1 RapidMiner source

Concerning the part of the RapidMiner Server, it exposes a process that provides the temperature data from the sample data set. It accepts a parameter determining from which city the user wants to acquire this information. In short, it provides a filtering option by city.

3.2 Python source

In this project I demonstrate a proof-of-concept use-case, when the Python data source component reads information from a database and also from an external API service. To be more precise, in the database, I store the measured daily minimum and maximum temperature data from 2012 to 2017 in New York. Concerning the the API part, I created a small web application with a REST API that exposes historical highest and lowest temperature values for a given day of the year, also in New York. In the middleware written in Python, I implemented an example business logic which counts on how many days in a month (from October 2012 to November 2017) the measured temperature got close to the all-time records. I have to mention, that the calculation of these historical highest and lowest values is also heuristic. I only took data from January 1959 to September 2012 into account.

I believe, that this is a quite common problem, to have some data in one's storage, but for a better business competence, the usage of external services is also necessary. Hence, this example set-up could serve as an applicable demonstration for further possibilities.

Chapter 4

Design

4.1 Architecture

The designed architecture of the project can be observed in Figure 4.1. There are three data sources connected to Grafana through an extended version of the official SimpleJSON data source plugin:

- RapidMiner Server
- JSON backend
- Python data source

Each data source accesses the data it provides to Grafana in different ways; through an outside service, from a database or from memory.

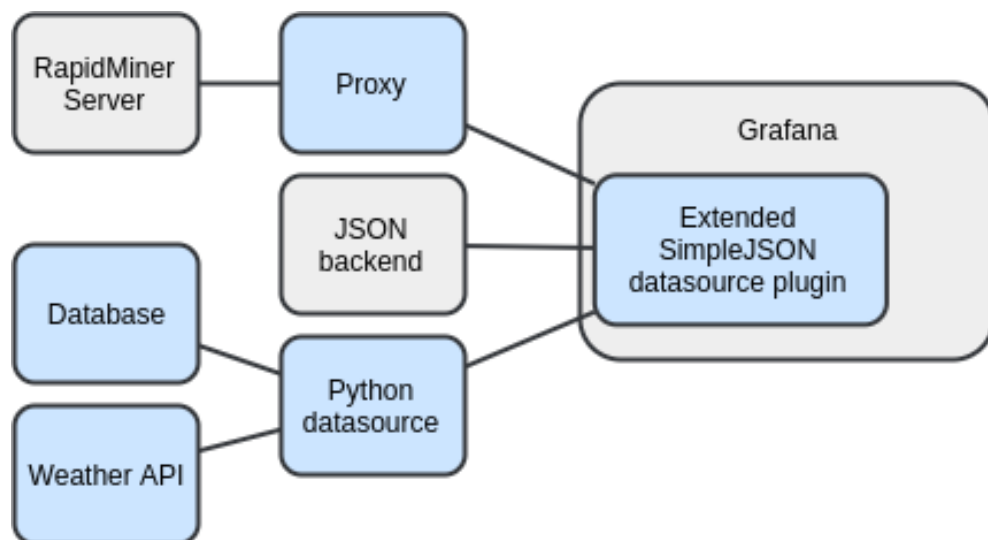


Figure 4.1: Architecture diagram

4.2 Components

In this section, each component's design is presented, focusing on their responsibilities.

4.2.1 Extended SimpleJSON datasource plugin

Grafana uses data source plugins to connect to different data storage backends. These components usually poll their backends, sending query requests to acquire the recorded information. Each data source plugin exposes a Grafana specific interface, which allows Grafana to communicate with every data source plugin the same way.

The SimpleJSON data source is made by the Grafana team and is available on GitHub. [26]

It has two main purposes. One is to act as an example implementation to make writing custom data source plugins easier for the community. The other is to enable Grafana to read data from services that expose data in JSON format (which is widely popular throughout the industry).

For this thesis project, the latter role seems to be more important, as it is possible to create a tool that receives data from different kind of formats and translates them into JSON. This way, we can send the transformed data to Grafana, which as a result, would be able to display the collected data that originally came from various sources in one place.

Hence, instead of designing a data source plugin for Grafana from scratch, I chose to customize this already available component to dodge many caveats of developing an own plugin for a complex system.

The SimpleJSON data source plugin requires its backend to implement the following endpoints:

- `/` - This endpoint is used for testing the connection between Grafana and the data backend. If everything is in order on the side of the backend, this endpoint should return a HTTP 200 response.
- `/search` - This endpoint is used for finding the available metric options. For example the names of different time series.
- `/query` - This endpoint is used to acquire the actual metrics data from the backend.

- */annotations* - This endpoint is used to return objects called annotations that are additional information attached to the metrics data. In the context of this project, we do not use this feature, however, it is needed for the data source plugin to run without errors.

In order to introduce additional interactivity capabilities, when integrating the RapidMiner web service, the SimpleJSON data source plugin needs to be extended. Since it is possible for a RapidMiner web service to accept parameters, which can filter the result, it would be useful to be able to acquire these available exposed parameters, so we can make more accurate metric queries with Grafana.

This means that the plugin has to be able to send another type of request to the backend, which in return would respond with the list of the accessible parameters:

- */parameters* - This endpoint is used for acquiring the available query parameters exposed by the backend.

During operation, this data source plugin will periodically poll its connected data sources for data, sending HTTP requests to the above described endpoints. The time-interval between the polls depends on the settings in Grafana.

4.2.2 Proxy (Gateway)

The main responsibility of this component is to translate between the RapidMiner web service, which the RapidMiner Server exposes and the SimpleJSON data source plugin. The problem is that RapidMiner Server makes its result available in JSON, but in another format, than the SimpleJSON data source plugin accepts.

To accomplish that this proxy component could communicate with Grafana, it must implement the endpoints required by the SimpleJSON plugin. These were explained in section 4.2.1 describing the plugin.

So the gateway component should be able to handle HTTP requests from SimpleJSON as well as forwarding them to RapidMiner after the translation. For this reason, it must be a constantly available service.

There are some RapidMiner web service specific considerations which need to be taken into account while designing the gateway component. We have to define the actions made by the proxy towards the RapidMiner Server in an abstract way, in order to properly implement the component.

4.2.2.1 Searching the targets

In order for Grafana to be able to make queries to request data, it needs to know where this data can come from, what is the address of the service that exposes the recorded information. For that, Grafana (and indirectly the SimpleJSON data source plugin) first asks for the available targets of the given data source backend. As it was mentioned in section 4.2.1, SimpleJSON uses the `/search` endpoint for acquiring this information.

In our case, the Proxy component connects to RapidMiner Server, which exposes its data providing processes through web services. Thus, when accepting requests on the `/search` endpoint the gateway should return with the names of the available RapidMiner web services in a format that the data source plugin accepts. For that, it must send a request to the RapidMiner Server, asking for these names each time, so it is ensured that the information is always up-to-date. This is crucial, as the name of the RapidMiner web service determines the address where the gateway has to send the query requests later.

4.2.2.2 Acquiring the parameters

To enable the customization of the queries, the Proxy's `/parameters` endpoint should return the parameters exposed by a given web services. This information also falls in the category that should not be cached, as the possession of false knowledge can lead to failed queries that ends up in no data displayed in Grafana.

4.2.2.3 Querying the data

After we have the name of the web service and its available parameters, we can finally request the actual data. To accomplish that, Grafana sends a request to the `/query` endpoint of the Gateway component. Grafana can handle data in two formats: time series, and table (see later in section 5.2.1.3). This means that the Proxy component should be able to convert the acquired data from its backend into one of these formats.

4.2.3 JSON backend

This component is an example backend implementation for the SimpleJSON data source plugin. It serves as a base for creating other backends for the SimpleJSON. It also further expresses the general usability of the plugin. [4]

As this component can work with the SimpleJSON data source plugin out-of-the-box, I used it during the thesis project mainly for testing purposes. For example to check if the connection is still healthy between the components, or to inspect the specific data formats which are sent to or received from the SimpleJSON plugin.

4.2.4 Python data source

Although Grafana has multiple built-in plugins to communicate with databases, there exists some use-cases, when having a custom component between the data source and the visualization tool is feasible.

With an additional component in the middle, we have extra control over the data, which travels from the data storage backend (in our case, MySQL) to the visualization platform. This means that we do not have to rely solely on the capabilities of the database, which can lead to simpler queries and smaller communication overhead with the database.

Having a custom middleware also makes it possible to implement the business logic in a separate component and only display business-relevant information with the visualization tool.

It also enables us to aggregate information from different backends and provide only one kind of interface towards the visualization which can result in better maintainability. For example in our case, the Weather API component acts as a second backend.

Similarly to the Proxy component, the Python data source also needs to have those endpoints which are required by the SimpleJSON data source plugin, so this part is analogous to that in the Proxy. The effects of invoking them are slightly different than in case of the Gateway, because this Python source uses two components as backends, the 'external' API service and a separate database as described in section 3.2. So in order to get the requested data, the Python data source has to turn to both of its backends. This means, that the Python data source has to possess more sophisticated communication capabilities. It needs to be able to handle requests from Grafana, send them back, make connections to the database and query its contents and to send requests to the 'external' API service and accept the results from it.

4.2.5 Weather API

As it was already described in section 3.2 describing the sample use-case, I implemented a simple service, that can return the all-time (calculated in a heuristic way, as it was already mentioned) maximum and minimum temperatures measured in New York for a given day of the year.

This component represents the previously mentioned external service. Its responsibility is to expose a service that can be utilized by other softwares in order to acquire additional business-relevant information.

It is worth to mention, that there are already several publicly available APIs that can be used to retrieve weather related data. For example, the API services of OpenWeather[28] or AccuWeather[1]. However, these services are usually not free or only offer a free trial version, which lasts just a couple of days long. This is why I decided to make an own API service that can be used during the whole time of preparing the thesis project.

4.2.6 MySQL database

In section 3.2, it was stated, that one of the backends used by the Python data source is a separate database. This database stores the data of the measured daily maximum and minimum temperatures in New York throughout a couple of years.

Chapter 5

Implementation

In this chapter, the previously described components are explained in further details, focusing on how they are implemented, what technologies were used and in addition, some extra fine tunes are presented, which demonstrate the extendability of the open source Grafana.

The source code for the thesis project is available and can be viewed in my GitHub repository.[27]

5.1 Architecture

5.1.1 Docker

Throughout this project, I run the different components using Docker containers. For this reason, it seems appropriate to briefly introduce this technology.

A container is a standard unit of software that packages up code and all its dependencies so the application runs quickly and reliably from one computing environment to another. A Docker container image is a lightweight, standalone, executable package of software that includes everything needed to run an application: code, runtime, system tools, system libraries and settings.

Container images become containers at runtime and in the case of Docker containers - images become containers when they run on Docker Engine. Available for both Linux and Windows-based applications, containerized software will always run the same, regardless of the infrastructure. Containers isolate software from its environment and ensure that it works uniformly despite differences for instance between development and staging.[7]

5.1.2 Docker Compose

In order to be able to set up an architecture as the one described in section 4.1, I used Docker Compose.

Docker Compose is a tool for defining and running multi-container Docker applications. With Compose, we can use a YAML file to configure application's services. Then, with a single command, we can create and start all the services from the configuration.[8]

The `docker-compose.yml` file for the project can be found in the GitHub repository of the thesis project. It defines all the necessary components with the appropriate configuration.

```
2 proxy:
3   build: ./proxy
4   ports:
5     - 5000:5000
6   restart: always
7   volumes:
8     - "./proxy/proxy.py:/code/proxy.py"
9
```

Listing 5.1: Extract of the `docker-compose.yml`

5.2 Proxy (Gateway)

It was established in the design section 4.2.2, that the main responsibility of the Gateway component is to translate between the JSON data formats used by the RapidMiner Server and the Grafana SimpleJSON data source plugin.

For this task, I had two possibilities. One is to use a tool, which defines the transformation in a declarative way. For example, I could use XLST, which is able to convert a JSON format into another [5]. The other option was to implement an own algorithm which handles the transformation of the data format. I chose the latter alternative as the structure of the data was not exceptionally complex, thus it was quite simple to implement a function for this job. The other reason was that this way, I did not have to integrate another tool and call it every time to transform a simple JSON object, which in general reduced the number of possible sources for errors.

As it was described in section 4.2.2, the Gateway component must be able to handle requests from Grafana, as well as be able to forward these requests to the RapidMiner Server after the format translation.

For this task, I implemented the Gateway in Python using the `flask`[33] and the `requests`[32] packages and ran it in a Docker container. Flask is a lightweight web application framework library that enables quick and simple development. Requests can be thought of as the de facto standard for making HTTP requests in Python. It abstracts the complexities of making requests behind a simple API.

5.2.1 Endpoints

As it was explained in section 4.2.2, the Gateway component has to expose the endpoints that are required by the SimpleJSON data source plugin.

With the `requests` package, it is quite convenient to implement these endpoints, since we only have to declare a decorated function for each endpoint, as it is shown in the code snippet 5.2.

```
10 @app.route('/')
11 def check_connection():
12     response = requests.get(server_host)
13     if response.status_code == 200:
14         return 'Server connection OK'
15     return "Server connection error"
```

Listing 5.2: Test the connection to the server

5.2.1.1 Searching the targets

To be able to get the names of the available RapidMiner web services, the Gateway component should use the `/api/rest/service/list` endpoint of the RapidMiner Server. This endpoint returns the names and parameters of the web services in JSON format. The Gateway extracts the names of the services and transforms this data into a format that SimpleJSON can understand.

The endpoint is implemented as displayed in the following 5.3 code snippet.

```

16 @app.route('/search', methods=['POST'])
17 def search():
18     response = requests.get(server_host + '/api/rest/service/list',
19                             auth=('admin', 'changeit'))
20     webservices_json_list = json.loads(response.text)
21     webservice_names = []
22     for webservice in webservices_json_list:
23         webservice_names.append(webservice['name'])
24     return json.dumps(webservice_names)

```

Listing 5.3: Get the names of the web services

5.2.1.2 Acquiring the parameters

To get the available parameters of the exposed web services, the Gateway component uses the same endpoint of the RapidMiner Server (`/api/rest/service/list`), as for searching the targets.

The reason for that these two features are separated, even though they use the same endpoint, is that concerning the Gateway, the functionality of exposing the available targets is required by the SimpleJSON by default while querying the parameters is an extra feature. This means that SimpleJSON expects a specific data format, which only includes the names of the targets. Thus returning the parameters additionally with the targets would break the compatibility between the Gateway component and the SimpleJSON data source plugin.

Acquiring the parameters is implemented the following way, as in the code snippet 5.4.


```

25 @app.route('/parameters', methods=['GET'])
26 def parameters():
27     if request.args:
28         args = request.args
29         webserviceName = args.get('webserviceName')
30         if webserviceName == None:
31             raise ValueError('No value provided for "webserviceName"')
32         # get the list of webservices and get the parameters of the one with the
           name provided in the query
33         response = requests.get(server_host + '/api/rest/service/list',
34                                 auth=('admin', 'changeit'))
35         webservices_json_list = json.loads(response.text)
36         webservice_params = []
37         for webservice in webservices_json_list:
38             if webservice['name'] == webserviceName:
39                 webservice_params = webservice['parameters']
40             break
41         return json.dumps(webservice_params)
42     return 'Please provide a query parameter in the URL'
43

```

Listing 5.4: Get the parameters for a given web service

5.2.1.3 Querying the data

When Grafana sends a request to the Gateway component, it specifies the data format, in which it expects to receive the results. This can be a time series format or a table format which can be seen in the code snippets below.

```

1  [
2  {
3      "target": "
weather_retrieve_process?city=
Vancouver",
4      "datapoints": [
5          [284.63, 1573882025382],
6          [284.629, 1573885625382],
7          [284.627, 1573889225382],
8          [284.625, 1573892890284],
9          [284.623, 1573896490284],
10         [284.621, 1575746856319],
11         [284.619, 1575750456319],
12         [284.617, 1575754056319]
13     ]
14 }
15 ]
16

```

Listing 5.5: Time series format

```

1  [
2  {
3      "columns": [
4          {"text": "Month", "type": "
string"},
5          {"text": "Maxs", "type": "number
"}
6      ],
7      "rows": [
8          ['2012 October', 1],
9          ['2012 November', 1],
10         ['2012 December', 0],
11         ['2013 January', 0]
12     ],
13     "type": "table"
14 }
15 ]
16

```

Listing 5.6: Table format

The time series response format contains the target name, which in this case is the name of the RapidMiner web service with an additional parameter attached to it and the data points. The first value in a data point is the actual value, the second is the timestamp in UNIX Epoch time in milliseconds.

The table format describes the name and the type of each column in the `columns` array. The actual data is in the `rows` array, every row is defined with a list of values in an order that is correspondent to that of the columns.

5.3 Python data source

As it was mentioned in section 3.2 and section 4.2.2, the Python data source communicates with a database and a separate API service in order to prepare the requested data for Grafana.

The Python data source is also connected to Grafana, so it needs to expose the endpoints that are needed by the SimpleJSON data source plugin (discussed in section 4.2.1), which are implemented similarly as in the Gateway.

The differing ability of the Python data source compared to the Gateway component is that it can connect to a MySQL database and an external API to get the requested data by Grafana. To be able to implement these features, I used the `requests` and

the `mysql.connector` packages along with the `flask` library, which is needed to be able to send HTTP requests (as in the case of the Gateway component).

Reading the data from the MySQL database is implemented as the following pseudo code shows (5.7).

```
1  def read_data_from_db():
2      try:
3          connection = mysql.connector.connect(
4              <credentials>
5          )
6          sql_select_records_query = "SELECT * FROM newyork"
7          cursor = connection.cursor()
8          cursor.execute(sql_select_records_query)
9          records = cursor.fetchall()
10         data = []
11         for row in records:
12             record = {
13                 <parse data from a record>
14             }
15             data.append(record)
16         return data
17     except Error as error:
18         print("Error reading data from MySQL ", error)
19     finally:
20         <close the connection to the database>
21
```

Listing 5.7: Reading data from MySQL

Getting the recorded information from the 'external' Weather API is much simpler thanks to the level of abstraction the `requests` package provides. (5.8)

```
1  def get_all_time_records():
2      response = requests.get(weather_api_host + '/all')
3      json_data = json.loads(response.text)
4      return json_data
5
```

Listing 5.8: Reading data from the Weather API

After the Python data source possesses the data both from the MySQL database and the Weather API, it aggregates the collected information (`create_table_data()` function) according to the sample business-logic already discussed in section 3.2 and then exposes it on its `/query` endpoint. (5.9)

```

1 @app.route('/query', methods=['POST'])
2 def query():
3     table_data = create_table_data()
4     return json.dumps(table_data)
5

```

Listing 5.9: Exposing the prepared data

5.4 Additional features

After the integration of the two data sources, I implemented some additional features in Grafana to increase its interactivity capabilities. These are mainly developments in the graphical interface, thus they do not affect the already presented architectural model.

5.4.1 Customized Grafana Query Editor GUI

As it was already discussed in section 2.6.3, the Query Editor determines what data Grafana requests from its data sources, hence, what data will be visualized on the panel.

With the usage of the extra `/parameters` endpoint of the Gateway component, I implemented the dynamic listing of available parameters for a web service in the Query Editor of the extended SimpleJSON data source plugin.

This means that the user does not have to be familiar with the exact name or amount of the exposed parameters for a web service. When he or she chooses a target to query, Grafana asks the data source to get this information. An example of this dynamic parameter listing can be seen in Figure 5.1. There we have a RapidMiner web service called `Predictive_Maintenance_web_service_with_parameters` with two available parameters called `machineID` and `sensor1`.



Figure 5.1: Dynamic listing of available parameters

5.4.2 Dynamic bar chart in Grafana

In section 2.6.6.1, it was already discussed, that it is possible to change the time interval of the whole Dashboard by selecting a time range on a Graph Panel.

The Graph Panel offers other display possibilities as well apart from the graph diagram. It can visualize time series data with bar-charts and histograms [25]. I focused on the bar-chart format, which groups the data by series and not time, so with this type of diagram, we can display aggregated information about the series. For example the total value, the average, the maximum or the count of the data points.

However, I noticed, that when I change the time range of the Dashboard, these basic statistical indices do not get refreshed based on the new time interval. They keep their original values that were calculated for the whole time series when Grafana received the information from one of its data sources. This phenomenon can be quite misleading in cases when we have multiple Graph Panels with the same querying settings, but with different visualization modes.

To solve this issue, as a part of my thesis project, I successfully extended the built-in Graph Panel, so it calculates the aggregated values only from the data points that are in the time interval of the dashboard. This feature enables a more interactive and valuable insight of the visualized data.

To accomplish this, I used the source code of the built-in Graph Panel configured with the `webpack` module bundler which enabled the simple integration of this customized panel as a separate plugin for Grafana. [6]

5.5 Grafana Dashboard

As a final, easy to demonstrate result of the integration task of this project, I created a Dashboard in Grafana to display the collected data from various sources that can be seen in Figure 5.2. As it was already expressed in chapter 3, I used a sample data set containing information about weather in different cities in order to be able to visualize the results of the created architecture.

The Graph Panel in the middle shows the same two time series data as the five bar-chart diagrams that display some basic statistical indices in a time-dependent manner as discussed before in section 5.4.2 introducing the dynamic bar-chart.

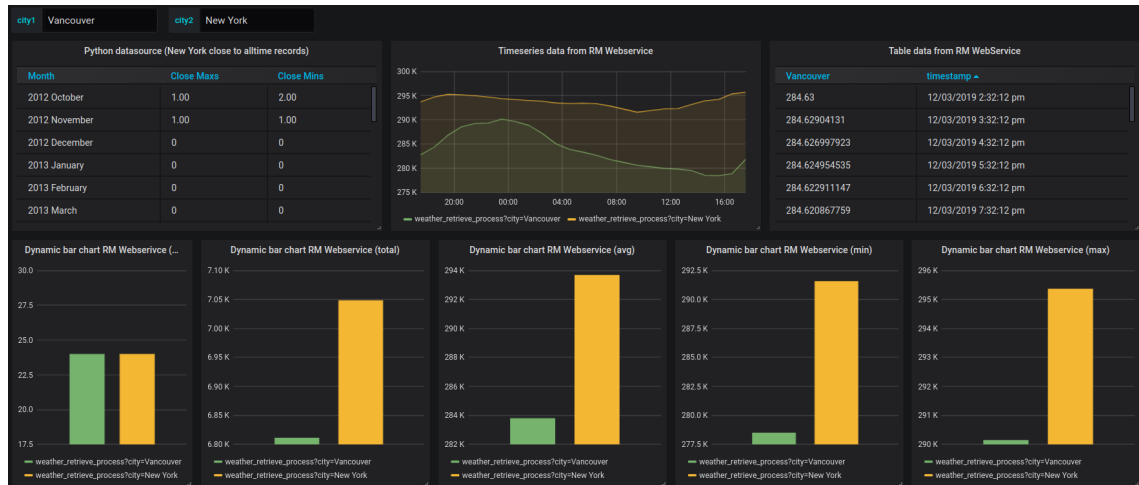


Figure 5.2: Dashboard showing the results

All the visualized data on this Dashboard comes from the RapidMiner Server component through exposed web services, except for the table in the top-left corner, which shows recorded information originating from the Python data source unit.

On the top of the Dashboard, two templating variables can be seen, which determine the two cities that we use to filter the displayed data.

Chapter 6

Evaluation

In this chapter, I present the evaluation of the implemented Gateway component, introducing its advantages and disadvantages.

6.1 Advantages

The Gateway component I created, successfully suits the declared requirements discussed in section 1.3 and 4.2.2.

It implements the necessary interfaces in order to be able to communicate with Grafana (specifically, with the SimpleJSON data source plugin). It can also send requests to its backend storage, which is a RapidMiner Server exposing multiple web services.

It conforms to the expectations of having the capabilities to transform between the data format that the RapidMiner Server uses to provide its results and the format that the SimpleJSON data source plugin requires so it can parse the requested data in order for it to be visualized in Grafana.

Furthermore, the Gateway component introduced a new feature to the built-in SimpleJSON. It enabled the querying of the available parameters for each web service, which made it possible to dynamically list them for the user, who now does not have to be familiar with the details of customizing the queries. This ability enforces the many interactivity features of Grafana.

Regarding the effectiveness of this component, there is also an operations related convenience that needs to be mentioned among its advantages. The created Gateway runs in a Docker container, which enables the simple portability of this tool, enhancing its usability in various types of environments.

6.2 Disadvantages

Despite that the Proxy component conforms to all of the expressed requirements, there are also some disadvantages that present room for further improvements.

First of all, the way it is currently realized is that it runs on a `flask` development server that enables quick progress during the implementation phase, however, it does not provide favorable performance in a production grade environment.

Concerning the data format transformation, it was discussed in section 5.2 why I did not choose an existing tool that enables defining JSON transformations in a declarative way. Yet, in order to prepare for more complex data structures in the future, it would be profitable to integrate such a tool instead of further extending my own algorithm.

Another downside of the current implementation is that it does not provide any information about the possible values of the available parameters. For example in the case of the Dashboard that was mentioned in section 5.5, the user does not know which cities can write into the text box of the variable without further knowledge about the data set. Of course, in order for this functionality to work, the backend storage would have to support it too, but nonetheless, the Gateway component could have this feature.

There is also a performance issue regarding the Gateway component which does not reside on code level, but rather in the design. There are use-cases, when the exposed processes are not time-dependent or change their results over longer periods of time, for example every day or week. Querying these processes too frequently can cause a significant unnecessary overhead for the system. Some kind of caching method would probably solve this problem, for example if the Proxy component tracked the incoming requests by the name of the web service and the attached parameters. Additionally, the backend storage would have to expose some meta information about processes of such kind, providing the usual time interval for each process after which the results are probably different as those of the previous queries.

I have to mention some security concerns too about the current realization of the Gateway component. In order to be able to query the results of the web services, one must possess the correct credentials to invoke these endpoints on the RapidMiner Server. At the moment, these credentials are hard-coded into the Proxy component, which presents a serious security vulnerability. A possible solution for this problem would be reading these sensitive information from environment variables, which are set on container startup.

6.3 Focus on time series

Grafana mainly concentrates on the visualization of time-dependent data. This can be deduced from the fact that the majority of the data sources, which Grafana supports, are storing data time series data or data with a timestamp attribute. However, despite the heavy time series focus, it is capable of working with other data formats as well.

The created Gateway component is able to handle the time series format and also the table format, which is used to display other formats of data in Grafana, for example, recorded information from a relational database.

Chapter 7

Future work

In this chapter, some possibilities for future development are discussed concerning the implemented components of this thesis project.

First of all, it must be mentioned that during this thesis project, writing optimal code for the various implementations was not priority, as the main focus of this work was the integration of different tools. Hence, a feasible enhancement could be to rewrite the custom parts and components concentrating on the performance.

7.1 Gateway

One possible development of the Gateway component could be to integrate it with the SimpleJSON data source plugin in order to create one tool to connect Rapid-Miner Server with Grafana. This would introduce several advantages compared to the current architectural setup.

Merging the Gateway component with SimpleJSON would mean, that the data format translation between these units could happen directly in Grafana. Thus, the communication overhead of the system could be reduced, as there would not be an extra component on the path of the data to be collected.

Another advantage of having one component instead of two is in regard of packaging and distribution. As it was already stated, Grafana is an open source project, meaning it heavily relies on the contribution of the community. Grafana allows the development of custom Data Sources - and also Panels - that can be published on the Grafana plugin marketplace. With an integrated component it would be easier to accomplish to have a publicly available data source plugin specifically for RapidMiner Server.

Further alternatives for improving the Proxy component can be the amendment of its disadvantages, which are discussed in section 6.2.

7.2 Dynamic Graph Panel

Concerning the time-dependent bar-chart visualization mode in the modified Graph Panel, there are also some alternatives to improve it in the future.

Currently, the extended Graph Panel displays the series defined in its Query Editor according to the time interval of the Dashboard only, when its selected visualization mode is graph-diagram (Time mode) or bar-chart (Series mode). But there exists a third mode, called Histogram. The possible improvement of this Panel could be to modify the Histogram to be time-dependent too.

Another potential enhancement would be to implement a feature that enables the possibility to switch between the time-dependent mode and the original static mode of calculating the basic statistical indices of the time series data. This would lead to the result that only one Graph Panel type would be needed, as right now, the user can choose between to original Graph Panel and the extended one, however, looking at their capabilities in general, they offer the same features.

Chapter 8

Related works

8.1 RapidMiner and Grafana

The need for retrieving and integrating data from various information sources is not new. Grafana was designed in a way to enable uncomplicated extendability capabilities through its plugin framework.

Regarding the integration of RapidMiner Server with Grafana, there was no solution for this task before this thesis work.

However, there are already multiple data source plugins available to install with Grafana [17]. As it is an open source project, developers can inspect these plugins in order to help them during the creation of other custom plugins. Still, since each data source has its own special features and communication protocols, these data source plugins rather serve as a demonstration for the achievable capabilities aside from a sample implementation of the interfaces required by Grafana.

8.2 Interactive Grafana Panels

Concerning the created dynamic bar-chart discussed in section 5.4.2, there were already some implementations aiming at the further extension of the interactivity capabilities of a Grafana Dashboard.

For example, an interactive pie chart plugin that has two main features [9]. The pie chart panel can display aggregated values of multiple time series. When we click on a slice of the pie chart, the corresponding time series is displayed in or removed from a list of Graph Panels. The other feature is that when we hover over a Graph Panel that displays an aggregated value of multiple series over time, we can inspect

the proportion of each time series on a pie chart corresponding to the given time defined by the position of the mouse-cursor.

Chapter 9

Summary

Nowadays, organizations must handle the challenging task of managing data coming from all kinds of sources with varying features including the data format, the frequency of new information records and the peculiarity of the different technologies they are built with. There are plenty of reasons why merging the data from various sources is so profitable, for example it enables the visualization of the collected data in one place in order to provide a clean, understandable way of overseeing the ongoing processes and results in a company.

In this thesis, I first conducted a brief research on the different types of data sources, introducing their distinctive characteristics and the main use-cases, where they prove to be the most effective.

Following that, I inspected the features of Grafana, an industry standard open source visualization platform, focusing on its interactivity capabilities. I discovered several means in it that allows its user to make various interactions with the displayed data ranging from zooming into time intervals to template variables. In addition, I discovered the requirements for creating custom plugins for Grafana, which granted the possibility of implementing unique features.

Afterwards, I designed and implemented an architecture with a gateway that allowed using RapidMiner Server as a data source for Grafana. I extended the built-in SimpleJSON data source plugin with the ability to query the available parameters of an exposed process in order to further increase the level of interactivity on the user side. I also created a component in Python that served as a data source for Grafana, demonstrating the usability and the reasoning of a custom middleware between the data storage backend and the visualization platform.

Furthermore, I introduced some additional enhancements concerning the graphical user interface of Grafana. It consisted of being able to dynamically list the available

parameters of a given web service and extended Graph Panel with the ability of displaying time-dependent bar-chart diagrams.

After completing the implementation, I analyzed the properties of the created Gateway component focusing on its advantages and disadvantages. Following that, I revealed some possibilities for future developments concerning the Gateway and even for the graphical interface.

Finally, I ended the thesis work with a brief discussion about related works regarding the functionality of the Gateway component and the extended user interface options.

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