

Hochschule Ulm



Masterproject

Geocoding and Routing with Pelias and Valhalla

Contributors:

Martin Schmid, Sergej Dechant

Expert: Prof. Dr. von Schwerin

Expert: Prof. Dr. Herbort

Expert: Prof. Dr. Goldstein

Wednesday 18th September, 2019

Contents

1	Project Presentation and Scope	2
1	Introduction	2
2	Requirements	3
2	Pelias	4
1	General	4
1.1	Capabilities	4
1.2	Database	6
2	System Requirements	6
2.1	Software Requirements	6
2.2	Hardware Requirements	6
3	Installation and Configuration	7
3.1	Installation with Docker	7
3.2	Installation from scratch	9
3	Data Acquisition and Preparation	12
1	Two-Digit Postcodes	12
4	Routing Engines	14
1	General	14
1.1	Comparison of Routing Engines	14
1.2	Graphopper vs Valhalla	18
1.3	Conclusion	20
2	Valhalla	20
5	Conclusion and Outlook	22

Appendix A	Pelias	26
1	Docker installation config files	26
1.1	.env-File:	26
1.2	Elasticsearch.yml-File:	26
1.3	pelias.json-File:	27
1.4	docker-compose.yml-File:	32
2	Pelias from scratch instllation guide	35
Appendix B	Valhalla Routing	46
1	Valhalla Routing Output	46

Chapter 1

Project Presentation and Scope

1 Introduction

The purpose of this paper is to document the progress of the "junior team" during the first half of the data science project in form of a technical report. Moreover, this report should allow readers to gain an understanding of the topics covered in the data science project as well as be able to reproduce and extend the developed and utilized solutions. The covered tasks during the first half of the project can be categorized into three main areas:

1. Infrastructure
 - Set up a virtual machine (Ubuntu Linux)
 - Install and configure Pelias and Elasticsearch
 - Install and evaluate different routing engines
2. Data acquisition and preparation
 - Gather postcode data of European countries from different sources
 - Merge postcode data into a single data source of Pelias and Elasticsearch
3. Geocoding and Routing
 - Test geocoding with Pelias based on precalculated two-digit postcode centroids
 - Test routing between two-digit postcode centroids with a routing engine

2 Requirements

The main requirements were to evaluate Pelias as an open source geocoding service and as an alternative to Nominatim as well as to realize routing from one two-digit postcode to another. In order to achieve this it was necessary to build a database of postcodes and create a map of Europe based on data provided by Openstreetmaps, Whosonfirst, Geonames and Postcode-info. Furthermore, routing engines as an alternative to Graphhopper had to be evaluated. Last but not least an adequate documentation on how these requirements can be fulfilled and the outcome reproduced had to be written.

Chapter 2

Pelias

1 General

1.1 Capabilities

Pelias is a software solution/library used for geocoding. Geocoding is the process of taking input text, such as an address or the name of a place and returning a latitude/longitude location on the Earth's surface for that place. The "senior team" used Nominatim for geocoding, which is a tool for geocoding just like pelias. One of our main tasks in the course of the first half of the project was to test and evaluate pelias as an alternative open-source geocoder to Nominatim.

Here are some benefits of the pelias API `TODO ZITAT EINFUEGEN` (<https://github.com/pelias/pelias>):

- Completely open-source and MIT licensed
- A powerful data import architecture: Pelias supports many open-data projects out of the box but also works great with private data
- Support for searching and displaying results in many languages
- Fast and accurate autocomplete for user-facing geocoding
- Support for many result types: addresses, venues, cities, countries, and more
- Easy installation with minimal external dependencies

As mentioned above, pelias has the ability to import data from many different open-data projects as well as own private data. The importers filter, normalize, and ingest geographic datasets into the Pelias database. Currently there are five officially supported importers TODO ZITAT EINFUEGEN (<https://github.com/pelias/pelias>):

- **OpenStreetMap:** supports importing nodes and ways from OpenStreetMap
- **OpenAddresses:** supports importing the hundreds of millions of global addresses collected from various authoritative government sources by OpenAddresses
- **Who's on First:** supports importing admin areas and venues from Who's on First
- **Geonames:** supports importing admin records and venues from Geonames
- **Polylines:** supports any data in the Google Polyline format. It's mainly used to import roads from OpenStreetMap
- **Custom Data Importer:** creates a Pelias record for each row in a CSV file. Each row must define a source, latitude, longitude, and either an address, name, or both. This feature was used to import two-digit postcodes into Pelias.

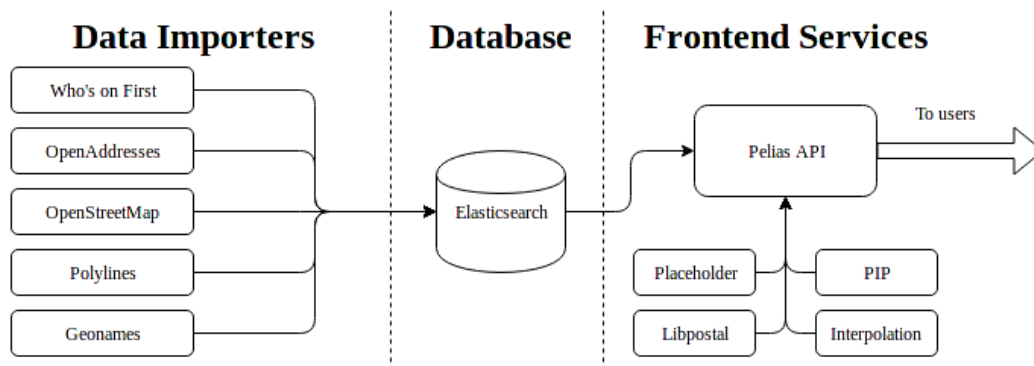


Figure 1.1: Overview of the pelias architecture

1.2 Database

The underlying datastore that powers the search results and does query-lifting is Elasticsearch. Currently version 2.4 and version 5 is supported, with plans to support Elasticsearch 6 soon. The developers built a tool called pelias-schema that sets up Elasticsearch indices properly for Pelias.

2 System Requirements

2.1 Software Requirements

- **Node.js:** Version 8 or newer is required, version 10 is recommended for improved performance.
- **Elasticsearch:** Version 2.4 or 5.6
- **SQLite:** Version 3.11 or newer
- **Libpostal:** Pelias relies heavily on the Libpostal address parser. Libpostal requires about 4GB of disk space to download all the required data.

2.2 Hardware Requirements

- At a minimum 50GB disk space to download, extract, and process data
- 8GB RAM for a local build, 16GB+ for a full planet build. Pelias needs a little RAM for Elasticsearch, but much more for storing administrative data during import
- As many CPUs as possible. There's no minimum, but Pelias builds are highly parallelizable, so more CPUs will help make it faster.

Actual system used for the project (Europe build):

- 1 virtual machine (Ubuntu Linux) with 64 GB RAM, 500GB HDD, 4 CPU cores 5

- RAM utilization is at 30 GB, however during the import of openstreetmaps data and calculating polylines from it up to 40 GB of RAM were used. Imports and calculations maxed out all CPU cores. It is possible to reduce the required amount of RAM for imports and calculations. However, this requires splitting up openstreetmap files in smaller files with other tools beforehand.
- Including “raw data” (before the import and calculations) around 400GB of data are persisted on HDD, Elasticsearch uses 100GB.

3 Installation and Configuration

Pelias can be installed as Docker Image, manually from scratch or with Kubernetes. For testing purposes installing Pelias as a Docker Images is strongly recommended by the developers [?]. Pelias can also be installed manually from scratch, but due to the large amount of dependencies this is not recommended by the developers. To use Pelias in production, the development team suggests an installation with Kubernetes, which is by far the most well tested way to install Pelias according to the development team.

3.1 Installation with Docker

On the virtual machine Pelias was installed and maintained with Docker and Docker-Compose. Install Docker and Docker-Compose:

```
sudo apt-get update
sudo apt-get install \
apt-transport-https \
    ca-certificates \
        curl \
            gnupg-agent \
                software-properties-common
curl -fsSL https://download.docker.com/linux/ubuntu/gpg
| sudo apt-key add -
sudo add-apt-repository \ "deb_[arch=amd64]_https://
download.docker.com/linux/ubuntu_\
        $(lsb_release -cs)_stable"
sudo apt-get update
```

```

sudo apt-get install docker-ce docker-ce-cli containerd
.io
sudo groupadd docker
sudo usermod -aG docker $USER
sudo systemctl enable docker
sudo curl -L "https://github.com/docker/compose/
releases/download/1.24.0/docker-compose-$(uname -s)-
$(uname -m)" -o /usr/local/bin/docker-compose
sudo chmod +x /usr/local/bin/docker-compose

```

Afterwards Pelias can be installed by cloning Pelias' git repository. In this repository Pelias' developers provide example projects (e.g. Beligum, Portland Metro, etc.). Pelias' "planet" project was used as a starting point for a Europe build. For this Pelias was forked on Github and cloned onto the VM. The project can be found in the following folder:

```
/home/dataproject/git/pelias-docker/projects/Europe
```

In order to build and run Pelias with data for Europe four configuration files in this folder are needed:

1. .env
2. Elasticsearch.yml
3. pelias.json
4. docker-compose.yml

The files can be found in the appendix on page 26.

In .env DATA_DIR and DOCKER_USER are important entries/variables. DATA_DIR specifies where Pelias will store downloaded data and build its other services. DOCKER_USER specifies the user id. This user id will be used for accessing files on the host filesystem in DATA_DIR since Pelias' processes run as non-root users in containers. In Elasticsearch.yml both thread pool sizes had to be increased since the default values were too small. Pelias importers delivered too much data concurrently for Elasticsearch which resulted in corrupted data. In pelias.json all Pelias services are configured. These services run as docker containers. Therefore, it is not necessary to provide complete full paths on the host filesystem or IP/DNS addresses. Paths are mapped to the paths provided in the docker compose file and

.env file. Docker has its own networking and DNS. Services in a docker network can be addressed by using docker compose service names as well as container names and ids. Container ports can be mapped to host ports. The variables DOCKER_USER and DATA_DIR in docker-compose.yml are mapped to the corresponding entries in .env. Inside containers pelias.json is made available in /code/pelias.json. Ports are mapped in the following way: hostport:containerport. The "image" directive tells docker from where it has to pull the container image. In this case all images are pulled from the Pelias repository on Docker-Hub. After the colon a tag is specified (e.g. master or a version/hash). If no tag is provided, the latest version will be pulled. With this configuration it is possible to build Europe completely with the following commands and order (cd to Europe project folder first):

```
pelias compose pull
pelias elastic start
pelias elastic wait
pelias elastic create
pelias download all
pelias prepare all
pelias import all
pelias compose up
```

3.2 Installation from scratch

In order to do a clean installation of the pelias service and its dependencies on a production server at a later point in time we decided to try the installation from scratch and wrote an installation guide. The complete guide can be found in the appendix on page 35. We did the installation on a Linux VM running Ubuntu 18.04.

Installing Dependencies

Node.js: Version 8 or newer required, version 10 recommended

```
curl -sL https://deb.nodesource.com/setup_10.x | sudo -  
E bash -  
sudo apt-get install -y nodejs
```

Elasticsearch: Version 2.4 or 5.6

```
wget -qO - https://artifacts.elastic.co/GPG-KEY-
    elasticsearch | sudo apt-key add -
echo "deb https://artifacts.elastic.co/packages/5.x/apt
    _stable_main" | sudo tee -a /etc/apt/sources.list.d/
    elastic-5.x.list
sudo apt update && sudo apt upgrade
sudo apt install apt-transport-https uuid-runtime pwgen
    openjdk-8-jre-headless
sudo apt-get update
sudo apt update
sudo apt install elasticsearch
```

SQLite: Version 3.11 or newer

```
sudo apt-get update
sudo apt-get install sqlite3
sqlite3 --version
sudo apt-get install sqlitebrowser
```

Libpostal: In order to install libpostal you will have to manually compile the source code.

```
sudo apt-get install curl autoconf automake libtool pkg
    -config
cd /
git clone https://github.com/openvenues/libpostal
cd libpostal
./bootstrap.sh
./configure --datadir=[...some dir with a few GB of
    space...]
make -j4
sudo make install
sudo ldconfig
```

Installing Pelias

Once you are done installing all the dependencies and downloaded the data for your pelias build you can start installing pelias itself.

```
for repository in schema whosonfirst geonames
    openaddresses openstreetmap polylines api
```

```
placeholder interpolation pip-service; do  
git clone https://github.com/pelias/${repository}.git #  
    clone from Github  
pushd $repository > /dev/null # switch into importer  
    directory  
npm install # install npm dependencies  
popd > /dev/null # return to code directory  
done
```

After the installation you will have to set up the elasticsearch schema in order to use pelias.

```
cd /pelias/schema # assuming you have just run the bash  
    snippet to download the repos from earlier  
./bin/create_index
```

Chapter 3

Data Acquisition and Preparation

1 Two-Digit Postcodes

CSV Data provided by geonames.org [?] and postcode.info, which was scrapped and provided by a fellow student [?], was used as basis for calculating two-digit postcodes for European countries. At the first iteration two-digit postcodes were calculated from Geonames data. In order to achieve this Python scripts were written [?]. These scripts process a Geonames CSV file and provide a new CSV file with two-digits postcodes including their centroids. Here is an example of six calculated two-digit postcodes in Germany:

DE80	geonames2d	80	postalcode	48.1615	11.5509
DE81	geonames2d	81	postalcode	48.1254	11.5726
DE82	geonames2d	82	postalcode	47.911	11.2502
DE83	geonames2d	83	postalcode	47.8713	12.2803
DE84	geonames2d	84	postalcode	48.4086	12.4327
DE85	geonames2d	85	postalcode	48.4174	11.6308

Table 3.1: Geonames Two-Digit Postcodes

At the second iteration Geonames and Postcode data were combined after having done some preparation steps on the Postcode data. Again Python scripts were written [?]. Here is an excerpt:

DE80	geonamesandpostcodeinfo	80	postalcode	48.1512	11.5938
DE81	geonamesandpostcodeinfo	81	postalcode	48.1331	11.6046
DE82	geonamesandpostcodeinfo	82	postalcode	47.9419	11.2759
DE83	geonamesandpostcodeinfo	83	postalcode	47.888	12.2627
DE84	geonamesandpostcodeinfo	84	postalcode	48.4367	12.4206
DE85	geonamesandpostcodeinfo	85	postalcode	48.4171	11.6294

Table 3.2: Geonames and Postcode.info Two-Digit Postcodes

Comparing these two tables one can see that the coordinates changed slightly. This is due to the fact that now two different data sources were used for the calculation of centroids resulting in more accurate coordinates. Postcodes in Malta were aggregated and their centroids calculated using the first three digits as requested by one of the project’s experts.

Chapter 4

Routing Engines

1 General

The Pelias API and Pelias services are only suited for the purpose of geocoding and reverse geocoding. Geocoding retrieves coordinates (latitude and longitude) for a given address or postcode and reverse geocoding finds the nearest known address or postcode for a provided pair of latitude and longitude. In order to find the shortest or fastest route between two given addresses Pelias has to be used in conjunction with a routing engine. The two addresses are fed into Pelias and Pelias provides coordinates for them which are then used as input values for finding a route from one coordinate to the other using a routing engine and the metrics inside the routing engine. The senior team used the routing engine Graphhopper in connection with their geocoding service Nominatim. Graphhopper as you will see later in this report is a very good and fast routing engine, however the developers of the Pelias service recommend using the routing engine Valhalla which is developed by the same company (Mapzen) as Pelias and therefore has better service interoperability with Pelias than any other routing engine.

1.1 Comparison of Routing Engines

Part of this project was to research and evaluate possible routing engines for Pelias. Internet research conducted by the junior team revealed a comparison of open source routing engines which was done by one of the members of Openstreetmaps. The following two figures illustrate the required computing

time (in ms) to calculate a route depending on the length of the route (in km)[?]:

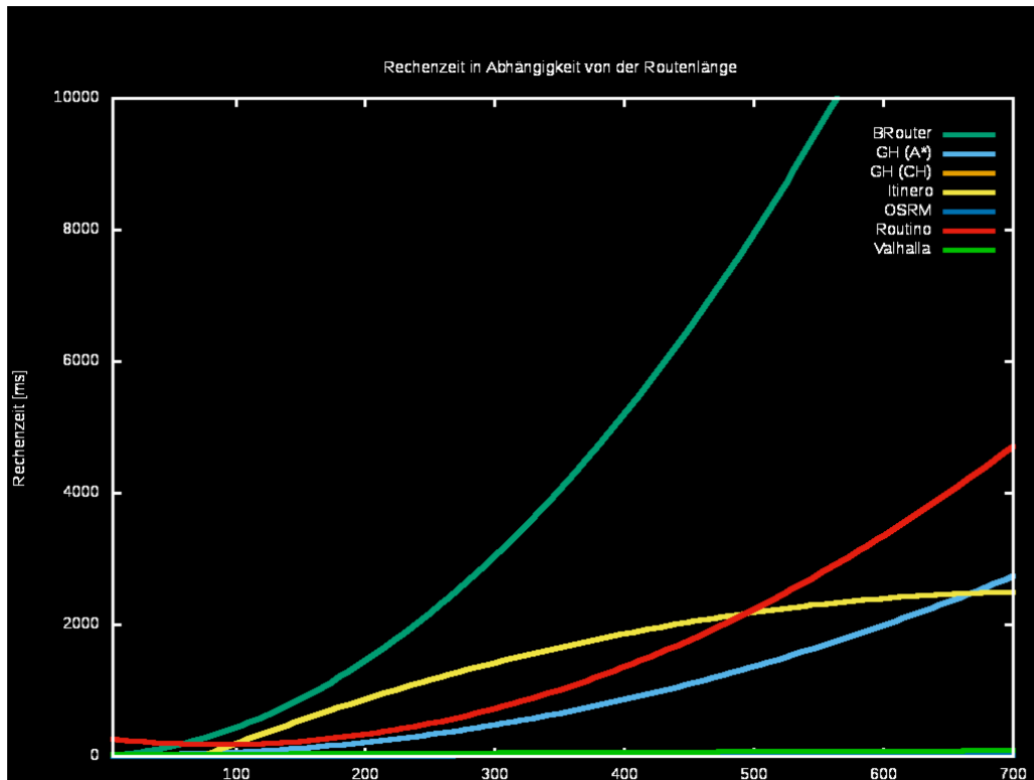


Figure 1.1: Comparison of all open source Routing Engines

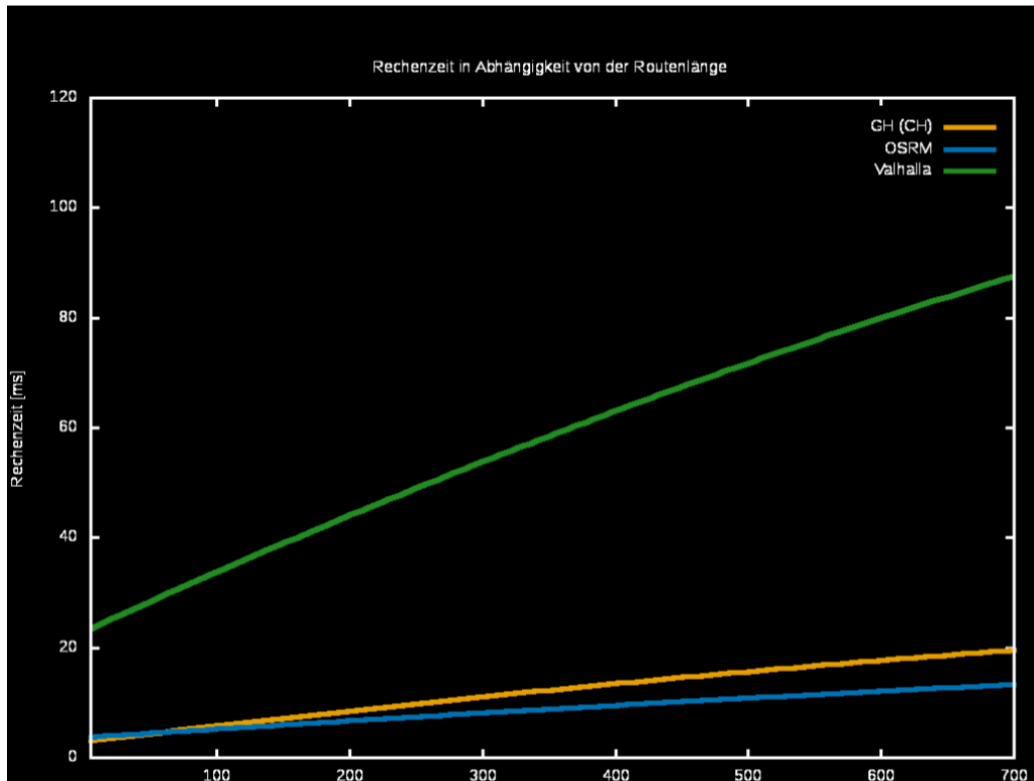


Figure 1.2: Comparison of fastest open source Routing Engines

As can be seen, Graphhopper (GH), Open Source Routing Machine (OSRM) and Valhalla are the best-performing open source routing engines. Therefore, a closer look can be taken at those three in the table 4.1.

Table 4.1: Comparison of Routing Engines

Comparison Criteria	Graphhopper	Valhalla	OSRM
License	Apache-License (proprietary in parts)	MIT license	BSD license
OS	Java (also Android, iOS)	C++, Apple/Linux	C++ (NodeJS), Apple/Linux/Windows
Continued on next page			

Table 4.1: Comparison of Routing Engines (Continued)

Comparison Criteria	Graphhopper	Valhalla	OSRM
Algorithm	Contraction Hierarchies, Dijkstra/A*, Hybrid	A* with individual improvements	Contraction Hierarchies
Documentation & Setup	Good documentation, ‘quick start’	Good documentation, ‘quick start’, ubuntu repository with web-frontend	Good documentation, setup with docker or self-compiled
Routing-features	Turn restriction (A*), guidepost, alternatives, height data optional	Turn restriction, guidepost, height data optional	Turn restriction (A*), driving lanes, guidepost, alternatives, no height data
Special Features	Track Matching, cost != time, TSP with jsprit	Tile-based data storage, dynamic cost, matrix, isochrones, intermodal, Designed for working with OpenStreetMap	Matrix, track matching, TSP, data tiles, cost != time

Unfortunately OSRM has very high hardware requirements[?]. Pre-processing the car profile requires at least 175 GB of RAM and 280 GB of disk space. Additionally, 35 GB are needed for the planet osm.pbf (Openstreetmaps) and 40 to 50 GB for the generated data files. For the foot profile 248 GB of RAM are needed. During runtime the car profile requires around 64 GB of RAM, the foot profile even more. Basically OSRM loads the pre-processed files completely into RAM[?]. The project team’s VM had only 64 GB of RAM and half of it was already used for Pelias and Elasticsearch. Hence, it was not possible to install OSRM and evaluate it completely.

1.2 Graphhopper vs Valhalla

We performed an in-depth comparison of the time it takes for routing from one point to another with Graphhopper and Valhalla. The results of these test series can be seen in the table 4.2.

Table 4.2: Graphhopper vs. Valhalla test row

		Route 1	Route 2	Route 3	Route 4	Route 5	Route 6
	Route from	Catania, Italy Latitude: 37.502236 Longitude: 15.08738	1100-148 Lisbon, Portugal Latitude: 38.707751 Longitude: -9.136592	Ulm, Baden-Württemberg, Germany Latitude: 48.3974 Longitude: 9.993434	Paris, France Latitude: 48.856697 Longitude: 2.351462	37011 Bardolino VR, Italy Latitude: 45.553553 Longitude: 10.637519	North Cape, E 69, Norway Latitude: 71.169951 Longitude: 25.785889
	Route to	1357 Copenhagen, Denmark Latitude: 55.686724 Longitude: 12.570072	Warsaw, Warszawa, Poland Latitude: 52.231924 Longitude: 21.006727	Munich, Bavaria, Germany Latitude: 48.137108 Longitude: 11.575382	Venice, Venezia, Italy Latitude: 45.437191 Longitude: 12.33459	Gunterstraße 8, 70191 Stuttgart, Germany Latitude: 48.806576 Longitude: 9.178105	89032 Bianco RC, Italy Latitude: 38.087176 Longitude: 16.148511
GH	first try	real 0m0.735s user 0m0.013s sys 0m0.006s	real 0m0.300s user 0m0.016s sys 0m0.006s	real 0m0.031s user 0m0.004s sys 0m0.011s	real 0m0.083s user 0m0.016s sys 0m0.000s	-	real 0m0.261s user 0m0.013s sys 0m0.011s
	second try	real 0m0.188s user 0m0.019s sys 0m0.000s	real 0m0.407s user 0m0.014s sys 0m0.005s	real 0m0.022s user 0m0.014s sys 0m0.000s	real 0m0.042s user 0m0.014s sys 0m0.004s	-	real 0m0.216s user 0m0.024s sys 0m0.004s
Continued on next page							

Table 4.2: Graphhopper vs. Valhalla test row (Continued)

		Route 1	Route 2	Route 3	Route 4	Route 5	Route 6
	dis- tance (in km)	2753	3318	139	1113	-	5112
VH	first try	real 0m2.098s user 0m0.014s sys 0m0.013s	real 0m4.805s user 0m0.013s sys 0m0.021s	real 0m0.668s user 0m0.012s sys 0m0.006s	real 0m3.121s user 0m0.020s sys 0m0.003s	real 0m1.037s user 0m0.012s sys 0m0.009s	real 0m1.784s user 0m0.030s sys 0m0.003s
	sec- ond try	real 0m0.279s user 0m0.018s sys 0m0.008s	real 0m0.498s user 0m0.030s sys 0m0.003s	real 0m0.083s user 0m0.014s sys 0m0.004s	real 0m0.571s user 0m0.014s sys 0m0.008s	real 0m0.086s user 0m0.017s sys 0m0.005s	real 0m0.607s user 0m0.026s sys 0m0.008s
	dis- tance (in km)	2682	3408	141	1116	579	4996
	re- mark					Coordinates of the starting point in the middle of lake garda. Graph- hopper couldn't calculate a route	

The API requests were executed directly on the Graphhopper and Valhalla host machines using the command line programs time and curl. We

can see, that Graphhopper compared to Valhalla does a significantly better job when calculating a new route for the very first time. The execution time in Valhalla varies from the first calculation to the second calculation by up to the factor of ten. This means calculating a route or part of it, which has already been calculated before, the execution time is almost ten times faster compared to the first calculation. Valhalla achieves this with caching routes in RAM. Graphhopper however has a problem, if there is no road or street to be routed from or to for a given start- or end-point. Valhalla in this case just takes the closest routable point instead. Choosing one routing engine over the other depends on the goal which should be achieved. For fastest execution time (not regarding first or second execution) Graphhopper fits best. If you want to make sure, that you receive a route whichever point you calculate from or to, then it is recommended to use Valhalla.

1.3 Conclusion

OSRM is the fastest routing engine on the open-source market. But because of the very high memory requirements of OSRM it is not suitable for the use-case of our project and the cost/benefit-factor is too low. Valhalla would be a good alternative to Graphhopper, because it is compared to other routing engines nearly as fast as Graphhopper and is designed to work with Openstreetmaps-data and also recommended by the Pelias developers to be used in connection with Pelias as a geocoder. Also Valhalla is capable of routing from or to points, which do not have a road or street directly nearby. A very valuable feature especially for two-digit postcode centroids, which Graphhopper does not have. However, in this early state of the project Graphhopper totally fits all the needs and therefore there is no need in replacing Graphhopper with Valhalla.

2 Valhalla

Valhalla was installed and configured according to the official documentation on Github [?]. Tiles and polylines were calculated using the same openstreetmaps pbf file (Europe) which was already used for Pelias. Routing can be achieved by querying Valhalla's api:

```
curl http://141.59.29.110:8002/route --data '{  
  "locations":[{"lat":48.1331,"lon":11.6046,"type":}
```

```
break"}},{ "lat":47.9419,"lon":11.2759,"type":"break
"}], "costing":"auto", "directions_options":{"units":"
km"}}}' | jq '.'
```

Result:

```
1  "summary": {
2    "max_lon": 11.605507,
3    "max_lat": 48.133167,
4    "time": 2397,
5    "length": 38.536,
6    "min_lat": 47.943157,
7    "min_lon": 11.260186
8  },
9  "locations": [
10   {
11     "original_index": 0,
12     "type": "break",
13     "lon": 11.6046,
14     "lat": 48.133099,
15     "side_of_street": "right"
16   },
17   {
18     "original_index": 1,
19     "type": "break",
20     "lon": 11.2759,
21     "lat": 47.941898,
22     "side_of_street": "right"
23   }
24 ]
```

The complete output and routing instructions are in the appendix page 46.

Chapter 5

Conclusion and Outlook

The requirements described in chapter 1 section 2 were achieved completely. We installed Pelias and all of its' services as a docker image as well as a from scratch installation. The Team built a complete map of Europe based on data provided by OpenStreetmaps, WhosOnFirst and OpenAddresses. Furthermore, we calculated tiles and polylines based on OpenStreetmaps data. This process initially failed, since calculating polylines for complete Europe requires more than 32 GB of RAM-Memory. After an upgrade of the virtual machine to 64 GB this step finished successfully. During the calculation and import steps several bugs in Pelias were found and submitted. Luckily, they were fixed, or workarounds were provided within a few days.

The postcode data was gathered from Geonames.org and Postcode.info. The data from Geonames.org can be downloaded as ZIP-files separated in Countries, or as one single ZIP-file which contains the whole world. The data from Postcode.info had to be scraped from their website by our fellow student Ankur Mehra. After the data from Geonames.org and Postcode.info had been merged, we could calculate the 2-digit postcodes and import our newly generated data basis as a custom data-source into Pelias and Elasticsearch. On this data basis we can now do geocoding in Pelias for 2-digit postcodes in Europe. We did research on several routing engines and decided to use Valhalla as an alternative to the already existing Graphhopper which is used by the senior team. Valhalla offers similar performance for cached data/routes (including start and end points in the vicinity of previously used coordinates) as Graphhopper with a good trade-off between resource requirements and performance/time to calculate a route. Furthermore, polylines calculated from OpenStreetmaps data with Pelias' tools can be used in Valhalla

and vice versa.

All in all, we can say, that the first semester of our project has been successful, and we reached our overall goal of testing Pelias as an alternative to Nominatim. Most of our tasks were finished, although some tasks couldn't be finished during the last sprint. Those tasks are mainly concerned about a VPN connection to the cluster of computers located at campus Albert-Einstein-Allee. As soon as those tasks are finished successfully, we could proceed with installing an instance of our Pelias build on the cluster and run this build as some kind of production-system. However in the coming project phase we will probably be more focused on data analytics and machine learning depending on the product owners requirements.

B Illustration Directory

1.1	Overview of the pelias architecture	5
1.1	Comparison of all open source Routing Engines	15
1.2	Comparison of fastest open source Routing Engines	16

List of Tables

3.1	Geonames Two-Digit Postcodes	12
3.2	Geonames and Postcode.info Two-Digit Postcodes	13
4.1	Comparison of Routing Engines	16
4.1	Comparison of Routing Engines (Continued)	17
4.2	Graphhopper vs. Valhalla test row	18
4.2	Graphhopper vs. Valhalla test row (Continued)	19

Appendix A

Pelias

1 Docker installation config files

1.1 .env-File:

```
1 COMPOSE_PROJECT_NAME=pelias
2 DATA_DIR=/data/pelias-docker-compose/
3 DOCKER_USER=1003
4 ENABLE_GEONAMES=true
5 DATA_DIR: directory where Pelias will store
   downloaded data. Also used to build its
   other services.
6 DOCKER_USER = All Pelias processes in
   containers run as non-root users. This
   user ID will be used for accessing files
   on the host filesystem in DATA_DIR.
```

1.2 Elasticsearch.yml-File:

```
1 network.host: 0.0.0.0
2 bootstrap.memory_lock: true
3 indices.breaker fielddata.limit: 85%
4 indices.fielddata.cache.size: 75%
5 thread_pool.bulk.queue_size: 500
```

```
6 thread_pool.index.queue_size: 1000
```

1.3 pelias.json-File:

```
1 {
2   "logger": {
3     "level": "info",
4     "timestamp": false
5   },
6   "esclient": {
7     "apiVersion": "2.4",
8     "hosts": [
9       {
10        "host": "elasticsearch"
11      }
12    ]
13  },
14  "elasticsearch": {
15    "settings": {
16      "index": {
17        "refresh_interval": "10s",
18        "number_of_replicas": "0",
19        "number_of_shards": "5"
20      }
21    }
22  },
23  "acceptance-tests": {
24    "endpoints": {
25      "docker": "http://api:4000/v1/"
26    }
27  },
28  "api": {
29    "targets": {
30      "canonical_sources": [
31        "whosonfirst",
32        "openstreetmap",
33        "openaddresses",
```

```

34         "geonames",
35         "geonamesandpostcodeinfo"
36     ],
37     "layers_by_source": {
38         "geonames2d": [
39             "country",
40             "postalcode",
41             "source",
42             "layer"
43         ],
44         "geonamesandpostcodeinfo": [
45             "name",
46             "source",
47             "layer",
48             "lat",
49             "lon",
50             "country",
51             "postalcode"
52         ],
53         "openstreetmap": [
54             "address",
55             "venue",
56             "street"
57         ],
58         "openaddresses": [
59             "address"
60         ],
61         "geonames": [
62             "country",
63             "macroregion",
64             "region",
65             "county",
66             "localadmin",
67             "locality",
68             "borough",
69             "neighbourhood",
70             "venue",
71             "postalcode"

```

```

72     ],
73     "whosonfirst": [
74         "continent",
75         "empire",
76         "country",
77         "dependency",
78         "macroregion",
79         "region",
80         "locality",
81         "localadmin",
82         "macrocounty",
83         "county",
84         "macrohood",
85         "borough",
86         "neighbourhood",
87         "microhood",
88         "disputed",
89         "venue",
90         "postalcode",
91         "continent",
92         "ocean",
93         "marinearea"
94     ]
95 },
96 "source_aliases": {
97     "osm": [
98         "openstreetmap"
99     ],
100    "oa": [
101        "openaddresses"
102    ],
103    "gn": [
104        "geonames"
105    ],
106    "wof": [
107        "whosonfirst"
108    ],
109    "2dpg": [

```

```

110         "geonames2d"
111     ]
112 }
113 },
114 "textAnalyzer": "libpostal",
115 "services": {
116     "pip": {
117         "url": "http://pip:4200"
118     },
119     "libpostal": {
120         "url": "http://libpostal:4400"
121     },
122     "placeholder": {
123         "url": "http://placeholder:4100"
124     },
125     "interpolation": {
126         "url": "http://interpolation:4300"
127     }
128 },
129 "defaultParameters": {
130     "focus.point.lat": 48.88,
131     "focus.point.lon": 2.32
132 }
133 },
134 "imports": {
135     "adminLookup": {
136         "enabled": true
137     },
138     "geonames": {
139         "datapath": "/data/geonames",
140         "countryCode": "ALL",
141         "sourceURL": "http://download.geonames.org/
            export/dump/"
142     },
143     "openstreetmap": {
144         "download": [
145             {

```



```

146         "sourceURL": "https://download.geofabrik.
           de/europe-latest.osm.pbf"
147     }
148 ],
149     "leveldbpath": "/tmp",
150     "datapath": "/data/openstreetmap",
151     "import": [
152         {
153             "filename": "europe-latest.osm.pbf"
154         }
155     ]
156 },
157     "openaddresses": {
158         "datapath": "/data/openaddresses",
159         "files": [
160         ]
161     },
162     "polyline": {
163         "datapath": "/data/polylines",
164         "files": [
165             "europe.polyline"
166         ]
167     },
168     "whosonfirst": {
169         "datapath": "/data/whosonfirst",
170         "sqlite": true,
171         "importVenues": false,
172         "importPostalcodes": true
173     },
174     "csv": {
175         "datapath": "/data/geonamesandpostcodeinfo/",
176         "files": [],
177         "download": []
178     }
179 }
180 }

```

1.4 docker-compose.yml-File:

```
1 version: '3'
2 networks:
3   default:
4     driver: bridge
5 services:
6   libpostal:
7     image: pelias/libpostal-service
8     container_name: pelias_libpostal
9     user: "${DOCKER_USER}"
10    restart: always
11    ports: [ "4400:4400" ]
12  schema:
13    image: pelias/schema:master
14    container_name: pelias_schema
15    user: "${DOCKER_USER}"
16    volumes:
17      - "./pelias.json:/code/pelias.json"
18  api:
19    image: pelias/api:master
20    container_name: pelias_api
21    user: "${DOCKER_USER}"
22    restart: always
23    environment: [ "PORT=4000" ]
24    ports: [ "4000:4000" ]
25    volumes:
26      - "./pelias.json:/code/pelias.json"
27  placeholder:
28    image: pelias/placeholder:master
29    container_name: pelias_placeholder
30    user: "${DOCKER_USER}"
31    restart: always
32    environment: [ "PORT=4100" ]
33    ports: [ "4100:4100" ]
34    volumes:
35      - "./pelias.json:/code/pelias.json"
36      - "${DATA_DIR}:/data"
```

```

37     - "./blacklist/:/data/blacklist"
38 whosonfirst:
39     image: pelias/whosonfirst:master
40     container_name: pelias_whosonfirst
41     user: "${DOCKER_USER}"
42     volumes:
43     - "./pelias.json:/code/pelias.json"
44     - "${DATA_DIR}:/data"
45     - "./blacklist/:/data/blacklist"
46 openstreetmap:
47     image: pelias/openstreetmap:relations_bugfix-201
48         9-04-25-cc778095371c142147e31249947a3b43fb57d
49         46d
48     container_name: pelias_openstreetmap
49     user: "${DOCKER_USER}"
50     volumes:
51     - "./pelias.json:/code/pelias.json"
52     - "${DATA_DIR}:/data"
53     - "./blacklist/:/data/blacklist"
54 openaddresses:
55     image: pelias/openaddresses:master
56     container_name: pelias_openaddresses
57     user: "${DOCKER_USER}"
58     volumes:
59     - "./pelias.json:/code/pelias.json"
60     - "${DATA_DIR}:/data"
61     - "./blacklist/:/data/blacklist"
62 geonames:
63     image: pelias/geonames:master
64     container_name: pelias_geonames
65     user: "${DOCKER_USER}"
66     volumes:
67     - "./pelias.json:/code/pelias.json"
68     - "${DATA_DIR}:/data"
69     - "./blacklist/:/data/blacklist"
70 csv-importer:
71     image: pelias/csv-importer:master
72     container_name: pelias_csv_importer

```

```

73     user: "${DOCKER_USER}"
74     volumes:
75         - "./pelias.json:/code/pelias.json"
76         - "${DATA_DIR}:/data"
77         - "./blacklist/::data/blacklist"
78     transit:
79         image: pelias/transit:master
80         container_name: pelias_transit
81         user: "${DOCKER_USER}"
82         volumes:
83             - "./pelias.json:/code/pelias.json"
84             - "${DATA_DIR}:/data"
85     polylines:
86         image: pelias/polylines:master
87         container_name: pelias_polylines
88         user: "${DOCKER_USER}"
89         volumes:
90             - "./pelias.json:/code/pelias.json"
91             - "${DATA_DIR}:/data"
92     interpolation:
93         image: pelias/interpolation:master
94         container_name: pelias_interpolation
95         user: "${DOCKER_USER}"
96         restart: always
97         environment: [ "PORT=4300" ]
98         ports: [ "4300:4300" ]
99         volumes:
100             - "./pelias.json:/code/pelias.json"
101             - "${DATA_DIR}:/data"
102     pip:
103         image: pelias/pip-service:master
104         container_name: pelias_pip-service
105         user: "${DOCKER_USER}"
106         restart: always
107         environment: [ "PORT=4200" ]
108         ports: [ "4200:4200" ]
109         volumes:
110             - "./pelias.json:/code/pelias.json"

```

```

111     - "${DATA_DIR}:/data"
112   elasticsearch:
113     image: pelias/elasticsearch
114     container_name: pelias_elasticsearch
115     restart: always
116     environment: [ "ES_JAVA_OPTS=-Xmx12g" ]
117     ports: [ "9200:9200", "9300:9300" ]
118     volumes:
119       - "./elasticsearch.yml:/usr/share/
120         elasticsearch/config/elasticsearch.yml:ro"
121       - "${DATA_DIR}/elasticsearch:/usr/share/
122         elasticsearch/data"
123   ulimits:
124     memlock:
125       soft: -1
126       hard: -1
127     nofile:
128       soft: 65536
129       hard: 65536
130   cap_add: [ "IPC_LOCK" ]
131   fuzzy-tester:
132     image: pelias/fuzzy-tester:master
133     container_name: pelias_fuzzy_tester
134     user: "${DOCKER_USER}"
135     restart: "no"
136     command: "--help"
137     volumes:
138       - "./pelias.json:/code/pelias.json"
139       - "./test_cases:/code/pelias/fuzzy-tester/
140         test_cases"

```

2 Pelias from scratch instllation guide

```

1 Dependencies:
2 1. Node.js:
3 Version 8 or newer required, version 10 recommended

```

```

4 Ubuntu or Debian:
5 Node.js v11.x:
6 # Using Ubuntu
7 curl -sL https://deb.nodesource.com/setup_11.x |
  sudo -E bash -
8 sudo apt-get install -y nodejs
9 # Using Debian, as root
10 curl -sL https://deb.nodesource.com/setup_11.x |
  bash -
11 apt-get install -y nodejs
12 Node.js v10.x:
13 # Using Ubuntu
14 curl -sL https://deb.nodesource.com/setup_10.x |
  sudo -E bash -
15 sudo apt-get install -y nodejs
16 # Using Debian, as root
17 curl -sL https://deb.nodesource.com/setup_10.x |
  bash -
18 apt-get install -y nodejs
19 CentOS:
20 NodeJS 11.x
21 curl -sL https://rpm.nodesource.com/setup_11.x |
  bash -
22 NodeJS 10.x
23 curl -sL https://rpm.nodesource.com/setup_10.x |
  bash -
24     Optional: install build tools
25     To compile and install native addons from
      npm you may also need
26     to install build tools:
27 yum install gcc-c++ make
28 # or: yum groupinstall 'Development Tools'
29 2. Elasticsearch:
30 Version 2.4 or 5.6
31 wget -qO - https://artifacts.elastic.co/GPG-KEY-
  elasticsearch | sudo apt-key add -
32 echo "deb https://artifacts.elastic.co/packages/5.x/
  apt stable main" | sudo tee -a /etc/apt/sources.

```

```

    list.d/elastic-5.x.list
33 sudo apt update && sudo apt upgrade
34 sudo apt install apt-transport-https uuid-runtime
    pwgen openjdk-8-jre-headless
35 sudo apt-get update
36 sudo apt update
37 sudo apt install elasticsearch
38 mkdir /elasticsearch
39 mkdir /elasticsearch/data
40 mkdir /elasticsearch/logs
41 make sure elasticsearch has rights to access the
    folders:
42 sudo chown -R elasticsearch:elasticsearch /
    elasticsearch
43 if you get Errors like:
44     ERROR Null object returned for RollingFile
        in Appenders
45 that most likely means that elasticsearch doesn't
    have permissions to access the logs and data
    folders.
46 After the installation, a default configuration file
    will be populated to
47 /etc/elasticsearch/elasticsearch.yml
48 Most lines are commented out, edit the file to tweak
    and tune the configuration.
49 E.g, you can set correct cluster name for your
    applications:
50 cluster.name: my-application
51 Recommended Settings:
52 cluster.name: pelias-el-search
53 path.data: /elasticsearch/data
54 path.logs: /elasticsearch/logs
55 network.host: 127.0.0.1
56 http.port: 9200
57 Note that the default minimum memory set for JVM is
    2gb, if your server has small memory size, change
    this value:
58 $ sudo vim /etc/elasticsearch/jvm.options

```

```

59 Change:
60 -Xms2g
61 -Xmx2g
62 And set your values for minimum and maximum memory
    allocation. E.g to set values to 512mb of ram,
    use:
63 -Xms512m
64 -Xmx512m
65 After you have modified the configuration, you can
    start Elasticsearch:
66 $ sudo systemctl daemon-reload
67 $ sudo systemctl enable elasticsearch.service
68 $ sudo systemctl restart elasticsearch.service
69 Check status:
70 $ sudo systemctl status elasticsearch.service
71 elasticsearch.service - Elasticsearch
72 Loaded: loaded (/usr/lib/systemd/system/
    elasticsearch.service; disabled; vendor preset:
    enabled)
73 Active: active (running) since Sun 2019-05-01 10:39:
    54 UTC; 18s ago
74 Docs: http://www.elastic.co
75 Process: 14314 ExecStartPre=/usr/share/elasticsearch
    /bin/elasticsearch-systemd-pre-exec (code=exited,
    status=0/SUCCESS)
76 Main PID: 14325 (java)
77 Tasks: 38 (limit: 2362)
78 CGroup: /system.slice/elasticsearch.service
79 14325 /usr/bin/java -Xms512m -Xmx512m -XX:+
    UseConcMarkSweepGC -XX:
    CMSInitiatingOccupancyFraction=75 -XX:+
    UseCMSInitiatingOccupancyOnly -X
80 That's all for the installation of Elasticsearch 5.x
    on Ubuntu 18.04 LTS (Bionic Beaver) Linux.
81 3. SQLite:
82 Version 3.11 or newer
83 sudo apt-get update
84 sudo apt-get install sqlite3

```



```

85 sqlite3 --version
86 sudo apt-get install sqlitebrowser
87 4.Libpostal:
88 sudo apt-get install curl autoconf automake libtool
      pkg-config
89 cd /
90 git clone https://github.com/openvenues/libpostal
91 cd libpostal
92 ./bootstrap.sh
93 ./configure --datadir=[...some dir with a few GB of
      space...]
94 make -j4
95 sudo make install
96
97 # On Linux it's probably a good idea to run
98 sudo ldconfig
99 Pelias:
100 Data:
101 Download all the rawdata you need and copy it into
      respective folders such as
102 "/data/rawdata/whosonfirst",
103 "/data/rawdata/geonames",
104 "/data/rawdata/openaddresses",
105 "/data/rawdata/openstreetmap",
106 "/data/rawdata/polylines"
107 Pelias:
108 mkdir /pelias
109 cd /pelias
110 for repository in schema whosonfirst geonames
      openaddresses openstreetmap polylines api
      placeholder interpolation pip-service; do
111     git clone https://github.com/pelias/${
          repository}.git # clone from Github
112     pushd $repository > /dev/null
                                # switch into
                                importer directory
113     npm install

```

```

# install npm dependencies
114 popd > /dev/null

#

return to code directory
115 done
116 Create a file "config.json" in the home directory
    (~/) of the pelias user. Paste following into
    pelias.json:
117 {
118   "esclient": {
119     "apiVersion": "5.6",
120     "keepAlive": true,
121     "requestTimeout": "120000",
122     "hosts": [{
123       "env": "development",
124       "protocol": "http",
125       "host": "localhost",
126       "port": 9200
127     }],
128     "log": [{
129       "type": "stdio",
130       "json": false,
131       "level": [ "error", "warning" ]
132     }]
133   },
134   "elasticsearch": {
135     "settings": {
136       "index": {
137         "number_of_replicas": "0",
138         "number_of_shards": "5",
139         "refresh_interval": "1m"
140       }
141     }
142   },
143   "interpolation": {
144     "client": {
145       "adapter": "null"
146     }
147   }
148 }

```

```

147     },
148     "dbclient": {
149         "statFrequency": 10000
150     },
151     "api": {
152         "accessLog": "common",
153         "textAnalyzer": "libpostal",
154         "host": "http://pelias.mapzen.com/",
155         "indexName": "pelias",
156         "version": "1.0",
157         "targets": {
158             "auto_discover": false,
159             "canonical_sources": ["whosonfirst", "
                openstreetmap", "openaddresses", "geonames"
160             ],
161             "layers_by_source": {
162                 "openstreetmap": [ "address", "venue", "
163                     street" ],
164                 "openaddresses": [ "address" ],
165                 "geonames": [
166                     "country", "macroregion", "region", "
167                     county", "localadmin", "locality", "
168                     borough",
169                     "neighbourhood", "venue"
170                 ],
171                 "whosonfirst": [
172                     "continent", "empire", "country", "
173                     dependency", "macroregion", "region", "
174                     locality",
175                     "localadmin", "macrocounty", "county", "
176                     macrohood", "borough", "neighbourhood",
177                     "microhood", "disputed", "venue", "
178                     postalcode", "continent", "ocean", "
179                     marinearea"
180                 ]
181             },
182         "source_aliases": {
183             "osm": [ "openstreetmap" ],

```

```

175         "oa": [ "openaddresses" ],
176         "gn": [ "geonames" ],
177         "wof": [ "whosonfirst" ]
178     },
179     "layer_aliases": {
180         "coarse": [
181             "continent", "empire", "country", "
182             dependency", "macroregion", "region", "
183             locality",
184             "localadmin", "macrocounty", "county", "
185             macrohood", "borough", "neighbourhood",
186             "microhood", "disputed", "postalcode", "
187             continent", "ocean", "marinearea"
188         ]
189     }
190 },
191 "schema": {
192     "indexName": "pelias"
193 },
194 "logger": {
195     "level": "debug",
196     "timestamp": true,
197     "colorize": true
198 },
199 "acceptance-tests": {
200     "endpoints": {
201         "local": "http://localhost:3100/v1/",
202         "dev-cached": "http://pelias.dev.mapzen.com.
203         global.prod.fastly.net/v1/",
204         "dev": "http://pelias.dev.mapzen.com/v1/",
205         "prod": "http://search.mapzen.com/v1/",
206         "prod-uncached": "http://pelias.mapzen.com/v1
207         /",
208         "prodbuild": "http://pelias.prodbuild.mapzen.
209         com/v1/"
210     }
211 },

```

```

206 "imports": {
207     "adminLookup": {
208         "enabled": true,
209         "maxConcurrentRequests": 100,
210         "usePostalCities": false
211     },
212     "blacklist": {
213         "files": []
214     },
215     "csv": {
216     },
217     "geonames": {
218         "datapath": "/data/rawdata/geonames",
219         "countryCode": "ALL"
220     },
221     "openstreetmap": {
222         "datapath": "/data/rawdata/openstreetmaps",
223         "leveldbpath": "/tmp",
224         "import": [{
225             "filename": "europe-latest.osm.pbf"
226         }]
227     },
228     "openaddresses": {
229         "datapath": "/data/rawdata/openaddresses",
230         "files": []
231     },
232     "polyline": {
233         "datapath": "/data/rawdata/polylines",
234         "files": []
235     },
236     "whosonfirst": {
237         "datapath": "/data/rawdata/whosonfirst",
238         "importVenues": false
239     }
240 }
241 }
242 Add the pelias.json to the PATH variable by adding
    the followinbg line at the bottom of the .bashrc-

```

```

    file:
243 export PATH=$PATH:PELIAS_CONFIG=/home/<username>/
    pelias.config
244 Set up Elasticsearch Schema:
245 cd /pelias/schema # assuming you have just run the
    bash snippet to download
    the repos from earlier
246 ./bin/create_index
247 Run the Importers:
248 For each importer (openaddresses, openstreetmaps,
    whosonfirst, geonames and polylines) navigate
    into their folders under
249 cd /pelias/<importer_folder>
250 and execute the importer via
251 npm start
252 In case you want to delete the imported data and
    restart from import phase, run the following:
253 # !! WARNING: this will remove all your data from
    pelias!!
254 node scripts/drop_index.js #it will ask for
    confirmation first
255 ./bin/create_index
256 Install and start the pelias services:
257 Add the following to the bottom of the pelias.json
    file in your home directory. This will tell the
    pelias API to use all the services running
    locally and on their default ports.
258 {
259   "api": {
260     "services": {
261       "placeholder": {
262         "url": "http://localhost:3000"
263       },
264       "libpostal": {
265         "url": "http://localhost:8080"
266       },
267       "pip": {
268         "url": "http://localhost:3102"

```

```

269     },
270     "interpolation": {
271         "url": "http://localhost:3000"
272     }
273 }
274 }
275 }
276 Start the pelias API:
277 To start the pelias API navigate into folder
278 cd /pelias/api
279 and execute
280 npm start
281 Geocoding with pelias:
282 Pelias should now be up and running and will respond
    to your queries.
283 For a quick check, a request to http://localhost:310
    0 should display a link to the documentation for
    handy reference.
284 Here are some queries to try:
285 http://localhost:3100/v1/search?text=london: a
    search for the city of London.
286 http://localhost:3100/v1/autocomplete?text=londo:
    another query for London, but using the
    autocomplete endpoint which supports partial
    matches and is intended to be sent queries as a
    user types (note the query is for londo but
    London is returned)
287 http://localhost:3100/v1/reverse?point.lon=-73.98602
    7&point.lat=40.748517: a reverse geocode for
    results near the Empire State Building in New
    York City.

```

Appendix B

Valhalla Routing

1 Valhalla Routing Output

```
1 {
2   "trip": {
3     "language": "en-US",
4     "status": 0,
5     "units": "kilometers",
6     "status_message": "Found route between points",
7     "legs": [
8       {
9         "summary": {
10           "max_lon": 11.605507,
11           "max_lat": 48.133167,
12           "time": 2397,
13           "length": 38.536,
14           "min_lat": 47.943157,
15           "min_lon": 11.260186
16         },
17         "maneuvers": [
18           {
19             "travel_type": "car",
20             "street_names": [
21               "Kirchenstrasse"
22             ],
```



```

23     "verbal_pre_transition_instruction": "
        Drive east on Kirchenstrasse for 30
        meters. Then Turn right onto
        Elsaesser Strasse.",
24     "instruction": "Drive east on
        Kirchenstrasse.",
25     "end_shape_index": 2,
26     "type": 2,
27     "time": 15,
28     "verbal_multi_cue": true,
29     "length": 0.033,
30     "begin_shape_index": 0,
31     "travel_mode": "drive"
32 },
33 {
34     "travel_type": "car",
35     "travel_mode": "drive",
36     "verbal_pre_transition_instruction": "
        Turn right onto Elsaesser Strasse.",
37     "verbal_transition_alert_instruction": "
        Turn right onto Elsaesser Strasse.",
38     "length": 0.424,
39     "instruction": "Turn right onto
        Elsaesser Strasse.",
40     "end_shape_index": 21,
41     "type": 10,
42     "time": 107,
43     "verbal_post_transition_instruction": "
        Continue for 400 meters.",
44     "street_names": [
45         "Elsaesser Strasse"
46     ],
47     "begin_shape_index": 2
48 },
49 {
50     "travel_type": "car",
51     "travel_mode": "drive",

```

```

52     "verbal_pre_transition_instruction": "
53         Turn right onto Orleansstrasse.",
54     "verbal_transition_alert_instruction": "
55         Turn right onto Orleansstrasse.",
56     "length": 0.887,
57     "instruction": "Turn right onto
58         Orleansstrasse.",
59     "end_shape_index": 57,
60     "type": 10,
61     "time": 149,
62     "verbal_post_transition_instruction": "
63         Continue for 900 meters.",
64     "street_names": [
65         "Orleansstrasse"
66     ],
67     "begin_shape_index": 21
68 },
69 {
70     "travel_type": "car",
71     "verbal_pre_transition_instruction": "
72         Continue on Auerfeldstrasse for 200
73         meters.",
74     "verbal_transition_alert_instruction": "
75         Continue on Auerfeldstrasse.",
76     "length": 0.161,
77     "instruction": "Continue on
78         Auerfeldstrasse.",
79     "end_shape_index": 68,
80     "type": 8,
81     "time": 42,
82     "street_names": [
83         "Auerfeldstrasse"
84     ],
85     "begin_shape_index": 57,
86     "travel_mode": "drive"
87 },
88 {
89     "travel_type": "car",

```

```

82     "verbal_pre_transition_instruction": "
        Continue on Welfenstrasse for 700
        meters.",
83     "verbal_transition_alert_instruction": "
        Continue on Welfenstrasse.",
84     "length": 0.708,
85     "instruction": "Continue on
        Welfenstrasse.",
86     "end_shape_index": 100,
87     "type": 8,
88     "time": 105,
89     "street_names": [
90         "Welfenstrasse"
91     ],
92     "begin_shape_index": 68,
93     "travel_mode": "drive"
94 },
95 {
96     "travel_type": "car",
97     "travel_mode": "drive",
98     "verbal_pre_transition_instruction": "
        Turn left onto Regerstrasse.",
99     "verbal_transition_alert_instruction": "
        Turn left onto Regerstrasse.",
100    "length": 0.155,
101    "instruction": "Turn left onto
        Regerstrasse.",
102    "end_shape_index": 113,
103    "type": 15,
104    "time": 18,
105    "verbal_post_transition_instruction": "
        Continue for 200 meters.",
106    "street_names": [
107        "Regerstrasse"
108    ],
109    "begin_shape_index": 100
110 },
111 {

```

```

112     "travel_type": "car",
113     "verbal_pre_transition_instruction": "
        Continue on Tegernseer Landstrasse
        for 600 meters.",
114     "verbal_transition_alert_instruction": "
        Continue on Tegernseer Landstrasse.",
115     "length": 0.631,
116     "instruction": "Continue on Tegernseer
        Landstrasse.",
117     "end_shape_index": 167,
118     "type": 8,
119     "time": 77,
120     "street_names": [
121         "Tegernseer Landstrasse"
122     ],
123     "begin_shape_index": 113,
124     "travel_mode": "drive"
125 },
126 {
127     "travel_type": "car",
128     "travel_mode": "drive",
129     "verbal_pre_transition_instruction": "
        Turn right onto Ichostrasse.",
130     "verbal_transition_alert_instruction": "
        Turn right onto Ichostrasse.",
131     "length": 0.183,
132     "instruction": "Turn right onto
        Ichostrasse.",
133     "end_shape_index": 179,
134     "type": 10,
135     "time": 27,
136     "verbal_post_transition_instruction": "
        Continue for 200 meters.",
137     "street_names": [
138         "Ichostrasse"
139     ],
140     "begin_shape_index": 167
141 },

```

```

142     {
143         "travel_type": "car",
144         "travel_mode": "drive",
145         "verbal_multi_cue": true,
146         "verbal_pre_transition_instruction": "
            Bear left to stay on Ichostrasse.
            Then Bear left onto Martin-Luther-
            Strasse.",
147         "verbal_transition_alert_instruction": "
            Bear left to stay on Ichostrasse.",
148         "length": 0.045,
149         "instruction": "Bear left to stay on
            Ichostrasse.",
150         "end_shape_index": 186,
151         "type": 16,
152         "time": 6,
153         "verbal_post_transition_instruction": "
            Continue for 50 meters.",
154         "street_names": [
155             "Ichostrasse"
156         ],
157         "begin_shape_index": 179
158     },
159     {
160         "travel_type": "car",
161         "travel_mode": "drive",
162         "verbal_pre_transition_instruction": "
            Bear left onto Martin-Luther-Strasse
            .",
163         "verbal_transition_alert_instruction": "
            Bear left onto Martin-Luther-Strasse
            .",
164         "length": 0.347,
165         "instruction": "Bear left onto Martin-
            Luther-Strasse.",
166         "end_shape_index": 211,
167         "type": 16,
168         "time": 46,

```

```

169         "verbal_post_transition_instruction": "
170             Continue for 300 meters.",
171         "street_names": [
172             "Martin-Luther-Strasse"
173         ],
174         "begin_shape_index": 186
175     },
176     {
177         "travel_type": "car",
178         "travel_mode": "drive",
179         "verbal_pre_transition_instruction": "
180             Continue on Tegernseer Landstrasse
181             for 100 meters. Then Turn right onto
182             Candidstrasse.",
183         "verbal_transition_alert_instruction": "
184             Continue on Tegernseer Landstrasse.",
185         "length": 0.121,
186         "instruction": "Continue on Tegernseer
187             Landstrasse.",
188         "end_shape_index": 219,
189         "type": 8,
190         "time": 13,
191         "verbal_multi_cue": true,
192         "street_names": [
193             "Tegernseer Landstrasse"
194         ],
195         "begin_shape_index": 211
196     },
197     {
198         "travel_type": "car",
199         "travel_mode": "drive",
200         "verbal_pre_transition_instruction": "
201             Turn right onto Candidstrasse.",
202         "verbal_transition_alert_instruction": "
203             Turn right onto Candidstrasse.",
204         "length": 0.933,
205         "instruction": "Turn right onto
206             Candidstrasse.",

```

```

198     "end_shape_index": 289,
199     "type": 10,
200     "time": 97,
201     "verbal_post_transition_instruction": "
        Continue for 900 meters.",
202     "street_names": [
203         "Candidstrasse"
204     ],
205     "begin_shape_index": 219
206 },
207 {
208     "travel_type": "car",
209     "travel_mode": "drive",
210     "verbal_pre_transition_instruction": "
        Take the B 2R ramp on the left.",
211     "verbal_transition_alert_instruction": "
        Take the B 2R ramp on the left.",
212     "instruction": "Take the B 2R ramp on
        the left.",
213     "end_shape_index": 297,
214     "type": 19,
215     "time": 9,
216     "street_names": [
217         "Candidstrasse"
218     ],
219     "begin_shape_index": 289,
220     "length": 0.124,
221     "sign": {
222         "exit_branch_elements": [
223             {
224                 "text": "B 2R"
225             }
226         ]
227     }
228 },
229 {
230     "travel_type": "car",
231     "travel_mode": "drive",

```

```

232     "verbal_pre_transition_instruction": "
233         Merge onto B 2R.",
234     "begin_street_names": [
235         "B 2R",
236         "Candidstrasse"
237     ],
238     "verbal_post_transition_instruction": "
239         Continue for 3 kilometers.",
240     "instruction": "Merge onto B 2R.",
241     "end_shape_index": 354,
242     "type": 25,
243     "time": 182,
244     "street_names": [
245         "B 2R"
246     ],
247     "length": 3.038,
248     "begin_shape_index": 297
249 },
250 {
251     "travel_type": "car",
252     "travel_mode": "drive",
253     "verbal_pre_transition_instruction": "
254         Take the A 95 ramp on the right
255         toward Garmisch-Partenkirchen,
256         Forstenried.",
257     "verbal_transition_alert_instruction": "
258         Take the A 95 ramp on the right.",
259     "instruction": "Take the A 95 ramp on
260         the right toward Garmisch-
261         Partenkirchen/Forstenried/
262         Fuerstenried/Grosshadern.",
263     "end_shape_index": 360,
264     "type": 18,
265     "time": 14,
266     "street_names": [
267         "Heckenstallertunnel"
268     ],
269     "begin_shape_index": 354,

```



```

261     "length": 0.305,
262     "sign": {
263         "exit_toward_elements": [
264             {
265                 "text": "Garmisch-Partenkirchen"
266             },
267             {
268                 "text": "Forstenried"
269             },
270             {
271                 "text": "Fuerstenried"
272             },
273             {
274                 "text": "Grosshadern"
275             }
276         ],
277         "exit_branch_elements": [
278             {
279                 "text": "A 95"
280             }
281         ]
282     }
283 },
284 {
285     "travel_type": "car",
286     "verbal_pre_transition_instruction": "
        Keep right at the fork. Then Bear
        right onto Luise-Kiesselbach-Platz.",
287     "verbal_transition_alert_instruction": "
        Keep right at the fork.",
288     "length": 0.025,
289     "instruction": "Keep right at the fork."
290     ,
291     "end_shape_index": 363,
292     "type": 23,
293     "time": 6,
294     "verbal_multi_cue": true,
    "begin_shape_index": 360,

```

```

295         "travel_mode": "drive"
296     },
297     {
298         "travel_type": "car",
299         "travel_mode": "drive",
300         "verbal_multi_cue": true,
301         "verbal_pre_transition_instruction": "
            Bear right onto Luise-Kiesselbach-
            Platz. Then Take the ramp on the left
            toward A 95.",
302         "verbal_transition_alert_instruction": "
            Bear right onto Luise-Kiesselbach-
            Platz.",
303         "length": 0.079,
304         "instruction": "Bear right onto Luise-
            Kiesselbach-Platz.",
305         "end_shape_index": 367,
306         "type": 9,
307         "time": 13,
308         "verbal_post_transition_instruction": "
            Continue for 80 meters.",
309         "street_names": [
310             "Luise-Kiesselbach-Platz"
311         ],
312         "begin_shape_index": 363
313     },
314     {
315         "travel_type": "car",
316         "travel_mode": "drive",
317         "verbal_pre_transition_instruction": "
            Take the ramp on the left toward A 95
            . Then Keep left at the fork.",
318         "verbal_transition_alert_instruction": "
            Take the ramp on the left toward A 95
            .",
319         "instruction": "Take the ramp on the
            left toward A 95.",
320         "end_shape_index": 369,

```

```

321     "type": 19,
322     "time": 5,
323     "verbal_multi_cue": true,
324     "begin_shape_index": 367,
325     "length": 0.037,
326     "sign": {
327         "exit_toward_elements": [
328             {
329                 "text": "A 95"
330             }
331         ]
332     }
333 },
334 {
335     "travel_type": "car",
336     "verbal_pre_transition_instruction": "
        Keep left at the fork. Then Take the
        B 2 ramp on the left.",
337     "verbal_transition_alert_instruction": "
        Keep left at the fork.",
338     "length": 0.087,
339     "instruction": "Keep left at the fork.",
340     "end_shape_index": 374,
341     "type": 24,
342     "time": 34,
343     "verbal_multi_cue": true,
344     "begin_shape_index": 369,
345     "travel_mode": "drive"
346 },
347 {
348     "travel_type": "car",
349     "verbal_pre_transition_instruction": "
        Take the B 2 ramp on the left.",
350     "verbal_transition_alert_instruction": "
        Take the B 2 ramp on the left.",
351     "instruction": "Take the B 2 ramp on the
        left.",
352     "end_shape_index": 381,

```

```

353     "type": 19,
354     "time": 25,
355     "begin_shape_index": 374,
356     "length": 0.264,
357     "sign": {
358         "exit_branch_elements": [
359             {
360                 "text": "B 2"
361             }
362         ]
363     },
364     "travel_mode": "drive"
365 },
366 {
367     "travel_type": "car",
368     "verbal_pre_transition_instruction": "
369         Merge onto A 95.",
370     "verbal_post_transition_instruction": "
371         Continue for 1.2 kilometers.",
372     "instruction": "Merge onto A 95.",
373     "end_shape_index": 387,
374     "type": 25,
375     "time": 81,
376     "street_names": [
377         "A 95"
378     ],
379     "length": 1.159,
380     "begin_shape_index": 381,
381     "travel_mode": "drive"
382 },
383 {
384     "travel_type": "car",
385     "travel_mode": "drive",
386     "verbal_pre_transition_instruction": "
387         Continue on B 2 for 80 meters. Then
388         Continue on A 95.",
389     "verbal_transition_alert_instruction": "
390         Continue on B 2.",

```

```

386     "length": 0.078,
387     "instruction": "Continue on B 2.",
388     "end_shape_index": 388,
389     "type": 8,
390     "time": 3,
391     "verbal_multi_cue": true,
392     "street_names": [
393         "B 2"
394     ],
395     "begin_shape_index": 387
396 },
397 {
398     "travel_type": "car",
399     "verbal_pre_transition_instruction": "
        Continue on A 95 for 11.5 kilometers
        .",
400     "verbal_transition_alert_instruction": "
        Continue on A 95.",
401     "length": 11.482,
402     "instruction": "Continue on A 95.",
403     "end_shape_index": 486,
404     "type": 8,
405     "time": 461,
406     "street_names": [
407         "A 95"
408     ],
409     "begin_shape_index": 388,
410     "travel_mode": "drive"
411 },
412 {
413     "travel_type": "car",
414     "verbal_pre_transition_instruction": "
        Take exit 4 on the right onto A 9 52
        toward Starnberg.",
415     "verbal_transition_alert_instruction": "
        Take exit 4 on the right.",
416     "instruction": "Take exit 4 on the right
        onto A 952 toward Starnberg.",

```

```

417     "end_shape_index": 510,
418     "type": 20,
419     "time": 51,
420     "begin_shape_index": 486,
421     "length": 1.172,
422     "sign": {
423         "exit_name_elements": [
424             {
425                 "text": "Dreieck Starnberg"
426             }
427         ],
428         "exit_toward_elements": [
429             {
430                 "text": "Starnberg"
431             }
432         ],
433         "exit_branch_elements": [
434             {
435                 "consecutive_count": 1,
436                 "text": "A 952"
437             }
438         ],
439         "exit_number_elements": [
440             {
441                 "text": "4"
442             }
443         ]
444     },
445     "travel_mode": "drive"
446 },
447 {
448     "travel_type": "car",
449     "verbal_pre_transition_instruction": "
450         Merge onto A 9 52.",
451     "verbal_post_transition_instruction": "
452         Continue for 4 kilometers.",
453     "instruction": "Merge onto A 952.",
454     "end_shape_index": 556,

```

```

453     "type": 25,
454     "time": 150,
455     "street_names": [
456         "A 952"
457     ],
458     "length": 3.984,
459     "begin_shape_index": 510,
460     "travel_mode": "drive"
461 },
462 {
463     "travel_type": "car",
464     "verbal_pre_transition_instruction": "
        Continue on B 2 for a half kilometer
        .",
465     "verbal_transition_alert_instruction": "
        Continue on B 2.",
466     "length": 0.458,
467     "instruction": "Continue on B 2.",
468     "end_shape_index": 563,
469     "type": 8,
470     "time": 28,
471     "street_names": [
472         "B 2"
473     ],
474     "begin_shape_index": 556,
475     "travel_mode": "drive"
476 },
477 {
478     "travel_type": "car",
479     "travel_mode": "drive",
480     "verbal_pre_transition_instruction": "
        Continue on Muenchner Strasse for 1.1
        kilometers.",
481     "begin_street_names": [
482         "B 2",
483         "Muenchner Strasse"
484     ],

```

```

485     "verbal_transition_alert_instruction": "
         Continue on Muenchner Strasse.",
486     "length": 1.14,
487     "instruction": "Continue on Muenchner
         Strasse.",
488     "end_shape_index": 603,
489     "type": 8,
490     "time": 91,
491     "street_names": [
492         "Muenchner Strasse"
493     ],
494     "begin_shape_index": 563
495 },
496 {
497     "travel_type": "car",
498     "travel_mode": "drive",
499     "verbal_pre_transition_instruction": "
         Continue on B 2 for 3.1 kilometers.",
500     "begin_street_names": [
501         "Hauptstrasse",
502         "B 2"
503     ],
504     "verbal_transition_alert_instruction": "
         Continue on B 2.",
505     "length": 3.086,
506     "instruction": "Continue on B 2.",
507     "end_shape_index": 679,
508     "type": 8,
509     "time": 189,
510     "street_names": [
511         "B 2"
512     ],
513     "begin_shape_index": 603
514 },
515 {
516     "travel_type": "car",
517     "verbal_pre_transition_instruction": "
         Enter the roundabout and take the 2nd

```



```

        exit.",
518     "verbal_transition_alert_instruction": "
        Enter the roundabout and take the 2nd
        exit.",
519     "length": 0.083,
520     "instruction": "Enter the roundabout and
        take the 2nd exit.",
521     "end_shape_index": 689,
522     "type": 26,
523     "time": 4,
524     "begin_shape_index": 679,
525     "roundabout_exit_count": 2,
526     "travel_mode": "drive"
527 },
528 {
529     "travel_type": "car",
530     "travel_mode": "drive",
531     "verbal_pre_transition_instruction": "
        Exit the roundabout onto Weilheimer
        Strasse, B 2.",
532     "begin_street_names": [
533         "Weilheimer Strasse",
534         "B 2"
535     ],
536     "verbal_post_transition_instruction": "
        Continue on B 2 for 5.8 kilometers.",
537     "instruction": "Exit the roundabout onto
        Weilheimer Strasse/B 2. Continue on
        B 2.",
538     "end_shape_index": 800,
539     "type": 27,
540     "time": 242,
541     "street_names": [
542         "B 2"
543     ],
544     "length": 5.768,
545     "begin_shape_index": 689
546 },

```

```

547     {
548         "travel_type": "car",
549         "travel_mode": "drive",
550         "verbal_pre_transition_instruction": "
            Bear right onto Starnberger Strasse."
551         ,
        "verbal_transition_alert_instruction": "
            Bear right onto Starnberger Strasse."
552         ,
        "length": 0.237,
553         "instruction": "Bear right onto
            Starnberger Strasse.",
554         "end_shape_index": 808,
555         "type": 9,
556         "time": 17,
557         "verbal_post_transition_instruction": "
            Continue for 200 meters.",
558         "street_names": [
559             "Starnberger Strasse"
560         ],
561         "begin_shape_index": 800
562     },
563     {
564         "travel_type": "car",
565         "travel_mode": "drive",
566         "verbal_multi_cue": true,
567         "verbal_pre_transition_instruction": "
            Bear left onto Feldafinger Strasse.
            Then Bear left to stay on Feldafinger
            Strasse.",
568         "verbal_transition_alert_instruction": "
            Bear left onto Feldafinger Strasse.",
569         "length": 0.108,
570         "instruction": "Bear left onto
            Feldafinger Strasse.",
571         "end_shape_index": 816,
572         "type": 16,
573         "time": 9,

```

```

574     "verbal_post_transition_instruction": "
        Continue for 100 meters.",
575     "street_names": [
576         "Feldafinger Strasse"
577     ],
578     "begin_shape_index": 808
579 },
580 {
581     "travel_type": "car",
582     "travel_mode": "drive",
583     "verbal_multi_cue": true,
584     "verbal_pre_transition_instruction": "
        Bear left to stay on Feldafinger
        Strasse. Then Bear right to stay on
        Feldafinger Strasse.",
585     "verbal_transition_alert_instruction": "
        Bear left to stay on Feldafinger
        Strasse.",
586     "length": 0.101,
587     "instruction": "Bear left to stay on
        Feldafinger Strasse.",
588     "end_shape_index": 820,
589     "type": 16,
590     "time": 9,
591     "verbal_post_transition_instruction": "
        Continue for 100 meters.",
592     "street_names": [
593         "Feldafinger Strasse"
594     ],
595     "begin_shape_index": 816
596 },
597 {
598     "travel_type": "car",
599     "travel_mode": "drive",
600     "verbal_pre_transition_instruction": "
        Bear right to stay on Feldafinger
        Strasse.",

```

```

601     "verbal_transition_alert_instruction": "
        Bear right to stay on Feldafinger
        Strasse.",
602     "length": 0.313,
603     "instruction": "Bear right to stay on
        Feldafinger Strasse.",
604     "end_shape_index": 830,
605     "type": 9,
606     "time": 21,
607     "verbal_post_transition_instruction": "
        Continue for 300 meters.",
608     "street_names": [
609         "Feldafinger Strasse"
610     ],
611     "begin_shape_index": 820
612 },
613 {
614     "travel_type": "car",
615     "travel_mode": "drive",
616     "begin_shape_index": 830,
617     "time": 51,
618     "type": 8,
619     "end_shape_index": 852,
620     "instruction": "Continue.",
621     "length": 0.78,
622     "verbal_transition_alert_instruction": "
        Continue.",
623     "time": 51,
624     "type": 8,
625     "end_shape_index": 852,
626     "instruction": "Continue.",
627     "length": 0.78,
628     "verbal_transition_alert_instruction": "
        Continue.",
629     "verbal_pre_transition_instruction": "
        Continue for 800 meters."
630 },
631 {

```

```

632         "travel_type": "car",
633         "travel_mode": "drive",
634         "begin_shape_index": 852,
635         "time": 0,
636         "type": 5,
637         "end_shape_index": 852,
638         "instruction": "Your destination is on
        the right.",
639         "length": 0,
640         "verbal_transition_alert_instruction": "
        Your destination will be on the right
        .",
641         "verbal_pre_transition_instruction": "
        Your destination is on the right."
642     }
643 ]
644 }
645 ],
646 "summary": {
647     "max_lon": 11.605507,
648     "max_lat": 48.133167,
649     "time": 2397,
650     "length": 38.536,
651     "min_lat": 47.943157,
652     "min_lon": 11.260186
653 },
654 "locations": [
655     {
656         "original_index": 0,
657         "type": "break",
658         "lon": 11.6046,
659         "lat": 48.133099,
660         "side_of_street": "right"
661     },
662     {
663         "original_index": 1,
664         "type": "break",
665         "lon": 11.2759,

```

```
666         "lat": 47.941898,  
667         "side_of_street": "right"  
668     }  
669 ]  
670 }  
671 }
```